Technical University of Lisbon
Instituto Superior Técnico

Title:

DEVELOPMENT OF CARGO BUSINESS IN COMBINATION AIRLINES: STRATEGY AND INSTRUMENT

Author:

Vasco Domingos Moreira Lopes Miranda dos **Reis**

Date:

July 2010

ABSTRACT

The overarching objective of this research work is to contribute to the competitiveness of the combination companies - passenger air transport companies - in the air cargo market. The strategic option herein proposed is *intermodality*. The departure hypothesis of this research work claims that integration in intermodal freight transport services can enhance the competitiveness of the combination companies in this market.

A conceptual framework representing the mechanisms of integration in intermodal freight transport services was developed. At the heart of the framework lies the concept of fitness that represents the increment of performance accruing from the integration of the transport agents. Five dimension of fitness were identified, being: physical, logical, liability, financial and strategic. The framework establishes the relation between the shippers' requirements, the level of fitness and the performance of the intermodal transport service.

A micro-simulation model of a freight transport market was also developed for purposes of validation of the conceptual framework and testing the hypothesis. A simulation assessment with a set of experiments was produced. In each experiment a given dimension of fitness was tested in different conditions.

The main conclusions to be drawn are that, firstly, integration is a feasible strategy to help the combination companies to improve their competitiveness in the air cargo market. However, the benefits of integration are affected by an eventual increase in the costs of production if they lead to an increase in the prices. And, secondly, the conceptual framework may be an adequate support tool to combination companies to achieve a better integration.

RESUMO

O objectivo principal desta dissertação é contribuir para a competitividade das companhias aéras de passageiros no mercado da carga aérea. A estratégia proposta consiste na promoção da intermodalidade entre as companhias aéreas de passageiros e as outras companhias de transporte. A hipótese desta dissertação refere que integração em serviços de transporte intermodal pode melhorar a competitividade das companhias aéreas de passageiros neste mercado.

Foi desenvolvido um modelo teórico que representa os mecanismos da integração em serviços de transporte intermodal. O conceito base deste modelo é o conceito de ajuste que representa o incremento de desempenho que é possivel de obter pela integração dos agentes de transporte. Foram ainda identificadas cinco dimensões de ajuste, a saber: física, lógica, responsabilidade, financeira e estratégica. O modelo define as relações entre os requisitos de procura dos clientes, o nível de ajuste e o desempenho da cadeia de transportes.

Um modelo de micro-simulação foi de igual modo desenvolvido com o objectivo de testar a hipótese e de validar o modelo teórico. Um conjunto de testes foi então produzido. Em cada teste uma dimensão do ajuste for testada.

As principais conclusões desta dissertação são, primeiro, que a integração pode ser uma estratégia utilizada pelas companhias aéreas de passageiros para melhorar a competitividade no mercado da carga aérea. No entanto, os benefícios da integração estão limitados pelo aumento eventual dos custos de producção, se estes forem reflectidos no preço. Em segundo lugar, o modelo teórico revelou-se adequado e poderá ser utilizado como um instrumento de apoio às companhias aéreas no processo de integração.

ACRONYMS

ABM – Agent Based Modelling;

AFETAS – Air Freight Transport Market Simulator;

CAS – Complex Adaptive Systems;

CASS – Cargo Account Settlement System;

FLIM – Fuzzy Logic Inference Mechanism;

IATA – International Air Transport Association;

ICAO – International Civil Aviation Organization;

LoT – Level of Trust;

OECD – Organisation for Economic Co-operation and Development;

PERT – Program Evaluation and Review Technique;

RTK - Revenue Tonne Kilometres;

ULD - Unit Load Device.

KEYWORDS

Air Transport;

Freight Transport;

Air Cargo Market;

Integration;

Fitness;

Agent Based Modelling.

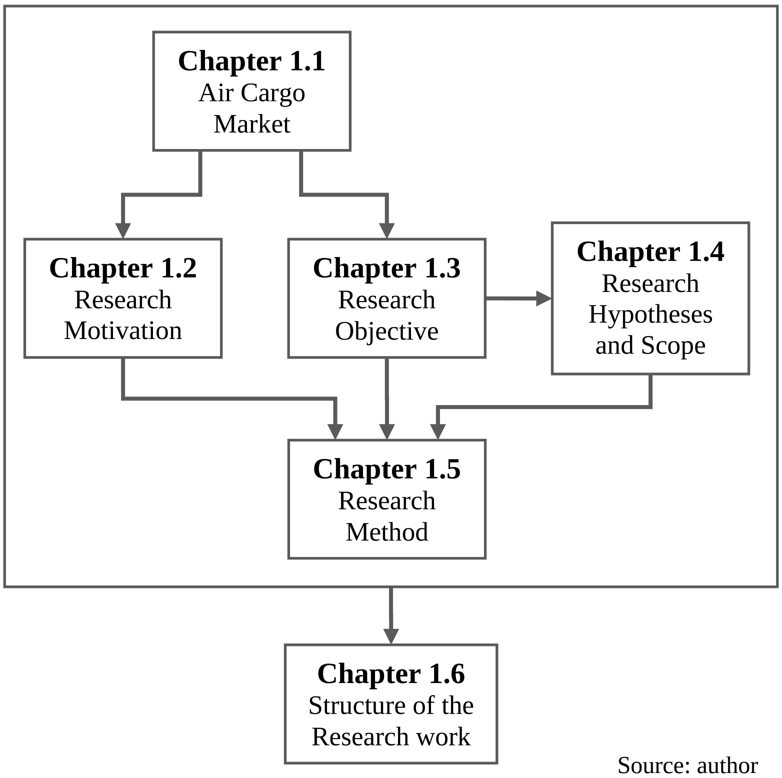
TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

1 INTRODUCTION

This first chapter introduces the fundamentals of this doctoral research work - *motivation, objective, hypothesis, scope* and *method* - and the structure of the research work. This chapter is structured into six chapters that can be grouped in two parts (Figure 1.1).



Source: author

Figure 1.1 – Structure of Chapter 1

1.1 Air Cargo Business

1.1.1 Air Cargo Market

1.1.1.1 Inception period: up to the 1940s

Civil aviation has greatly evolved since the first commercial initiatives[1] in the beginning of the twentieth century[2], until becoming the "lubricant [of] the modern world" (Button, 2002, pp ii).

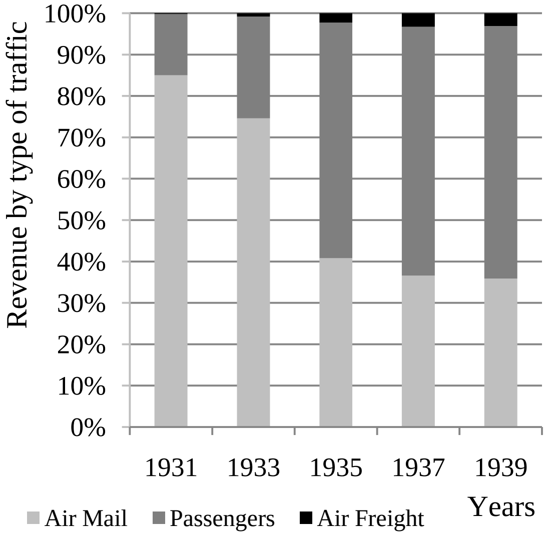
In Europe, just after World War I, the cargo business was the main driver of aviation's development. The continent had both communication and transport networks affected and there was the urgent need of securing the conveyance of people, post, and goods to the regions. Most air transport companies have had mixed transport services (for carrying people, mail and freight), and only very few of them were entirely dedicated to the transport of mail or freight (Allaz, 2004, pp 39, 130-134). This situation was in contrast with the United States, where the growth of air transport services was mainly driven by the mail transport services (Wensveen, 2007, pp 31, Sinha, 1999, pp 50, Allaz, 2004, pp 45). The importance of the mail services would however be short, as throughout the remaining period in-between World Wars freight segment has constantly grown at a faster pace than mail segment, and would eventually outpace it in due time (Figure 1.2 and Figure 1.3).

Throughout the forties, civil aviation has gradually shifted its business focus towards the passenger segment. Several factors contributed for this change. First, this segment has become dominant in terms of revenues (Allaz, 2004, pp 178). Second, aviation gained a political dimension and governments' primary concern was assuring adequate air transport services to populations for promoting social cohesion and equity (and to ensure the national sovereignty). And third, freight transport was in most cases already conveniently secured by surface communications, mainly rail transportation.

---

[1] The first freight commercial flight took place on 7th November 1910 between Dayton and Columbus (United States) (Allaz, 2004, pp 22) and the first regular passenger air service took place between January and March 1914 between Tampa and St Petersburg (United States) (Wensveen, 2007, pp 31).

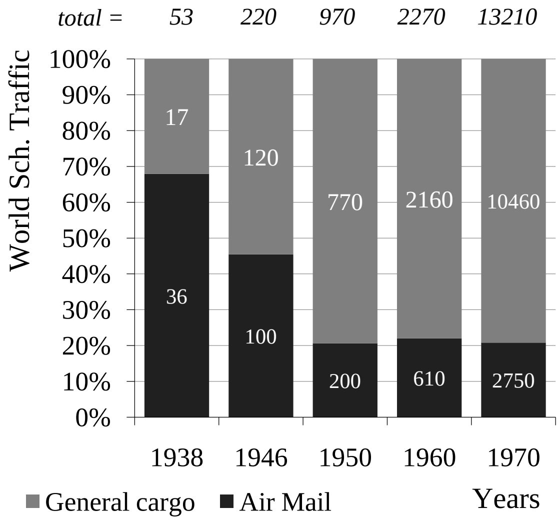
[2] A presentation of the history of civil aviation lies outside the scope of this research work. There are many good references in the literature, the interested reader is referred to, for example: Rhoades (2008), Allaz (2004) or Heppenheimer (1995).



Note: United States domestic contracting airlines

Source: Allaz (2004, pp 68)

Figure 1.2 – Development by segment of revenue



Note: world scheduled traffic, values in thousands Revenue Tonnes Kilometre (RTK)

Source: Allaz (2004, pp 228)

Figure 1.3 – Growth of mail and general-freight[3] traffic (income)

1.1.1.2 Growing period: mid 1940s – 1970s

The decades after the World War II were very favourable for the air cargo market. A robust economic development on the principal world's economic blocks and a stable period of cheap oil prices stimulated the demand for air freight services. Consequently, many freight companies have entered into the market and they have eventually took control of it. This was particularly notable in the United States, and the success was such that, in 1949 these operators carried eighty three percent of the freight traffic (measured in Revenue Tonnes Kilometres (RTK)) and generated seventy three percent of the revenues of the air cargo market (Allaz, 2004, pp 189). In parallel, many combination companies[4] start providing freight services. Freight was commonly carried on their passenger aircrafts' lower deck[5], as technological development was rendering larger aircrafts with enough space for both passengers' baggage, mail and other freight.

[3] General-freight is the air cargo that it is not classified as express freight nor as Air Mail. The various types of air cargo are detailed in Annex I – A Taxonomy for Air Cargo.

[4] Combination companies are air transport companies that supply passenger and freight transport services. The various transport agents are detailed in Annex II – The Agents in the Air Cargo Sector.

[5] It should be mentioned that many combination companies also have dedicated freight aircrafts, like for example: American Airlines in the United States or Air France in France.

The freight companies' domain would however fade out and by 1960 combination companies already controlled over eighty percent of international traffic and around seventy percent of the scheduled world freight traffic (measured in RTK). Two reasons may be pointed out. Firstly, the lack of suitable technology for constructing full freight aircrafts[6], which resulted in an increase of operational costs and in a decrease of the quality of service, coupled with a reduced number of orders that did not justify to invest in developing the technology. Secondly, the more favourable business model of the combination companies vis-à-vis the freight companies. The point is that the former run two businesses in parallel (passenger and freight) in the same vehicle (aircraft). The costs are therefore allocated to both business and, if necessary, cross-subsidisation may be done. Conversely, the latter only run one type of business and, thus, they have necessarily to allocate all the costs to this business. As a result, the unitary costs of production are inherently higher in the latter than in the former (Hoppin, 2005b, Clancy and Hoppin, 2004, Allaz, 2004, pp 189, 191).

1.1.1.3 Turmoil period: as of end 1970s

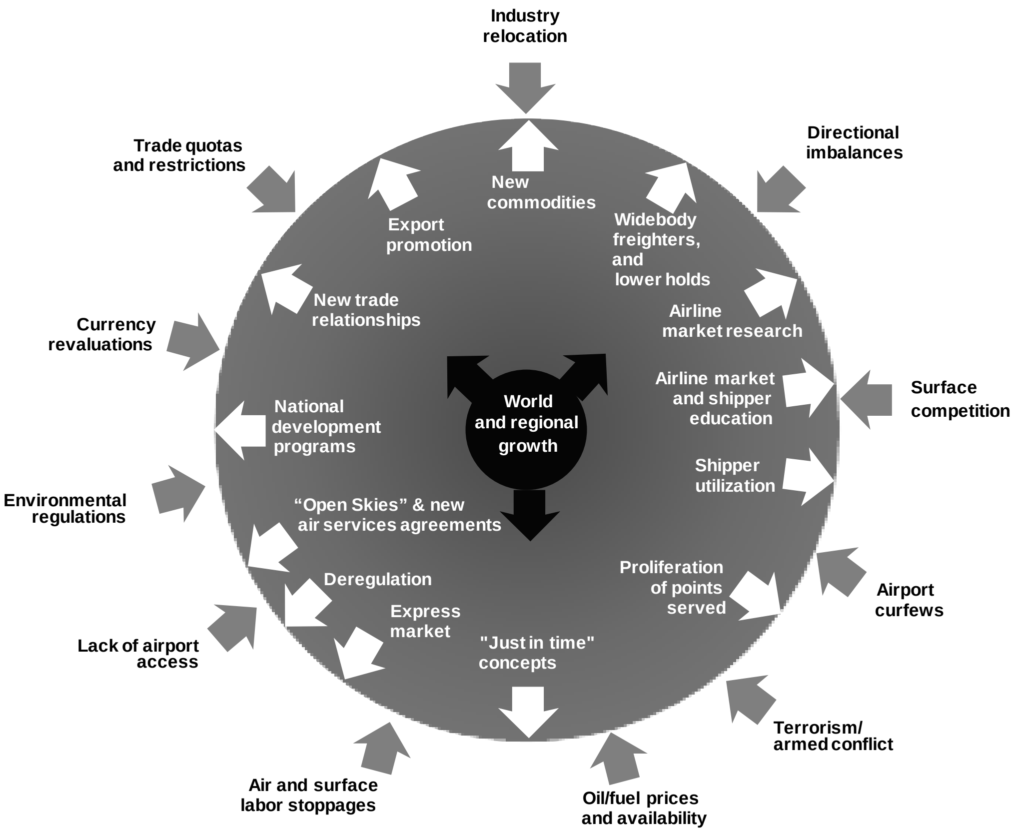
The last four decades have proved being considerably challenging to the air transport sector, with a large variety of forces and constraints driving its progress (Figure 1.4), such as: globalisation, economical development, technological development (Macário et al, 2008), volatility of oil prices, growing sustainability awareness, new threats (terrorism, diseases) or growing political instability in some regions (Kupfer et al, 2009, Rhoades, 2008, Doganis, 2006, Zondag, 2006). As a consequence of these forces, several trends have emerged, like for example: liberalisation and deregulation of the air transport markets[7], implementation of new safety and security rules, alliances and

---

[6] In terms of for example: reinforced fuselage and floor, ample doors or internal arrangements for anchoring freight.

[7] Examples of deregulations include the: United States (freight in 1977 and passengers in 1978), New Zealand (1983), Japan (1986 and 1996), India (1990), Australia (partially freight in 1977, totally freight in 1981 and passengers in 1990), European Union member states (from 1988 to 1997) or Indonesia (in 2000) (Sinha, 2001). Examples of bilateral agreements include the: United States with about fifty nine agreements signed in 2003 (Chang, 2004, pp 164), or New Zealand with seven agreements established by 1999. Multilateral agreements are still scarce, some examples include the: Asian Pacific Economic Cooperation region (in 2001) (APEC, 2007, pp 21-22), Association of South East Asian Nations (still being in a very incipient stage) (Forsyth et al, 2006, pp 144), European Union Europe with the Single European Act. (from 1988 to 1997) (Doganis, 2006, pp 45-50, Reis, 2005, pp 31-44, Association of

mergers amongst air transport companies and with other modes of transport, increase of competitiveness, environmental responsibility, or long term downwards trends of yields (Ezard, 2008, Clancy et al, 2008, Macário, 2008, Page, 2008, Rohades, 2008, Doganis, 2006, Zhang et al, 2004, Button and Stough, 2000).



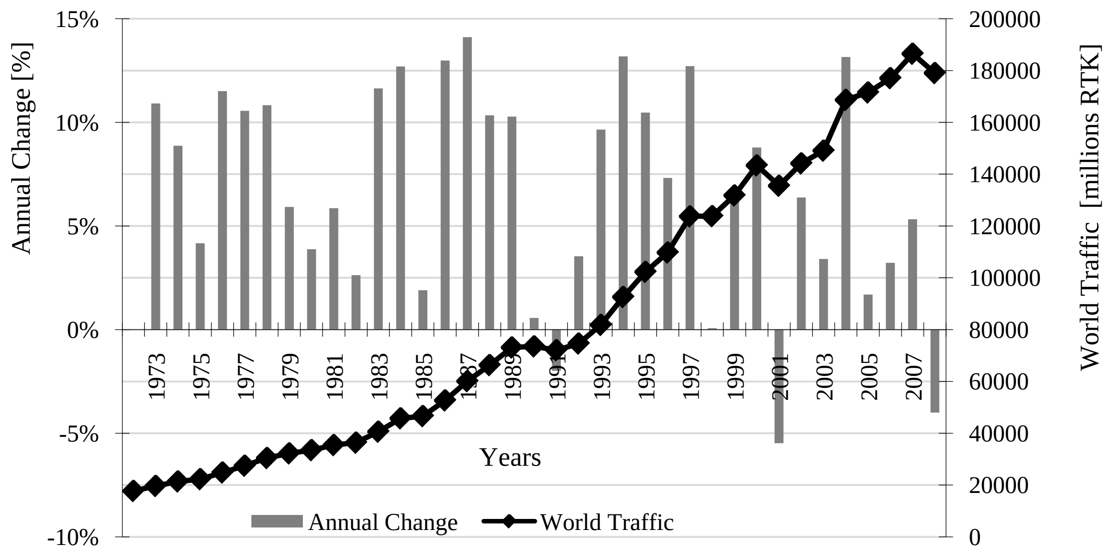
Source: Boeing (2008, pp 15)

Figure 1.4 – Forces and constraints for air cargo growth

Notwithstanding the turmoil, the air cargo market exhibits a notable growth over this period. A look over the past four decades (Figure 1.5) reveals an upwards trend, albeit punctuated by some years of stagnation or even contraction, namely, 1988, 1998, 2001 or 2008. These short term fluctuations have so far been conjectural, caused by external factors (such as, the economic downturns at the end of millennium and presently, or the 2001 terrorist attacks in the United States). Albeit such growth, air cargo market still

European Airlines, 2002, pp 49), or the Open Skies agreement between the United States and the European Union (in 2008) (Button, 2009, pp 64-65, Chang et al, 2009, pp 119. Doganis, 2006, pp 67).

remains a very small segment of the freight transport market[8], which evidences that only a small portion of the goods justify the cost of air transport.



Source: Boeing (2008b), IATA (2009a)

Figure 1.5 – Air cargo market [1972 – 2009]

A consequence of the progressive liberalisation of the air transport markets worldwide has been the emergence of the express freight[9] around the seventies by the hand of the integrators[10]. Nowadays, they still control this market segment, with a market share above eighty percent (Clancy et al, 2008, pp 34). In global terms, the express freight still represents a small portion of the world's total air cargo market. Boeing (2008, pp 5) calculated that in 1992 the express freight accounted for around four percent of world's international air cargo traffic (measured in RTK) an amount that grew to over thirteen percent in 2007.

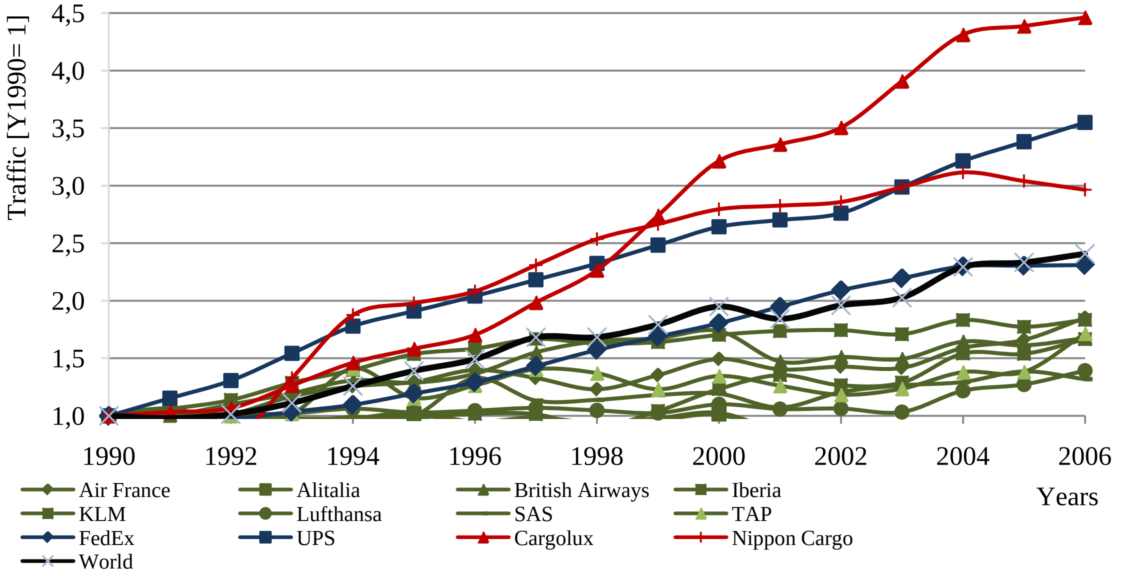
[8] For example, in the year 2007, the international air cargo accounted for around 2.5% of the size of the containerised shipping cargo market (Clancy et al, 2008, pp 36), or within United States the amount of cargo (measured in tonnes) carried by road was around one thousand times more than the amount of cargo transport by air (Boeing, 2008b).

[9] Express freight refers to the air freight traditionally carried by the integrators. The various types of air cargo are detailed in Annex I – A Taxonomy for Air Cargo

[10] Official statistics on express or general freight are scarcely available, because the term express freight was given by market operators (and not by official statistics bureaus or authorities). The problem is commonly addressed by considering that only Integrators (see definition in Annex I) carry express freight. This is not entirely correct as both air transport companies have increasingly moving express freight and that Integrators are being moving general-freight. It provides nonetheless a picture on the evolution of this type of cargo, since the large majority of express freight is moved by Integrators.

In what concerns the non-express freight market, the freight companies[11] have meanwhile regained the control of the non-express freight market. Clancy et al (2008, pp 42) estimated for the year 2007, a market share of thirty two percent and sixty eighty percent, respectively, for the passenger flights and for the full freights flights[12] in the intercontinental air cargo traffic (measured in RTK).

The Figure 1.6 presents the relative market growth of various transport providers: European combination companies[13] (green lines), freight companies (red lines) and integrators (blue lines), as of 1990.



Source: ATW Reports (several years)

Note: Combination companies: operating cargo tonnes kilometres, all markets, in passenger or combi flights, freight companies and integrators revenue tonnes kilometres

Figure 1.6 – Air cargo agents growth [1990-2008]

Albeit with a regional scope (European companies), the following conclusions may be drawn. Foremost, there is a long term trend upward growth, interrupted by some years

---

[11] Freight companies are air transport companies that only provide freight transport services. The various transport agents in the air transport freight market are detailed in Annex II – The Agents in the Air Cargo Sector.

[12] It should be noted that combination companies also operate full freight aircrafts and, thus, actual figures should revels a lower unbalance. Yet, they correspond to a relative small portion of total flights. Furthermore, this figure reports to 2007 before the major market contraction of 2008-2009, on which many full freight flights have been cancelled. IATA calculated a contraction as big as 30% in 2009 versus 2008 (IATA, 2009a). Therefore, it is expected a change in the figure since this year.

[13] Cargo figures per passenger and combi flights were only found for European companies.

of negative growth. These years of market contraction seem to affect with more intensity the combination companies[14] than their rivals. Secondly, since beginning of the millennium, the rate of growth of combination companies was reduced almost to zero; whereas their competitors exhibit a substantial growth. Finally, the set of combination companies represented in this figure have grown below the world total market (black line); while integrators (FedEx and UPS) and freight companies (Nippon Cargo and CargoLux) grew above. These conclusions are an evidence of the difficulties of combination companies in competing head-to-head with their direct competitors (integrators and freight companies).

1.1.2 Combination companies

1.1.2.1 Relevance of the air cargo business

In 2004, Georg Midunsky, managing director of Cargo Counts[15], pointed out that around ninety five percent of the combination companies considered air cargo segment as a secondary business (Conway, 2004). Zondag (2006, pp 35) argues that the relevance of air cargo business largely depends on how the companies' board of directors considers cargo: core, ancillary or dispensable.

Notwithstanding, air cargo business may play a key role on companies' financial performance. Its importance is visible at two levels. Firstly, at route level (or geographical market) level. Commonly, the profitability of the long distance (or intercontinental) transport services is ensured with the air cargo business (since passenger service is seldom able to generate enough revenues[16]). Air cargo business thus plays a key role for sustaining routes and thus market coverage (Conway, 2006, Hoppin, 2005b).

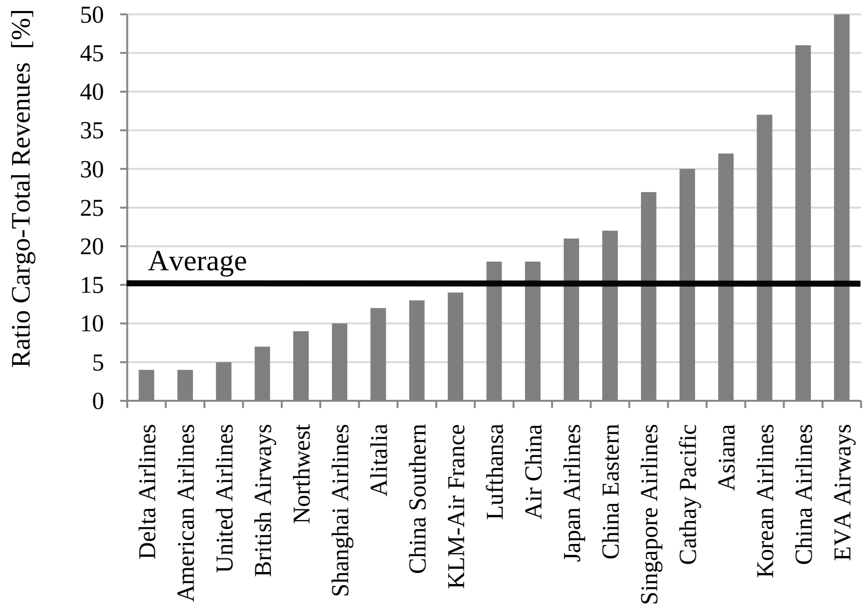
Secondly, at company level. Figure 1.7 presents the percentage of air cargo business's revenues on some combination companies. The interval is wide and if, indeed, for some companies air cargo business seams positively a marginal activity (as for example Delta

[14] A caveat should be made: these figures are only for passenger or combi flights. Most of these companies also operate freight flights and, therefore, overall figures may reveal a different behaviour.

[15] Cargo Counts is the Lufthansa's subsidiary that manages the capacity of other carriers

[16] Two reasons may be pointed out for this situation: first, low passenger demand and, secondly, fierce competition that drive air fares down.

Airlines contributing with as low as 4% of total revenues), for many others it should be considered a relevant business contributing with as much as fifty percent of total revenues. Zondag (2006, pp 37) also points out that the average relevance of cargo business in combination companies is around fifteen percent.



Source: Serpen and Mirza (2009)

Figure 1.7 – Cargo revenue as a percent of total revenues, in 2008

Bearing in mind that air transport business is characterised by both a cyclic behaviour and low profit margins[17] (Doganis, 2006, pp 4), even small extra revenues could make the difference between negative or positive results. Thus, air cargo business, albeit its reduced expression, may generate enough revenues (in a negative year) for helping company to breakeven or to eventually achieve profits.

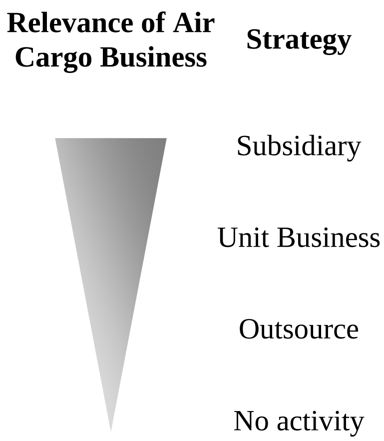
1.1.2.2 Strategies for air cargo business

The perspective and level of commitment towards air cargo business substantially differs amongst combination companies. Zondag (2006, pp 38) defines three types of commitment in this business:

[17] Operating results as percentage of revenues is seldom above 6%, and net results as percentage of revenues is seldom above 4% (Doganis, 2006, pp 7).

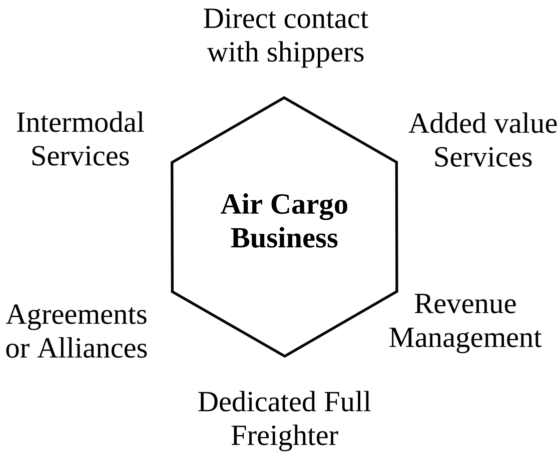
- Air cargo carriers by *choice* when the carriage of air cargo is regarded a core business;
- Air cargo carriers by *accident* when although taking seriously air cargo business, they prioritise on air passenger business in cases of conflicts of interest;
- Air cargo carriers by *incident* when do not take seriously marketing this business.

Naturally, different levels of commitment result in different strategies for air cargo business. Figure 1.8 offers a tentative categorization. The classification was developed based on the company's level of commitment towards cargo operations. Essentially, low commitment denotes less relevance or interest on the air cargo business, while higher commitment represents the opposite.



Source: author

Figure 1.8 – Business approaches to air cargo



Source: author

Figure 1.9 – Common features of air cargo unit business

The four basic strategies are:

1. *No air cargo business activity strategy* – it corresponds to the lowest possible commitment towards air cargo business, which is simply not providing air freight services at all[18].

[18] An example is the passenger air transport company Air Lingus that in 2004 withdrew air cargo market (Airline Business, 2004); yet, the typical case are the so-called low cost companies. These companies tend to operate small to medium range aircrafts (normally, Boeing B737 or Airbus A319), with limited air

2. *Outsource strategy* – it embraces those companies that provide air cargo services but keep to the minimum possible extent their efforts (and commitment) to this business[19]. The common strategy involves establishing long term block space agreements with third parties, such as: freight forwarders[20], general sales agents or specialised air cargo management companies. The third party agrees on paying a certain amount for the air transport company's air cargo capacity. All the air cargo market related activities are responsibility of the third party, while the involvement of air transport company is reduced to the physical transport of the freight.
3. *Unit Business* - it embraces all those companies that have a dedicated air cargo unit business within the organisation. This unit can range from a simple cargo department with a low level of autonomy, up to a separate division that pays the parent company for the utilisation of the resources (Zondag, 2006, pp 39).

   This is by far the most diverse group and the exact array of services depends on the air transport company's strategy. Figure 1.9 presents some of the common services offered by an unit business.

   Cargo departments commonly follow simple strategies, offering airport-to-airport services on the passenger aircrafts' lower deck (utilisation of combi-aircrafts or full freighters is not common). Commonly, all costs are borne by the passenger business and air cargo is commonly priced marginally, although, price management[21] could exist. Additionally, transport company may offer other added value services, such as: track and trace of goods, or customs clearance services.

---

cargo capacity, and they have very short rotation times that are not compatible with the unloading and loading operations.

[19] An example is the SN Brussels that in 2004 outsourced to European Cargo Services. The reason was the lack of knowhow since on the previous six years the air cargo business had been managed by Swissair (Conway, 2004).

[20] Freight Forwarders are servicing companies that, on behalf of shipper, assemble and manage their transport services. The various transport agents in the air transport freight market are detailed in Annex II – The Agents in the Air Cargo Sector

[21] Price management consists in adapting air cargo rates in function of demand, aiming to maximise revenues (Kader and Larew, 2003, pp 4).

Companies with higher level of commitment, run separate divisions[22] and exhibit complex strategies. They may operate combi-aircafts, have dedicated full freighter operating on the busiest markets, offer intermodal freight transport services (such as: airport-to-door, door-to-airport or even door-to-door[23]), which entails establishing agreements with other transport companies or air transport companies, entering into some sort of strategic alliancem or engaging in direct relations with shippers.

4. *Subsidiary Strategy* – it corresponds to the highest possible level of commitment towards the air cargo business, which is the establishment of a subsidiary unit[24]. A subsidiary is an independent company that is wholly or partly owned by the parent company, and normally shares its name (for better market recognition). A subsidiary unit has a great amount of autonomy: defining its own type services, operations and equipment. Commonly, it has an independent balance sheet. The only requirement is to use at maximum possible extent the parent company's available capacity. Apart from this, the subsidiary has total freedom to run the business, which may include, besides the already mentioned features depicted in Figure 1.9, to buy space in other air transport companies, or to have dedicated marketing strategies.

1.1.2.3 Challenges of the combination companies

The combination companies are nowadays in a difficult positioning in the air cargo market. Several evidences corroborate this assumption, namely:

1. Inferior rate of growth of these companies vis-à-vis the others;
2. Inferior market positioning;
3. Longstanding financial difficulties;

---

[22] Example of a passenger air transport companies with separate divisions are Air France and KLM, or British Airways (Zondag, 2006, pp 39)

[23] A door to door transport service, sometimes also designated by desk to desk, refers to a transport service by which cargo is collected at origin and delivered at final destination. An alternative transport solution is the so-called point to point transport service by which cargo is transported in-between intermediary locations (for example, in case of combination companies the transport service is between airports). There are also hybrid transport solutions, such as: door-to-point or point-to-door. Normally, the transport service is done under the responsibility of one transport agent (freight forwarder role), albeit the actual transport could be provided by more than one transport provider.

[24] Examples include the Lufthansa Cargo AG or Singapore Airlines Cargo (Zondag, 2006, pp 39).

4. Inadequate business model.

These evidences were collect from different sources. The first one was already discussed in this chapter (Figure 1.6). The second refers to the current market positioning of the combination companies. The third is linked with a property of the air transport market (i.e.: passenger and cargo businesses), but that naturally has consequences for the air cargo business in the combination companies. And the last one is visible in some of the combination companies with lower levels of commitment (Figure 1.8). It denotes lack of knowledge about the air cargo business, which it is naturally translated into difficulties of competing in the market.

Inferior Market Positioning

Combination companies have evolved towards an inferior market positioning in the air cargo business.

In a movement initiated after the World War II, combination companies have progressively adopted the outsource strategy and focussed on the passenger business, which has resulted in a vicious circle. The gradual reduction of the relevance of the air cargo business was accompanied by a rationalisation of the resources and of the efforts. And, since the costs of cargo operations increase as the volumes decrease (Kadar and Larew, 2003, pp 8), companies were further compelled rationalise this business. As a consequence of the outsource strategy, many companies have abdicated to market or to negotiate on this business, and they have reduced their activity to the simple role of transport suppliers. In this process, they relegated the business functions in third parties, opening the door for the freight forwarders to enter in the air cargo business. As a consequence, they started to directly negotiate with shippers, they became the combination companies' main customers (Figure 1.10 – left) and, over time, they have eventually took control of air cargo business.

This relationship was certainly more favourable to the freight forwarders than to the combination companies (Clancy and Hoppin, 2000). The former were in better position to understand the market requirements, because they had direct contact with the shippers. Conversely, the latter only indirectly contacted the market through the freight forwarders, which were likely to filter and to bias the information towards their own interests (Kadar and Larew, 2003, pp 4). Moreover, the freight forwarders could offer added valued services, such as: customs clearance or storage, while the combination companies only offered a standard transport service. Consequently, the competition between the combination companies became essentially based on the price (Zondag, 2006, pp 24), since this was the only distinguishing factor between them. Conversely, the competition in the freight forwarding market, besides the price, also involved the quality factors (that is, the added value services).

By this time, the main competitors in the cargo market (general-freight and air mail segments[25]) were the combination companies, the freight companies and the freight forwarders (although the latter essentially provided services). Two levels of competition occurred in the air freight market: one level, between the combination and the freight companies for the freight services of the freight forwarders; the other level, between the three agents for the freight services of the shippers. Yet, as already discussed, the second level of competition had a reduced expression since the general-freight segment was substantially controlled by the freight forwarders. Therefore, level one was the main type of competition.

The late seventies brought significant changes to the air transport markets with the progressive liberalisation of many relevant markets in late 1970s. Indeed, on the words of Rigas Doganis (2006, pp 12) “the most significant trend during the last 25 years or so has been the gradual liberalisation of international air transport”.

An important consequence of the liberalisation was the emergence of the integrators, since they brought a further reduction in the combination companies’ market positioning. The integrators targeted a specific and underserved market segment: the express freight. These agents control the entire transport chain and always kept a direct contact with the shippers. Since the very beginning, they were very successful and soon they gained control of the express freight market segment.

Recently, they have been moving towards the traditional market – general-freight (Clancy et al, 2008) and, thus, entering in direct competition with the combination companies. Although the integrators are specialised in the express freight, they have been able to directly compete with both the combination companies (in what concerns,

[25] General-freight is the air cargo that it is not classified as express freight nor as air mail. The various types of air freight are detailed in Annex I – A Taxonomy for Air Cargo.

the physical transport of the goods) and the freight forwarders (in what concerns the relation with the shippers).

Notably, the fundamental relationships in the general-freight segment[26] remained fairly untouched, as the freight forwarders kept control of this market. Clancy et al (2008, pp 36) estimated that freight forwarders controlled eighty five percent of the retail sales channel for general freight, and Hellermann (2006, pp 5-6) pointed out for an interval between ninety to ninety five percent. Attempts of the combination companies to engage in direct negotiations with end shippers have been occurring (Figure 1.10 – right), although with limited success. The obvious purpose is to gain direct access to the shipper and thus improve the market positioning. However, this is not an easy task. Firstly, it implies to bypass freight forwarders, which immediately react in diverse ways, such as: better market conditions or, even, ending the business relationships with the combination company[27] (Kadar and Larew, 2003, pp 7). Secondly, it implies an heavy investment (in equipment, people, marketing, etc), which is often not affordable by the combination companies (Moorman, 2007).

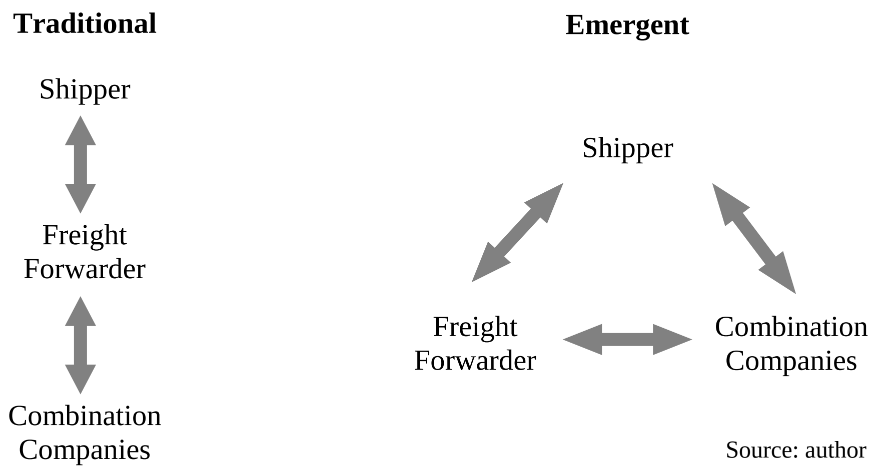


Figure 1.10 – Relationships in the air cargo market

In parallel, the recent years saw a progressive incursion of road and rail, in the medium distance (continental), and sea, in the long distance (intercontinental), into domains

---

[26] The air mail segment was intentionally dropped since it has become residual.

[27] Such threat is often taken seriously since it may provoke important damages. As an example, some years ago the Dutch combination company KLM initiated that movement but it was forced to retreat after some freight forwarders ended their businesses relationships.

(markets and goods) that were traditionally controlled by the air transport (Airline Business, 2007).

The momentum of the other modes of transport has some reasons. Firstly, they have been both increasing their levels of reliability (Airline Business, 2007) and, supported on technological developments, reducing their transit times. The same trends have not been paralleled by air transport companies (Airline Business, 2007, Boeing, 2008, pp 7). Secondly, air transport, although being by far the fastest mode of transport and highly reliable, is also the most expensive one[28]. Such difference, particularly in times of economic slowdown or downturn, is enough to make shippers carefully reflect on the importance of transit time. And, thirdly, there was a progressive reduction in the rate of creation of high value or mass market products[29] and the concomitant maturity of the current ones, which is reducing the importance of transit time and increasing the relevance of costs (Clancy et al, 2008, pp 28).

There is however no consensus on the actual impact of this hypothetical competition. On the one hand, Boeing (2008, pp 7) reports no significant shifts over the past decades from air towards sea transport, although acknowledges significant movement towards road transport in continental distances, particularly in the United States and Europe (Boeing, 2008, pp 26, 51). On the other hand, IATA (2009c) considers that, in addition to the normal cycles, there is a trend of air cargo going to containerised shipping. Regardless the situation, a steady increase of competitiveness of other modes of transport seams be occurring, which brings further pressure on the air cargo players.

In conclusion, the combination companies have evolved towards a difficult market positioning, which was the consequence of their inability to adapt to the market changes from both within and outside the air cargo market. In what concerns the air cargo market, the combination companies are stuck in-between Freight Forwarders that control the general-freight market (contact channels with end shippers) and Integrators that control express market and provide the highest quality services. In what concerns

[28] A rule of thumb says that an air consignment is ten folds more expensive than a sea consignment (Clancy et al, 2008, pp 38).
[29] Particularly in terms of electronic devices, such as: laptops, mobile phones, etc. (Clancy et al, 2008, pp 28).

the freight transport market, there are evidences of a growing erosion of the combination companies' natural competitive advantage.

Longstanding financial difficulties

As in any other business, capital availability is of paramount relevance for investing in new equipments or technologies, entering into new markets, proceeding with acquisitions, or surviving through the negative times.

The air transport market is characterised by marginal profits and a cyclic behaviour (Doganis, 2006, pp 4). Such behaviour is raising concerns on the sustainability of the sector in the long run (in particular, in the capacity of the positive years covering the negative plus generating enough internal capital) (Doganis, 2006, pp 6, Button, 2003, pp 5, 1996, pp 276). Although "no firm conclusions can be drawn" (Button, 2003, pp 13), some authors believe not (Moorman, 2007, Putzger, 2006) and, as evidence, they refer the successive public financings of some companies in the recent past, namely: Air France, Alitalia, Malaysian Airlines or New Zealand Airlines (Doganis, 2006, pp 7-8). Recalling that passenger business is the core business, it is thus natural that the companies channel the bulk of financial efforts towards this business and, only in case of availability, favour air cargo business[30].

Moreover, the cargo and passenger yields[31] have been following a long term downward trend[32]. A likely reason for such behaviour is a progressive increase of the competitive environment, which is leading companies to reduce prices. Other reason is the recent contraction of demand that was not accompanied by a decrease of supply (Doganis, 2006, pp 16, Boeing, 2008, pp 53, Hoppin, 2005b). Although yield does not provide whatsoever information about the company's financial health (because it does not incorporate costs), it is hardly questionable that a decreasing yield increases the difficulties in generating revenues and profits.

[30] Moorman (2007) refer the example of Delta Airlines that as part of a cost saving restructuring has almost ended with its cargo division.

[31] Yield is a measure of the weighted average rate, normally measured at aggregated level, calculated by dividing total revenue freight by the production (freight tonnes) on a flight (Boeing, 2008, pp 123).

[32] Between 1987 and 2007, cargo yields decrease at an average rate of 3.0%, in cargo business, and 2.2%, in passenger business (Boeing, 2008).

Other factor contributing for the financial difficulty is the steady rise of the costs. The fuel prices that account for as much as for thirty percent of an airline's total operating costs (O'Connor, 2001, pp 80), have become highly unstable over the past decades (Doganis, 2006, pp 13, Allaz, 2004, pp 256-268). For example, as recent as 2008, and in a matter of few months, the oil prices rocketed to unprecedented values, before decreasing again to acceptable levels. Besides its instability, fuel prices also denote an upward trends, as the finite sources of oil are being exhausted. Other source of additional cost is related with the increasing security and safety measures[33] that authorities have been imposing over the air transport sector, as the consequence of new kinds of threats to air transport sector, such as: terrorism or new diseases (Air Cargo World, 2008, Shipping Digest, 2008).

Finally, the inherent properties of cargo and passenger businesses in combination companies are prone to result in a downward price spiral. The reason lies on the fact that the costs of transport are borne by both businesses; consequently, cross-subsidisation may occur[34]. The gradual increase of the competitive environment is leading companies to give up revenues (allocating costs to the passenger business) and, consequently, driving prices down (in particular, in those companies that are not able to offer added value services) (Kadar and Larew, 2003, pp 4).

All these factors are contributing to the deterioration of the financial capacity of the combination companies, which may not only jeopardise their survivability as well as it may preclude their attempts of investing in the air cargo business.

[33] Like for example: screening of all belly cargo or quarantine (European Parliament, 2002). Screening freight poses several challenges vis-à-vis passenger luggage, for example: there is still no widespread technology for screening large pallets or volumes , requiring them to be dissembled into smaller pieces to be used on conventional devices; or certain goods are heavily dense rendering void non-intrusive screening processes (Airline Business, 2008c).

[34] Although occurring in both ways, it is the passenger business that traditionally borne the costs of the flight because, first, the decision for the flight is normally taken by the passenger business (only seldom is taken into consideration the cargo business), therefore, the cost are essentially allocated to this business (and revenues from cargo are seen as an extra); second, many combination companies still do not have revenues management systems and, therefore, lack control on the minimum amount of prices to charge for the cargo services.

Inadequate Business Model

There are still combination companies faithful to a business model that is no longer suitable for the current market conditions. Often, such business models were developed typically during a period of market regulation when business was done with different rules and when competition was restrained. The problem was that, meanwhile, market conditions and demands have greatly changed due to significant modifications in both air transport sector and its context, but some companies have not yet adapted accordingly.

Although varying amongst airlines, the traditional business model presents one or more of the following factors:

- Low level of integration in the logistic chain (airport to airport transport);
- Intensive labour;
- Low level of technological development (e.g.: sales tracing, etc.);
- Inadequate information to shipper;
- Outdated marketing.

A reason for this current situation was the progressive abovementioned abandonment of cargo business after the World War II, which over time led to the loss of both the contact with the final shipper and the knowhow about this business. Nowadays, combination companies lack the understanding about the requirements of the shippers and the behaviour of market. The attempt for overcoming such gap is difficult since it requires time and deployment of resources (for re-learning the business and gaining the trust of shippers), and it required to bypass the freight forwarders. In the absence of know-how, a common approach is to deploy in the cargo business the same marketing approaches used in the passenger business[35]. The lack of a suitable business model is thus an important factor of loss of competitiveness, since for example it precludes the company to offer added value services, control revenues and minimise costs.

---

[35] An interesting example is provided by Jan Carlzon, former CEO of SAS Airlines. In his book, he refers that at a given time has imposed a strategy for the cargo business similar to the passenger business. The outcome was a total failure. He then recognised his lack of knowledge about the specificities of cargo business (Carlzon, 2006, pp 61-62).

1.2 Research Motivation

From the discussion of the previous chapter, the following key ideas can be highlighted:

- Combinations carriers, notwithstanding still controlling a substantial part of the cargo business, have evolved towards a difficult market positioning (Chapter 1.1.1.3 and Chapter 1.1.2.3).
- The fundamental properties of the air cargo business in combination companies drive (or tends to drive) the profit margins towards zero, which, along with the current adversities, is making revenues and profit generation increasingly difficult (Chapter 1.1.2.3).
- Air cargo business is generally considered a secondary business to the passenger business (Chapter 1.1.2.1). Yet, the level of commitment varies considerably across market (Chapter 1.1.2.2) and, as such, multiple strategies towards air cargo business have been adopted (Chapter 1.1.2.3).
- Despite the previous, the air cargo business proved to be relevant and to positively contribute for the combination companies' financial results (Chapter 1.1.2.1). Air transport is a business with reduced profit margins (Chapter 1.1.2.3), thus, notwithstanding the minor contribution of the cargo business, it may be sufficient to tilt the financial balance towards the green.

These lines of thought provide explanatory insights for the presentation of the motivation and the overall objective of this research work. The <u>motivation</u> of this research work lies in the *difficult positioning of the combination companies in the cargo market*, which, although not being a core business, it may nonetheless be influential in their survival[36]. From the research motivation, the overall <u>objective</u> of this research work is defined as: *to contribute to the competitiveness[37] of the combination companies in the air cargo market.*

---

[36] Survival understood as the ability to continue operating in the air transport market.

[37] In this research work, the concept of competitiveness refers to a company's ability to conceptualise, produce and market its products and services better than those offered by the competitors. Thus, if a company's competitiveness is lower than its competitors, then it will go eventually out of the market. Yet, the concept of competitiveness is still focus of considerable debate on the literature. A review on this matter lies outside the scope of this research work, the interested reader is referred to: Alvares et al (2009), Ambastha and Momaya (2004) or Krugman (1994).

The analysis to the combination companies' competitors is provided in Chapter 1.1.2.3.

1.3 Research Objective

The solution proposed herein to help the combination companies to achieve the abovementioned objective is the strategic option of *intermodality*[38]. This proposal was devised from the analysis to the freight transport market.

Over the past decades, the demand for freight transport services has become quite complex and dynamical and, nowadays, it is to a large extent based on integrated, door-to-door transport services[39] (Macário et al, 2008). In this context, the combination companies, regardless of their strategies, will be called to participate in the production of intermodal transport services.

Arguably, the nature of their participation and the level of their integration in the intermodal transport service will ultimately influence the performance of the transport service. If the integration is not adequate, then losses of performance may occur at the frontiers of interaction, resulting in a reduction of the overall performance of the intermodal freight transport service and, ultimately, of its competitiveness. Conversely, if the integration is adequate, then the losses will be reduced and the intermodal transport service could achieve higher performance, which will enhance its competitiveness. Therefore, by contributing to the competitiveness of the intermodal freight transport service, the combination company is making herself relevant (and, eventually, irreplaceable) and inherently she is improving her positioning in the market and reinforcing her competitiveness.

We may then argue that the combination companies' competitiveness[40] is function of their ability to adequately[41] integrate with the other transport agents. Figure 1.11

---

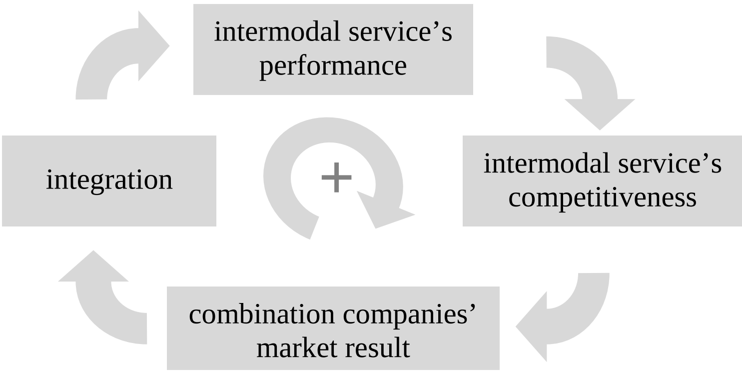
[38] The advantage of intermodality can also be justified through economies of density. Zhang et al (2007) present a theoretical proof of the existence of such economies in the air cargo for the combination companies. This however was not the rationale followed in this research work.

[39] A transport service resulting from the integration of more than one mode of transport is designated as intermodal transport. The definitions of integration and intermodal transport are provided in Chapter 2.1.

[40] In this research work, the concept of competitiveness refers to a company's ability to conceptualise, produce and market its products and services better than those offered by the competitors. Thus, if a company's competitiveness is lower than its competitors, then it will go eventually out of the market. More information is provided in Footnote 37.

[41] Adequate denotes a seamless movement of the various flows. The term adequate and the notion of flow will be better understood in Chapter 2.2 with the conceptual representation of an intermodal freight transport service.

summarises the argument in favour of integration: integration fosters the performance of intermodal freight transport service, which contributes to the enhancement of its competitiveness, which in turn spills into every transport company in the form of better market results, which ultimately leads the companies to pursue further integration.



Source: author

Figure 1.11 – Virtuous cycle of integration

Moreover, there are examples of very successful intermodal transport services produced by air transport companies, like for example: the air trucking services[42] or, even, the integrators. So, we may expect that intermodal transport services can contribute to enhance the position of the combination in the air cargo market.

The strategy of intermodality may be deployed in two different but not mutually exclusive possibilities:

I. Possibility One: combination companies plays the role of a transport agent in an intermodal transport service produced by a freight forwarder;
II. Possibility Two: combination company plays a double role: as a freight forwarder to produce an intermodal transport service, and as a transport agent in the intermodal transport service produced by herself.

[42] Air trucking corresponds to the utilisation of a road-based vehicle (normally: truck) instead of an aircraft. A flight number is assigned to all road-based vehicles, and freight is dispatched with an airway bill which in legal terms denotes to be considered as air freight. Air trucking is a widely used solution in some regions, namely: Europe and United States, to replace short- to medium-haul (domestic, regional or continental) feeder flights of medium- to long-haul (intercontinental) flights (Air Cargo Word, 2009. Traffic World, 2008, pp 29, Button and Stough, 2000, pp 295, Traffic World, 2000). Boeing (2008, pp 26, 54) reports, in the United States from 2005 to 2007, a growth of 9% on the number of road-based flight routes, and a growth of 34% on the frequency of road-based flights schedules. In Europe from 2002 to 2007, the same report computes an annual growth of 24%, from 3870 up to 11497, on the weekly road-based flights frequencies offered by passenger air transport companies (Figure 14).

In this strategy, the understanding of how the integration in the intermodal freight transport service works is of paramount relevance, since integration between transport agents influences its performance[43]. Moreover, this understanding can help the combination companies to deploy their own capabilities in the most adequate way or, alternatively, to guide them in the development of new ones.

From this reasoning, the operational objective of this research work is defined as *the development of a conceptual framework on the mechanisms of integration in intermodal freight transport services*. This framework is an instrument to support the combination companies to deploy the strategy of *intermodality*.

1.4 Research Hypotheses and Research Scope

The development of the research process of this research work was grounded on one hypothesis. The hypothesis was formulated from the above discussion about the current paradigm of demand for freight transport services and on the intermodality as a valid strategic option. The hypothesis that guided the research process is: *the integration of combination companies in intermodal freight transport services can enhance their competitiveness in the air cargo market.*

The scope of this doctoral research concerns the organisation of intermodal freight transport services with air transport services. In terms of the domain of the mode of transport, the scope is presented in Figure 1.12. The research frames under the overall domain of research of *transport systems*. Within this domain, it narrows the scope to the domain of *freight*. Within the domain of freight transport, it further narrows the scope to the topic of intermodality. Since the domain of research is the air transport, there is a higher focus on this mode of transport than the other ones.

In terms of the level of decision[44] of the combination companies, the research frames both within the strategic and tactical levels. A greater emphasis is however placed at the

[43] The integration determines one of the three sources of performance in an intermodal transport service. The sources of performance are discussed in Chapter 2.3.
[44] The author follows the definitions proposed by Crainic and Laporte (Crainic and Laporte, 1997, pp 411), being:

tactical level[45], because, although being at strategic level that the intermodality is decided as a priority, it is at tactical level that integration is set as an instrument for effective intermodality.

1.5 Research Method

A research inquiry[46] comprises a sequence of interrelated phases. In each phase a set of tools and techniques[47] are used to achieve pre-determined scientific goals. The set of phases forms the research method. The research method is therefore the methodical activity to be carried out by a person (or persons) - the researcher (or researchers) - over a specific subject or problem (Williams & May, 1996, pp 7).

The method is an integral part of a successful research inquiry, because as Black (1976, pp 2) writes “the research process is a chain that is no stronger than its weakest link”. Moreover, the “facts do not simply lie around waiting to be picked up. Facts must be carved out of continuous web of ongoing reality, must be observed within a specified frame of reference, must be measured with precision, must be observed where they can be related to other relevant facts. All of this involves ‘methods’” (Arnold M. Rose (1965), quoted in Black (1976, pp 6). Therefore, although the research method to not be

---

Strategic level refers to the long term planning taken by highest ranks of management (e.g.: administration boards). The temporal interval varies amongst organizations but ranges from 5 to 20 years. Examples of strategic decisions include: acquisitions and fusions, entry or exit or new markets, or investment decisions (renewal of fleet);

Tactical level refers to the medium term planning taken by the intermediary ranks of management (e.g.: divisions or units). The temporal interval goes up to a maximum of few months. The decisions aim to contribute for the achievement of the strategic decisions. Examples include: design of the transport network (routes, frequencies, transhipment points), or choice of transport partners (intermodal or single-modal.

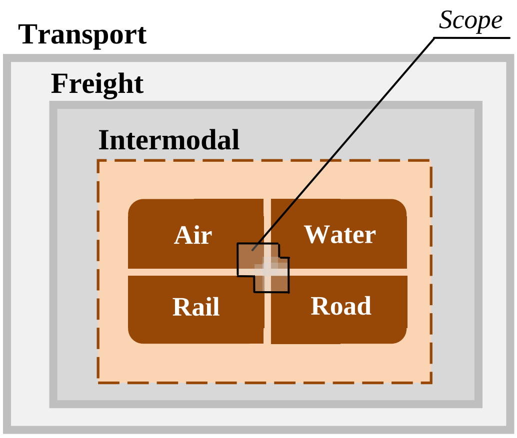
Operational level refers to the short term planning taken by the local management ranks. The temporal interval goes up to a maximum of some days. And concerns with the daily operations decisions, such as: driver scheduling, truck routing or maintenance of equipment.

[45] It should be clear that the tactical level is subordinated to the strategic level. If no commitment towards intermodality is set at the strategic level then no intermodality will occur at the tactical.

[46] Research inquiry is defined as being the "creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications” (OECD, 2002b, pp 30).

[47] There are multiple definitions on tools, techniques and scientific method on the literature. The author follows the definition proposed by Russell Ackoff. So, tool is “a physical or conceptual instrument that is used in the scientific inquiry”; technique is “a way of accomplish a scientific objective, a scientific course of action” (Ackoff, 1962, pp 5).

the sufficient condition for the achievement of valid scientific results, it may nevertheless preclude such attempt if badly or ill-conceived.



Source: author

Figure 1.12 – Scope of this research work

The craft of the research method must hence consider the eventual constraining factors, in particular, the constrains related with the state of the research inquiry. Macário (2005, pp 31-32) lists a set of potential constraints, being:

- The state of knowledge (extension and depth) about the key variables involved in the problem;
- The degree to which these variables are susceptible of controlled manipulation and observation;
- The availability of information about the context where data should be considered for correct interpretation;
- The capacity to simulate contextual impacts over key variables;
- The awareness of the degree of multidisciplinary interaction;
- The degree of complexity, nature and availability of existing data pertinent to the observation of the problem under analysis.

In what concerns this doctoral research, the author concludes and demonstrates along the research work the following characteristics that were influential in the design of the research method:

- The body of research in the domain of intermodal transport is still rather limited.

- The objective of the research work (Chapter 1.3) entails a multidisciplinary approach involving knowledge from diverse fields such as: of economy, management, engineering or policy. The air transport markets are highly dynamical owing to the fast developments at multiple levels, namely: political, environmental, societal, technological and economical.
- The intermodal freight transport services are rather complex due to the dynamics of competition, the nested processes and the high diversity of interacting agents.
- Experimentation under controlled conditions of key variables and hypotheses is not viable.
- There is a scarcity of valid and reliable data due to the eminently private nature of the object of analysis.
- There are few reported exercises of micro-simulation of freight transport markets.

The author follows Karl Popper's views on science. Particularly, the author believes that any theory is the result of an irrational cognitive process that takes place in researcher's mind. Moreover, truth is not achieved by the process (or in the moment) of building theory, but instead, it is an ongoing cumulative process whereby the successive gathering of supportive cases reinforces the likelihood of being truth. That is, theory building is a self-validation process[48].

The research method devised is presented in Figure 1.13, and it comprehends two main phases: induction process and deduction process. The induction process used evidences collected from the real world to construct the conceptual framework. The deductive process aimed to assess the validity of the framework and to test the hypothesis. This

[48] Popper's point is that validity would only be demonstrated if all possible instances of a phenomenon could be evaluated and proved truth. On the other hand, a single false instance is enough to refute the theory. He concludes that the purpose of research process is thus testing. "If the singular conclusion turns out to be acceptable, or verified, then the theory has, for the time being, passed its test: we have found no reason to discard it. But if the decision is negative, or in other words, if the conclusions have been falsified, then their falsification also falsifies the theory from which they were logically deduced […] It should be noticed that a positive decision can only temporally support the theory, for subsequent negative decisions may always overthrow it. So long as a theory withstands detailed and severe tests and is not superseded by another theory in the course of scientific progress, we may say that it has 'proved its mettle' or that it is 'corroborated'" (Popper, 1961, pp 33). Therefore, under his ideas, a new valid instance does not prove the validity of the theory only simply reinforces its likelihood of being truth. Popper has designated the process whereby a theory is proved to be false as *falsifiability test* (Popper, 1961, pp 86).

process was accomplished by resorting to a micro-simulation model (Chapter 5) that was developed to behave in a similar way than a real world freight transport market where intermodal air cargo services can occur. Consequently, the results of the simulation model are considered to be similar to those that would be obtained in a real world experiment. The need to resort to a model was, as it will be explained later in Chapter 4, consequence of the impossibility to use a real world case.

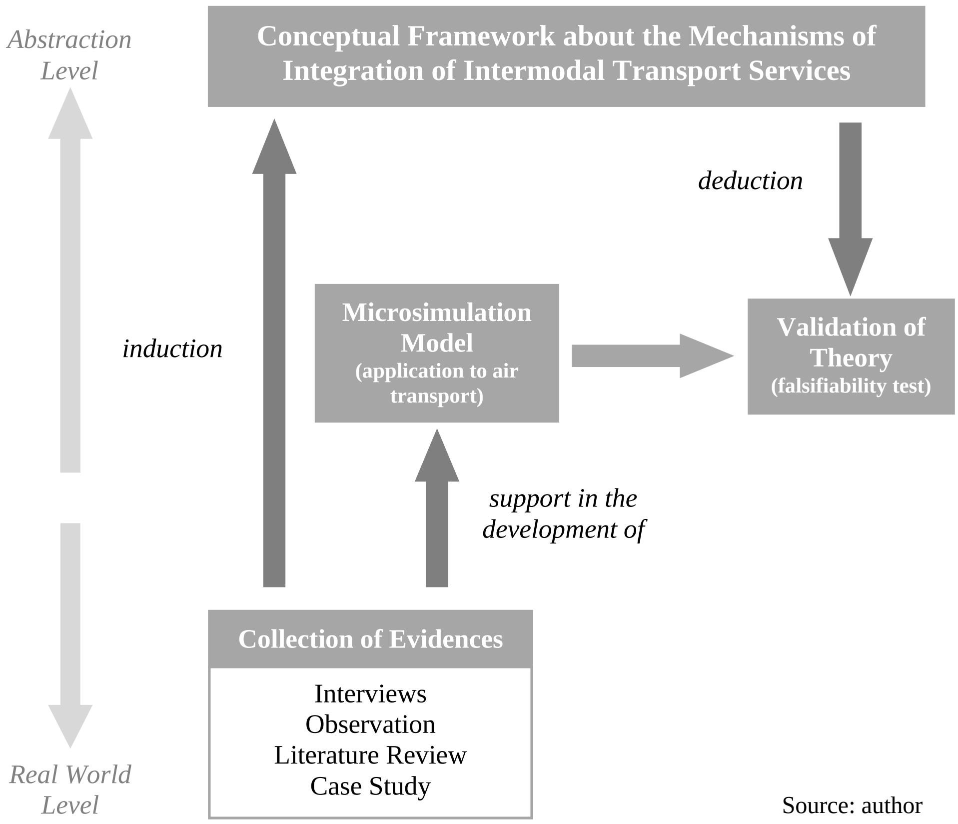


Figure 1.13 – Research method applied in this research work

1.5.1 Collection of evidences

An evidence is a piece of information about the object of research. The information should be factual, or at least to be the closest possible to the reality. The series of evidences forms the researcher's (or researchers') representation of the phenomenon in analysis, upon which the scientific inquiry is conducted.

An important matter in this phase is to decide about the necessary amount of evidences to collect (Phelan and Reynolds, 1996, pp 105). On the one hand, a reduced amount or poor set of evidences would yield an imperfect representation of the real world. On the other hand, an excess of evidences may imply a waste of time and consumption of resources, besides requiring efforts to eliminate the eventual redundancies. A key difficulty lies in the quantification of the amount and nature of the evidences to collect (Hughes, 1997, pp 3-4).

In this research work[49], the main problem was not the abundance but the scarcity of evidences. The following techniques and methods were used to collect evidences from the real world: literature review, interview, observing behaviour and participant observation and case study.

1.5.1.1 *Literature review*

The literature review is a technique that comprehends the collection and analysis of information about a certain topic or topics of interest (Yin, 2003, pp 85).

The type of literature review applied in this research work was the integrative research review as defined by Cooper (1989, pp 13). This type of literature review is focussed on the representation and characterisation of the body of research already accomplished. As such, this type of literature review enables the identification of the gaps and holes in the body of knowledge.

The literature review was accomplished by following the framework proposed by Cooper (1989, pp 14-16):

- *problem formulation phase* - identification of the relevant variables for the research process and definition of the scope of the literature review. The relevant

[49] The process of collecting the evidences was enriched with a set of four research visits. Two in an industry environment:

- Cargo terminal at the airport of Oporto (Portugal) - 10 weeks;
- Grupo Luís Simões, in the unit responsible for the intermodal transport operations – Terminal XXI (Portugal) - 1 week.

And, two in an academic environment:

- University of Antwerp (Belgium) - 7 weeks;
- Massachusetts Institute of Technology (Boston, United States) - 16 weeks.

These research visits provided valuable information about real world operations, opportunities for conducting interviews and opportunity for contacting with other researchers.

variables included both the domain of the research and similar domains (such as: air transport, freight transport or transport economics);

- *data collection phase* - collection of information relevant for the scope of the literature review[50]. This phase revealed to be of particular difficulty owing to the rather limited body of literature on the domains of interest of this research work[51];
- *data evaluation phase* - evaluation and judgment on the quality and relevance of the information gathered. Low quality information was withdrawn. This phase was somewhat difficult owing to the scarcity of available literature in the domain of research;
- *analysis and interpretation phase* - analysis and interpretation of the information collected. Interpretation entails the identification of patterns and inconsistencies in the information;
- *public presentation phase* - elaboration of a text that presents and enumerates the various phases and findings accomplished.

1.5.1.2 *Interviews*

Human based interactions, that are the basis of any social phenomenon, are imminently complex, dynamic and to some extend unpredictable, because every person rules her decisions influenced on a set of inner factors (such as: past experiences, beliefs, or expectations) which are unique. Such nature creates considerable barriers to the understanding of the causes or the mechanisms underlying the decisions, the behaviours or the events taken in the context of a social phenomenon.

---

[50] The sources of data include both Internet-based sources (including digests of research projects, papers in scientific journals or papers and news in magazines) and physical sources (including books and conference proceedings). In terms of books the author has the opportunity to search in libraries of several Universities, namely: libraries of Technical University of Lisbon (Portugal), library of the Faculty of Engineering of the University of Oporto Portugal), library of the Faculty of Applied Economics of the University of Antwerp (Belgium), libraries of the Technical University of Delft (Netherlands), and libraries of the Massachusetts Institute of Technology (United States).

[51] As an example, a search by title of “air cargo” in the Elsevier database (that includes the highest ranked transportation related journal) yielded a total of 37 papers (in a universe of several thousands of papers in all transport related journals and several decades of publishing). Search carried out on 21st August 2009. European Union founded projects in the field of air cargo are almost none. The author found only two projects with relevance for the research work AFTEI (Air Freight Transport and European Intermodality) and CO-ACT (Creating viable Concepts for Combined Air/Rail Cargo); unfortunately, the former was not possible to access and the latter was not finished.

Interviews can bridge this gap, because the researcher may go deep into the person's rationale and, in this way, to get access to information that otherwise would remain uncover. Through an interview the researcher can explore and understand the factors (their importance and self-interaction) underlying a certain reasoning or explore fictitious situations, such as case scenarios (Colin, 2002, pp 271).

Interviewing however presents some pitfalls, namely, the interviewee's lack of honesty or lack of knowledge and the interviewer's lack of capacity in addressing the adequate question (Yin, 2003, pp 90, Colin, 2002, pp 272, Selltiz et al, 1963, pp 236-237).

In this research work the author conducted diverse interviews. Some of these interviews were specially arranged while others were informal during meetings, conferences or site visits. Annex III – The List of Interviews contains the list of interviewees[52] carried out in the course of this research work. The interviews revealed to be of utmost importance in this research work, in all the stages, to uncover the hidden factors and variables influencing the production of intermodal air transport services. For example: in the initial phase, interviews were important for defining the research question; in the intermediary stage, interviews served both as a complement for the state of the art and during the construction of the conceptual framework; and in the final stage, interviews were highly relevant for the collection of real world data during the development and validation of the micro simulation model.

1.5.1.3 *Observing behaviour and participant observation*

Bryman (1988, pp 45) defines participant observation as "the sustained immersion of the researcher among those whom he or she seeks to study with a view to generating a rounded, in-depth account of the group, organization or whatever". Essentially, the researcher participates in the daily life events, aiming to get a deeper knowledge on the object (Yin, 2003, pp 93-94).

Participant observation is relevant in multiple situations, for example: when data (or records) is not available, when what is being searched is not easily translated in numerical (or other quantitative) format, or when the object of research encompasses

[52] This list solely includes the formal interviews. Many other informal interviews were conducted.

characteristics that refer to non-documentable factors such as, informal procedures or processes; or relationships and networks (Colin, 2002, pp 310).

The author accomplished two research periods in an industry environment (Footnote 49). In these periods the author had the opportunity to observe the daily life of a cargo terminal, contact with the employees, transport operators, freight forwarder and customs agents, and, even, participate in diverse tasks. It was during these periods that the author has built most of his perception about the air freight transport operations.

Despite these advantages, participant observation also has some drawbacks, such as: the possibility of the object of analysis changing its behaviour due to the presence of the observer (Colin, 2002, pp 311), the eventual impartiality of the observer (Selltiz et al, 1963, pp 205), or the difficulty of the observer to apprehend the social interactions[53] (Yin, 2003, pp 96, Selltiz et al, 1963, pp 207). The author, aware of such limitations, strove to minimise their possible influence.

1.5.1.4 *Case studies*

As the name reveals, a case study is meant to investigate - *study* - an instance - *case* - of a given real world phenomenon. Through a case study the object of analysis is researched within its contextual conditions (Yin, 2003, pp 13). Moreover, a case study is particularly suitable when there is the purpose of to study either the underlying mechanisms and causes, or the behavioural nature of the object of study. Yin (2003, pp 9) writes that case studies have distinct advantage “when a ‘how’ or ‘why’ question is being asked about a contemporary set of events, over which the investigator has little or no control”.

It should be noted that a case study research approach is by itself a comprehensive research method that comprises a set of tools, techniques, procedures and methods. Actually, it is a common practice to make use of this research approach on a standalone basis. In this research work, the case study was used along with other methodical approaches.

---

[53] The point is that the social phenomena are dispersed in space and time, which may lead the researched to choose for some aspects (or events) in detriment of others (Yin, 2003, pp 95). Moreover, the social phenomena are continuous in time requiring therefore continuous attention which may be difficult to deliver for a long period of time (Yin, 2003, pp 96, Selltiz et al, 1963, pp 207).

A limitation of the case study lies in the fact that it studies a sample or a few samples of real world instances, which limits its ability to support the development of theories. This is the situation of this research work, where either the air cargo market or the intermodal freight transport services are highly influenced by external dynamics.

Two cases studies were considered in this research work: GLS case study and SeaRoad case study. GLS case study[54] resulted from a short training period at the Portuguese logistic company Grupo Luis Simões. The case study provided very important information about the management of intermodal freight transport services, namely: in what concerns the frictions amongst transport agents. SeaRoad case study was object of development in another context[55], but the author has had the opportunity to fully follow its development (such as: participation in interviews, meetings and conferences with the persons responsible for the intermodal organisation offering the intermodal freight transport service). In brief, SeaRoad case study[56] concerns a failed RO-RO[57] initiative between the port of Leixões (Portugal) and Southampton (United Kingdom). This service ran for six months after which the bankruptcy was declared.

1.5.2 Induction

The next phase of the research process consisted in inducing the conceptual framework. Induction is the process of moving from particular instances to general laws of interactions (Black, 1976, pp 66, Popper, 1961, pp 27). In other words, with an induction a researcher is claiming that the laws of interaction, which are valid in a set of situations, are also valid in every possible situation. Consequently, the inducted conjectures cannot be considered true (or valid), but only more or less reliable (Phelan and Reynolds, 1996, pp 22).

This is the phase where the researcher has the highest degree of freedom and the highest responsibility. The researcher has to make the best use of her own capacities to devise a

[54] This case study is described in the reference Reis and Macário (2008) and it is attached in Annex IV – The GLS Case Study.

[55] Full development of this case study can be found in Baindur (2010).

[56] Whenever relevant more information is provided about this case study.

[57] The RO-RO service consisted in a three legs service: road, sea and road. The unit load was the trailer. A truck moved the trailer between origin and the port. Here the trailer was loaded in the ship, and transported to other port. Finally, a truck moved the trailer to final destination.

possible conjecture. She has to collect the necessary amount and type information and evidences in order to gain a broad and deep knowledge on the problem in analysis. Then, through her perception, intuition, and knowledge built around the problem, the researcher will attempt to devise plausible laws of interactions which will result in the production of a conjecture. As Nachmias and Nachmias (1976, pp 13) clearly state "theories are free creations of the mind" and "that a theory may be adequate and fruitful despite the fact that the evidence for it is necessarily indirect".

The induction process in this research work was based on the knowledge gathered and created during the evidence collection process, of particular relevance were the interviews and research periods. The theory - conceptual framework - was then consolidated in the remaining research period through the collection of further evidences and the maturing of the knowledge.

1.5.3 Conceptual Framework

Literature is populated with definitions and concepts of theory[58]. Karl Popper writes that "theories are nets cast to catch what we call the 'world': to rationalise, to explain, to master it. We endeavour to make the mesh ever finer and finer" (Popper, 1961, pp 59). In his work, Dubin proposes a complete definition of a frame of reference for building a theory. The properties that he considers that should be defined (and presented) in every theory are (Dubin, 1978, pp 7-8):

- variables;
- laws of interaction;
- boundaries;
- system states;
- propositions;
- empirical indicator;
- hypothesis.

The variables are "empirically applicable concepts" (Nachmias and Nachmias, 1976, pp 20). They are the basic units of any theoretical model, amongst which the interactions

[58] Black (1976, pp 55-56) provide a good source for other definitions.

occur. Black (1976, pp 34) defines variables as "relational units of analysis that can assume any value of a designated sets of values". These interactions should be fully understood and explicated, which form a body of laws of interaction. The laws of interaction define the web of casual relationships amongst the variables.

The theoretical model has also to clearly define the boundaries of the part of the World that are under research. Rarely the object of research is the whole World; instead the researcher defines a portion of the World with relevance to the research. Boundaries also define the conditions where the theoretical model is valid. The portion of the World within the boundaries forms by itself a system. Changes in the variables will induce alterations in the system. The various possible system states, or at least the most relevant ones, should be explicated by the theoretical model.

These four building blocks define the theoretical model, and *propositions* may now be derived. A propositional statement makes explicit a given cause-effect phenomenon between a set of variables (Black, 1976, pp 34). Propositions or conclusions are obtained through "logical and true deduction" (Dubin, 1978, pp 8) from the theoretical model. If there is the need or intension to verify if it indeed represents the portion of the World, then *empirical indicators* should be defined for the variables of the propositions. Finally, in order to test the validity of the theoretical model propositions have to be transformed into testable *hypothesis*.

Comparing Dubin's properties with the properties of the theoretical output - conceptual framework - of this research work, the author considers that all of them are present, although with different levels of development. In particular, the maturity of the properties (namely: variables, laws of interaction, system states and empirical indicator) is insufficient, being required more thought, knowledge and detail.

1.5.4 Deduction of hypothesis

Formulation and testing of hypotheses are two crucial steps in the research process and ultimately in the process of doing social science. Hypotheses formulation results from a process of deduction from the propositions (or laws of interaction) outlined in the theoretical model (Dubin, 1978, pp 16). Deduction conversely to induction is the process of moving from general laws to particular instances. Assuming that the general laws are true (or valid), so the particular laws are equally valid (or true) (Nachmias nad Nachmias, 1976, pp 4). As Phelan and Reynolds (1996, pp 22) clearly state "deductive arguments are sound by virtue of entailment[59], that is, that "provided the premises are correct, it is impossible to rationally resist the conclusion".

A hypothesis is a conditional prediction about the interactions between two or more variables (Black, 1976, pp 126, Nachmias and Nachmias, 1976, pp 23). Thus a hypothesis is by definition a hypothetical cause and effect inference (Selltiz et al, 1963, pp 35). Depending upon the research process “hypotheses can be derived deductively from theories, directly from observations, intuitively, or from a combination of these” (Nachmias and Nachmias, 1976, pp 23). In this research work:

- Hypotheses are derived from observation of real world (air cargo market) for purposes of sustaining the objective of this research work;
- Hypotheses are derived from the conceptual framework for purposes of purposes of assessment of the validation.

Proving a hypothesis evidences that the conjecture is valid on the phenomenon (that was used to test hypothesis), but it does not prove that theory is true (universally valid). Yet, the successive validation of the conjecture will eventually lead it to the status of theory. On the other hand, refuting a hypothesis means the conjecture is not correct and has to be reformulated. Hypotheses are therefore the cornerstone of the whole research and scientific process. Hypotheses have to necessarily be testable and measured, so that they could be put to empirical test and either proved or refuted (Black, 1976, pp 142).

1.5.5 Validation of the Theory

The final stage of the research method comprehends the process of validation the theory. The process consists in comparing the hypothesis of the theory against the real world phenomenon. If the hypothesis holds true (i.e. there is a match between the theory and real world) then the conjecture is validated in this instance of the real world; otherwise, the conjecture is not valid and should be discarded. Once again, this process does not yield definitive results (i.e.: the universality or truth of the theory) but simply

[59] For Phelan and Reynolds (1996, pp 59) the "concept of entailment means that the conclusion is contained in its premises and makes explicit what is already implicit"

demonstrate the conjecture holds against some instance of the real world. Therefore, the validation process should essentially seek for situations where the conjecture could be proved wrong (since this is the only conclusion than can be drawn from this process).

Validation in this research work was based on the deductive logic and largely built over the falsifiability test suggested by Karl Popper. The author was not able to find a single suitable real world case that could serve as test bed for the process of validation. The solution consisted in developing a micro-simulation model of a freight transport market where air transport services are possible. The model behaves in identical manner than a real world case and, therefore, it may be considered one. Additionally, the model has the advantage of emulating multiple instance of the real world, which favour the search for instances where the conjecture may not hold true.

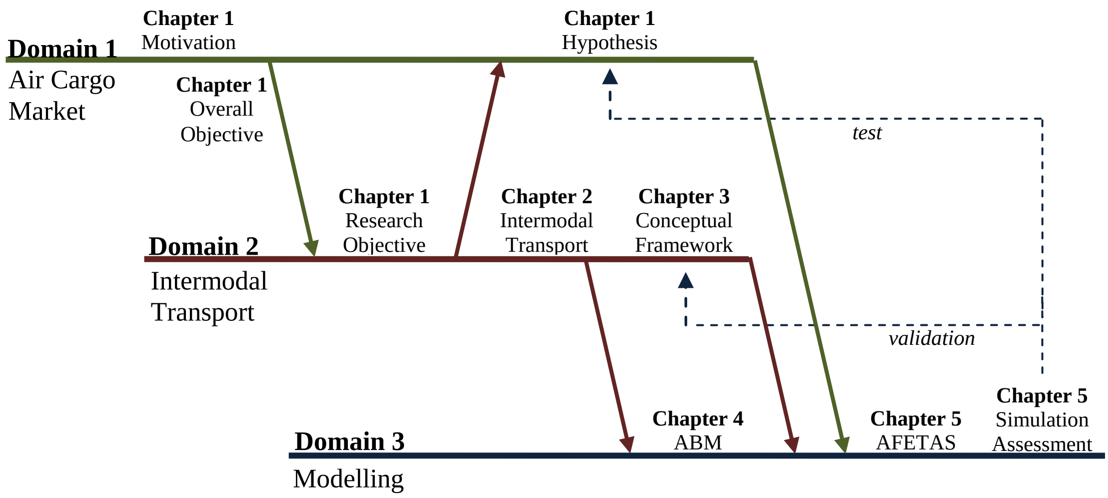
1.6 Structure of the research and of the dissertation

The Figure 1.14 charts the organisation of the research that was produced over the course of the doctoral work and that is described in this dissertation. The research work was developed in three different domains, being: air cargo market, intermodal transport and modelling.

The Domain 1 corresponds to the principal domain of research of this work, that is the air cargo market. On this Domain, the fundamentals of the research, described in Chapter 1, were elaborate, namely: the motivation, the overall research objective and the hypothesis. This research was motivated by the difficult positioning of the combination companies in the air cargo business, which, although not being a core business, it may nonetheless be influential in their survival (Chapter 1.2). The overall research objective was thereafter elaborated as: to contribute to the competitiveness of the combination companies in the air cargo market (Chapter 1.2). And, the hypothesis was phrased as follows: the integration of combination companies in intermodal freight transport services can enhance their competitiveness in the air cargo market (Chapter 1.4).

The Domain 2 corresponds to the object of research, that is the intermodal freight transport. The bulk of the theoretical research in this work was developed in this

Domain. The operational objective was defined after the definition of the overall objective (in the Domain 1) as being: to develop a framework about the mechanisms of integration in intermodal freight transport services (Chapter 1.3). The theoretical research is divided and presented in two parts. The first part is dedicated to the theoretical analyses of the intermodal freight transport (Chapter 2). This part establishes the theoretical foundation for the development of the second part. The second part is dedicated to the development of the conceptual framework about the mechanisms of integration (Chapter 3).



Source: author

Figure 1.14 - Organisation of the research

The last Domain corresponds to modelling. This Domain is divided in two main parts. The first part is dedicated to the construction of a simulation model of a freight transport market, in which intermodal air cargo services could occur. The model was named AFETAS that stands for: Air Freight Transport Market Simulator (Chapter 5.2 and Chapter 5.3). The need to resort to a simulation model laid in the impossibility of using a real world case. The Agent Based Modelling (ABM) was the modelling technique deployed in this research work (Chapter 4). In the second part, a simulation assessment was carried out to test the hypothesis and to validate the conceptual framework (Chapter 5).

The dissertation was structured to provide a clear and easy understanding of the above explained scientific work. Six chapters (including the present one) were defined. Figure

1.15 outlines the structure of the dissertation and presents the corresponding phases of the research method. Figure 1.14 also presents the Chapter of each building block of the research work.

Chapter 1, which is the current one, provides the fundamentals to the doctoral research. It contains the presentation of the domain of research, in Chapter 1.1; the motivation and the overall objective, in Chapter 1.2, the operational objective, in Chapter 1.3; the hypothesis of the research, in Chapter 1.4; and the method of the research, in Chapter 1.5. Finally in this Chapter, the structure of the research and of the dissertation are explained.

Chapter 2 is presents a theoretical analysis chapter about to the object of research, that is the intermodal freight transport. The analysis is done in four sub-chapters, each one dedicated to a specific topic, being: the definition, in Chapter 2.1, the conceptualisation, in Chapter 2.2, the analysis of the sources of the performance, in Chapter 2.3, and a reflection about the modal choice process, in Chapter 2.4.

Chapter 3 is the central chapter of this research work. It presents the conceptual framework about the mechanisms of integration of an intermodal freight transport service, in the last chapter - Chapter 3.4. The presentation of the framework is preceded by the detailing of its basic concepts: fitness, in Chapter 3.1 and friction, in Chapter 3.2. Follows, the analysis of the multidimensional nature of the concepts of fitness and friction in Chapter 3.3. Chapter 4 presents the fundamentals about the modelling technique used for testing the hypothesis: Agent Based Modelling (ABM). The presentation is done in six moments, being: the origin of the notion of agent and of ABM, in Chapter 4.1; the concept of ABM, in Chapter 4.2; the main components of ABM, in Chapter 4.3; the most relevant ABM models and development toolkits, in Chapter 4.4; the application of ABM in the domain of transport, in Chapter 4.5; and the explanation of the utilisation of ABM in this research work, in Chapter 4.6.

Chapter 5 is divided in two parts. The first part describes in detail the process that was adopted to construct the simulation model named AFETAS, namely: the fundamentals of modelling, in Chapter 5.1, the specifications, in Chapter 5.2; the architecture, in Chapter5.3; and the verification and validation, in Chapter 5.4. The second part presents the simulations carried out with AFETAS to test the hypothesis and to validate the conceptual model, in Chapter 5.5.

At last, the Chapter 6 presents the main conclusion, achievement and limitations of the research work. It also proposes topics for future research.

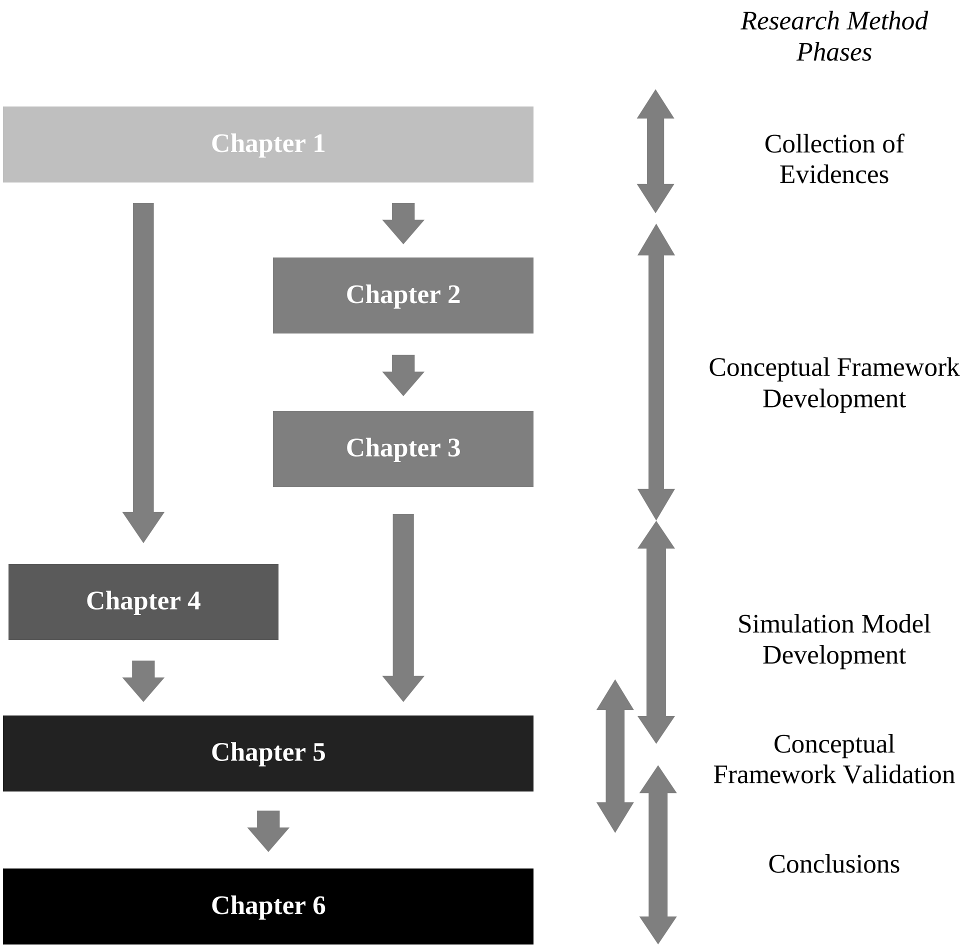
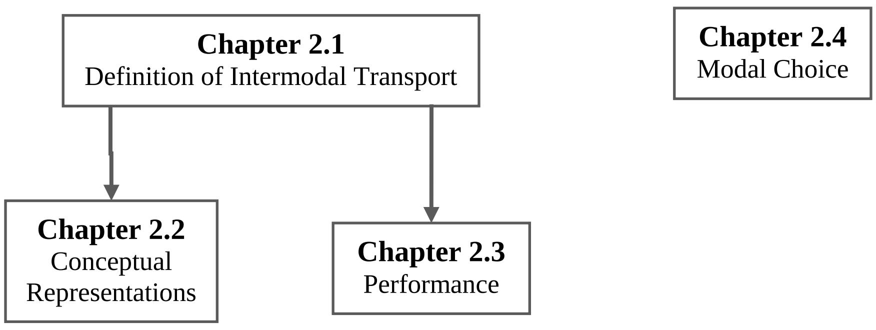


Figure 1.15 – Outline of the research work

2 DEPICTING THE INTERMODAL FREIGHT TRANSPORT AND THE MODAL CHOICE PROCESS

This chapter is divided in two parts. The first part introduces the object of research that is the intermodal transport. This introduction provides the background for the development of the conceptual framework (in Chapter 3). The presentation is done in three chapters – Chapter 2.1 to Chapter 2.3. Each one covers a specific thematic area.



Source: author

Figure 2.1 - Structure of Chapter 2

Chapter 2.1 reviews the definitions of intermodal transport and other similar transport solutions and it concludes with the definition adopted in this research work. Chapter 2.2 is dedicated to the concept of intermodal transport. It starts with a review to the existent representations proposed by other authors. Then it makes the description of an archetype of intermodal transport from two different perspectives: one perspective using the concept of process and other perspective using the concept of flows. Chapter 2.3 provides a theoretical description of both the concept and the sources of performance in intermodal transport.

The second part of this chapter comprehends a single chapter - Chapter 2.4 – and it makes a literature review on the modal choice process. This review supported the development of the agent based model (in Chapter 4).

2.1 Definition of Intermodal Freight Transport

The association of two or more modes of transport in a transport chain is a mature and regular practice in the freight transport business (Lowe, 2005, pp 3, Clack, 2001, pp 141). Over the years, different definitions have been put forth in the international fora by international organisations and academia to define such type of transport. Yet, so far no overall consensus on a universal definition has been reached. Such situation may be ascribable to either the lack of a theoretical body of knowledge on this kind of transport (Bontekoning et al, 2004, pp 8), or the large variety of real-world cases (many being hybrid-solutions of others) that render difficult to arrange an all-embracing definition. Regardless the case, a variety of concepts and definitions co-exist nowadays. The most common terms to refer to a transport solution involving two or more modes of transport are *multimodal transport, combined transport, intermodal transport* and *co-modality*. Now, the question that naturally arises is whether these concepts refer to equal or similar transport solutions or *de facto* they refer to different ones.

Looking firstly to the definitions proposed by the international organisations, one of the first attempts was conducted by the United Nations in 1980 with a definition on multi-modal transport (United Nations, 1980, pp 5):

> *"international multi-modal is the carriage of goods by at least two different modes of transport on the basis of a multimodal transport contract from a place in one country at which the goods are taken in charge by the multimodal transport operator to a designated place for delivery in a different country"*

This definition recognises the existence of both, a multimodal operator that is the legally responsible for providing services for international freight transport; and a multimodal transport contract amongst the companies involved on the transport service. However, it only considers international carriage.

Some years later, in 1997, the European Commission proposed a definition for intermodal transport (European Commission, 1997a):

> *"intermodality is a characteristic of a transport system that allows at least two different modes to be used in an integrated manner in a door-to-door transport chain. In addition, intermodal transportation is a quality factor of the level of integration between different transport modes. In that respect more intermodality means more integration and complementarity between modes, which provides scope for a more efficient use of the transport system"*

This definition considers that the simple association of various modes of transport, without any integration level, is not intermodal transport. This definition introduces a new dimension by considering intermodality as a quality variable of the integration level between modes of transport; and establishing a direct link between intermodality and performance of the transport service.

In 2001, three bodies: European Conference of Transport Ministers[60], United Nations Economic Commission for Europe and the European Commission, agreed on the definition of three terms: multimodal, intermodal and combined transport (European Conference of Ministers of Transport , 2005, United Nations, 2001). The definitions being:

> Multimodal Transport is the "*carriage of goods by two or more modes of transport*" (United Nations, 2001, pp 16);

> Intermodal Transport is the "*movement of goods in one and the same loading unit or road vehicle, which uses successively two or more modes of transport without handling the goods themselves in changing modes*" (United Nations, 2001, pp 17);

[60] Meanwhile renamed to International Transport Forum.

> Combined Transport is the "*intermodal transport where the major part of the European journey is by rail, inland waterways or sea and any initial and/or final legs carried out by road are as short as possible*" (United Nations, 2001, pp 18).

A brief comment on each of these definitions. The updated definition on multimodal transport enlarges the scope of the initial one to embrace any transport service that makes usage of different modes of transport (regardless of origin and destination or terms of contract).

The definition herein proposed on intermodal transport assumes that it involves at least two modes of transport and, for the first time, refers to how goods should be handled throughout the transport service. Goods are not to be directly handled during the journey but instead loaded within (or onto) unit loads - intermodal transport unit - which are the objects handled throughout the journey (European Commission, 2004, Janic and Reggiani, 2001, pp 471). However, this definition does not go into detail as to consider intermodality as an indicator of quality of transport (like the one early proposed by the European Commission).

Finally, the definition on combined transport reflects the beginning of the political concern on the protection of the environment. Some comments may be drawn. First, it carries a significant political commitment on the promotion of sustainable development. As a result, the definition has some bias towards some modes of transport and ignores other ones (e.g. air transport is not considered). Second, it is oriented to the externalities produced by the transport service and not to the transport service itself. Third, it also embraces the concept of intermodal transport unit (for example, container, swap body, semi-trailers, etc.) as a key enabler for the development of this kind of transport.

Recently the European Commission in the mid-term review of the European Commission's 2001 Transport White Paper (European Commission, 2001b, 2006) has proposed a the term of co-modality as being the *"efficient use of different modes on their own and in combination"* (European Commission, 2006, pp. 4).

This new term presents two important features. Firstly, it places the emphasis on efficiency. The explicit rationale is that the optimisation of the mode or modes of transport and the optimisation of the organisation of the chain "will result in an optimal and sustainable utilisation of resources" (European Commission, 2006, pp. 4). Secondly, it also embraces single-modal transport services[61], which is new in relation to the previous definitions. This term includes transport services that make use of the same mode of transport more than one (like for example: road-road transport services).

In the body of literature, the emphasis has been placed on the concept of intermodality (Lowe, 2005, Bontekoning et al, 2004, Zografos and Regan, 2004, Panayides, 2002, Janic and Reggiani, 2001, Slack, 2001, OECD, 2001, OECD, 2002a), although definitions for the other terms do exist (e.g. De Witt, 1995, pp 2, Lowe, 2005, pp 7 for multimodal transport, or Lowe, 2005, pp 7 for combined transport). The following table (Table 2.1) presents some of those proposed definitions found by Bontekoning and her colleagues (Bontekoning et al, 2004) on their literature review concerning transport chains involving road and rail transport.

From the analysis of the table, we may conclude on the significant variety of definitions, although most of them move around the early defined concepts of intermodal, combined and multimodal transport. The only common accepted characteristic is: intermodal transport involves more than one mode of transport.

Based on the definitions presented so far by both the governmental bodies and the researchers, the author elaborated the Figure 2.2. The figure sketchs the scope of each one and their overlaps. Although prone to discussion due to the diversity of definitions, the author believes that it provides an interesting perspective over the current body of literature.

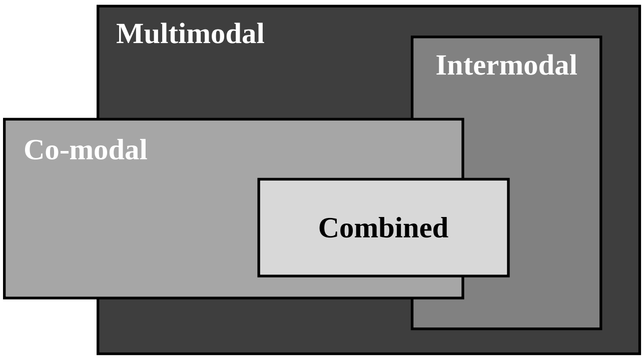
In our understanding, co-modality is the broadest term of the four since it embraces both single- and multi-modal transport services; whereas the others solely cover the latter transport services. This is the reason for the concept of co-modality to have an isolated portion in Figure 2.2. Follows the term of multimodality, since it encompasses all kind of transport chains services. The only requirement for a transport chain to be considered multimodal transport is the presence of at least two different modes of transport. The other three definitions are more restricted in the sense that they require some sort of organisation or coordination - integration - amongst modes of transport.

[61] These are transport services that make us of one mode of transport.

Table 2.1 – Intermodal Transport definitions

Author (date)	**Proposed definition**
Jones et al (2000)	The shipment of cargo and the movement of people involving more than one mode of transport during a single, seamless journey;
Southworth and Peterson (2000)	Movement in which two or more different transport modes are linked end-to-end in order to move freight and/or people from point to origin to point of destination;
Min (1991)	The movement of products from origin to destination using a mixture of various transport modes such as air, ocean lines, barge, rail, and truck
Van Schijndel and Dinwoodie (2000)	The movement of cargo from shipper to consignee using two or more different modes under a single rate, with through billing and through liability (Hayuth, 1987);
D'Este (1995)	A technical, legal, commercial, and management framework for moving goods door-to-door using more than one mode of transport;
TRB (1998)	Transport of goods in containers that can be moved on land by rail or truck and on water by ship or barge. In addition, intermodal freight usually is understood to include bulk commodity shipments that involve transfer and air freight (truck–air);
Ludvigsen (1999)	The movement of goods in the same load-carrying unit, which successively use several transport modes without handling of goods under transit
Tsamboulas and Kapros (2000)	The movement of goods in one and the same loading unit or vehicle, which uses successively several modes of transport without handling the goods themselves in changing modes (European Commission, 1997a)
Van Duin and Van Ham (1998)	The movement of goods in one and the same loading unit or vehicle, which uses successively several modes of transport without handling the goods themselves in changing modes (European Conference of Ministers of Transport, 1993)
Murphy and Daley (1998)	A container or other device which can be transferred from one vehicle or mode to another without the contents of said device being reloaded or disturbed (Jennings and Holcomb, 1996)
Newman and Yano (2000a,b)	The combination of modes, usually ship, truck or rail to transport freight
Taylor and Jackson (2000)	The co-ordinated transport of goods in containers or trailers by a combination of truck and rail, with or without an ocean-going link (Muller, 1995)
Slack (1996)	Unitised loads (containers, trailers) that are transferred from one mode to another
Spasovic and Morlok (1993)	The movement of highway trailers or containers by rail in line-haul between rail terminals and by tractor-trailers from the terminal to receivers (termed consignees) and from shippers to the terminal in the service area
Niérat (1997)	A service in which rail and truck services are combined to complete a door-to-door movement
Harper and Evers (1993)	One or more motor carriers provide the short-haul pick up and delivery service (drayage) segment of the trip and one or more railroads provide the long-haul or line haul segment
Evers (1994)	The movement of truck trailers/containers by both railroads and motor carriers during a single shipment
Nozick and Morlok (1997)	The movement of trucks and containers on railcars between terminals, with transport by truck at each end

Source: Bontekoning et al (2004)



Source: author

Figure 2.2 – Overlapping between concepts

The difference between intermodal transport and the other two lies on the perspective upon which the transport service is seen. The former places the emphasis on the level of integration. As a matter of fact, intermodal transport is the concept where the need of existence of integration is the most pronounced. For a transport service to be called intermodal it is required to have a high level of integration. Integration is so relevant that may be used to measure that level of quality of the transport service.

A transport service to be called as co-modal or combined transport has to follow a different perspective. The emphasis is on sustainability and on the optimisation of the consumption of natural resources. Thus, in these transport services integration is a requirement (but not the only one) to achieve the ultimate goal of reducing the environmental damage. Yet, combined transport definition puts higher emphasis on sustainability than co-modal concept. A combined transport should make extensive use of the so-called sustainable modes of transport (rail, sea or inland transport), while reducing at maximum the others (road and air transport). Co-modal concept, although placing emphasis in the achievement of sustainable transport solution, refers that modes of transport should be used at maximum efficiency, which opens the door for the utilisation of not so sustainable configurations (as long as they are the most efficient ones).

A particular aspect of the transport chains solutions concerns the way goods are handled between modes of transport. In both multimodal and co-modal transport definition there is no reference about this issue, but in the other definitions, they tend to agree on the need of utilisation of loading devices (containers or others). So, what is effectively handled are the loading devices and not the goods themselves.

The success and validity of a research process depends at large extent on the use of clear and precise definitions and concepts. A precise definition allows for the identification of what lies within and outside the concept's boundaries. On the other hand, dubious or not so clear definitions are prone to double meaning or misinterpretations, which may raise difficulties of interpretation of what is the object of analysis or what is being analysed.

The current dispersion around the concepts and definition of intermodality (and the other transport concepts) consubstantiate such non-acceptable situation. The author was thus compelled to choose a definition to be used on the current research work. So, for the terms of this research work intermodal freight transport should be understood as a concept of freight transport, ruled by a transport contract where at least two different modes of transport participate in an integrated manner.

This definition is made of three key conditions: *first*, the existence of transport contract (or contracts) ruling the entire transport service; *second*, the presence of at least two different modes of transport; and *third*, the need of some sort of integration amongst the agents participant in the transport service.

The first condition is only referred on the definition of multimodal transport proposed by the United Nations. An intermodal freight transport service should also act as a single entity in case of legal responsibility situations. Yet, an intermodal freight transport service can be compound by a set of independent companies (for example: each one participating with a single mode of transport). In these situations, the necessary legal cohesion is only granted through the existence of a contract (or contracts), that bounds all agents to the same terms and conditions, making them to behave as a single entity. Naturally, in those cases where one agent owns the various modes of transport, this situation does not exist, simply because the single entity is granted due to common ownership (like what happens in the Integrators, like DHL or TNT).

The second condition is in line with the definitions presented above. An intermodal transport is a transport service where at least two modes of transport should participate. The connexion between two consecutive modes of transport is assured through a transhipment terminal where the goods are handled and shifted between vehicles; they can also be stored or undergo any other activity allowed under the terms of the transport contract.

The third condition is the most important one for distinguishing an intermodal transport from any other type. Integration can be understood as the existence of coordination or alignment amongst modes of transport, and can be felt at different levels, like for example: technological (when agents decide to more towards higher level of interoperability), procedural (when agents decide to align and uniform the processes along the transport chain), or legal (when agents decide on simple and fair mechanisms to compensate shippers for eventual losses). Integration is of paramount importance because it generates synergies amongst modes of transport allowing them to achieve higher levels of performance and it reduces waste and inefficiencies.

Integration does not emerge spontaneously along a transport chain, conversely, it is the result of an active role performed by a specialised agent that actively seeks and promotes that integration. The missions of this agent are, firstly, arranging and assembling the transport chain that potentially better fits into the shipper’s demands and, secondly, managing that transport chain so that it actually delivers the expected performance. This role is commonly called as freight forwarding and can be assumed by either, one the participating agents in the transport service (and, in this situation, this agent plays a double role: transport provider and freight forwarder), or a specialised third party: the freight forwarder.

2.2 Conceptual Representation of Intermodal Freight Transport

2.2.1 A review to the conceptual representations of intermodal freight transport services

Intermodal freight transport has received a growing interest over the past few decades. Such growth is evidenced in the increasing number of specialised publications

(Bontekoning et al, 2004, pp 6). Also recently, Bontekoning and her colleagues claimed that an independent domain of research on intermodal transport was emerging, and that time it was still in what they designated as a "pre-paradigmatic phase" characterised by (Bontekoning et al, 2004, pp 2):

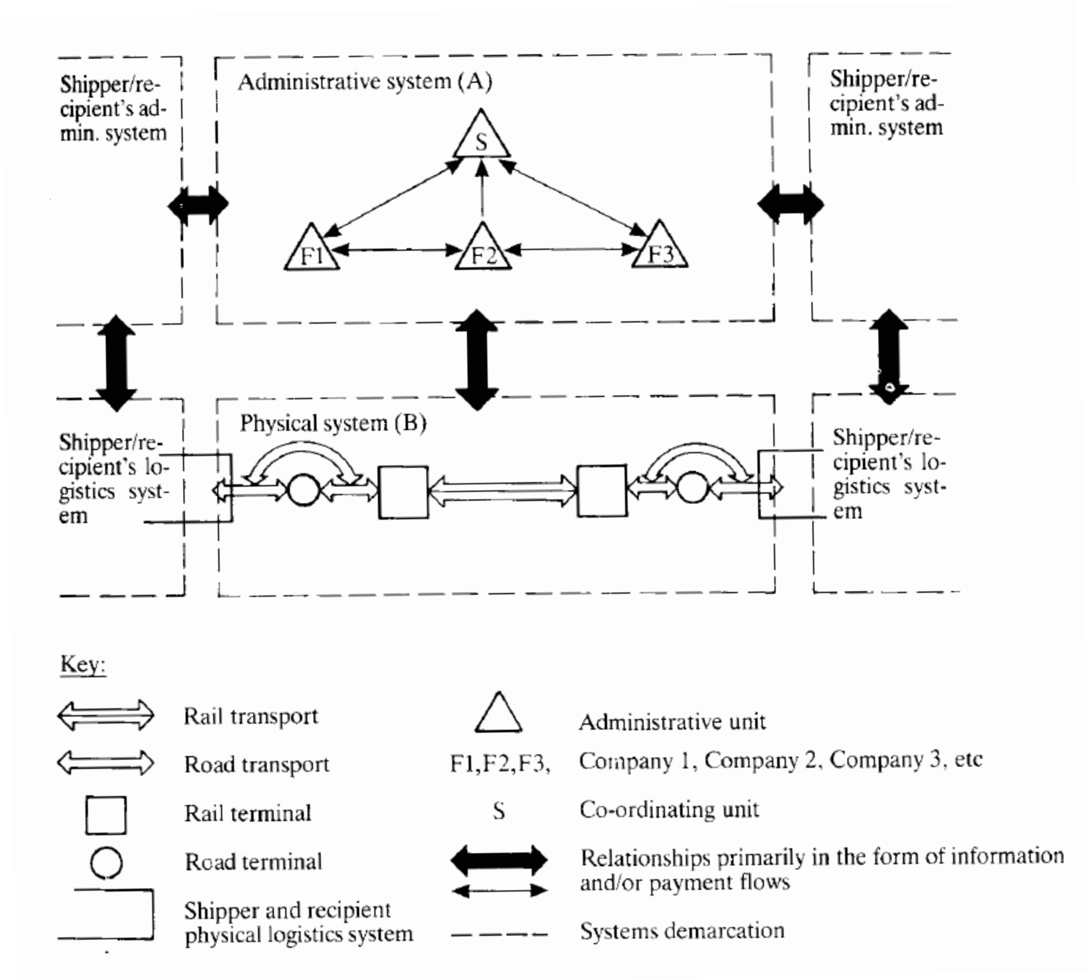
- the existence of several small research communities working on their own problems;
- few cross-references amongst researchers located in different research groups;
- a lack of common problem definitions, hypothesis, definitions or concepts.

Despite the early stage of development, over the years, several conceptual representations (or frameworks) of intermodal freight transport services have been put forth. They are herein briefly reviewed.

In 1990, Jensen proposed a conceptual framework for describing intermodal freight transport services (Woxenius, 1998, pp 79). Jensen's representation of the intermodal transport (Figure 2.3) is based on a division between a physical and an administrative sub-system.

The physical sub-system comprehends all the activities and resources (technology and people) required to transport the goods from the origin to the destination. Two types of activities are considered: transport (provided by a transport agent) and transhipment (conducted at the terminals). The administrative sub-system comprehends all the administrative and management activities taken in the production of the intermodal transport system.

Additionally, this framework represents an intermodal freight transport service through a set of three types of flows: goods, information and money. The goods are exchanged within the physical sub-system and they flow from origin towards destination. The money is exchanged within the administrative sub-system. Finally, the information is exchanged both within the administrative sub-system and between the two sub-systems. The information flow provides and establishes the cohesion between the two sub-systems.



Source: Woxenius (1998, pp 81)

Figure 2.3 - Jensen's conceptual framework

A final consideration about this framework is that it considers that the intermodal freight transport service is a subset of a larger system: the logistic system.

In the following year, the association Lloyds of London proposed another conceptual framework (D'Este, 1996, pp 4), which is a development of Jensen's proposal. The framework is depicted in Figure 2.4. The intermodal freight transport service is described in terms of layers and components. There is a total of five layers[62], each one representing an essential function of the service; and a total of thirty three components, distributed along these five layers. Moreover, the relative width of each components (in each layers) reflects its influence in the performance of the service (D'Este, 1996, pp 4).

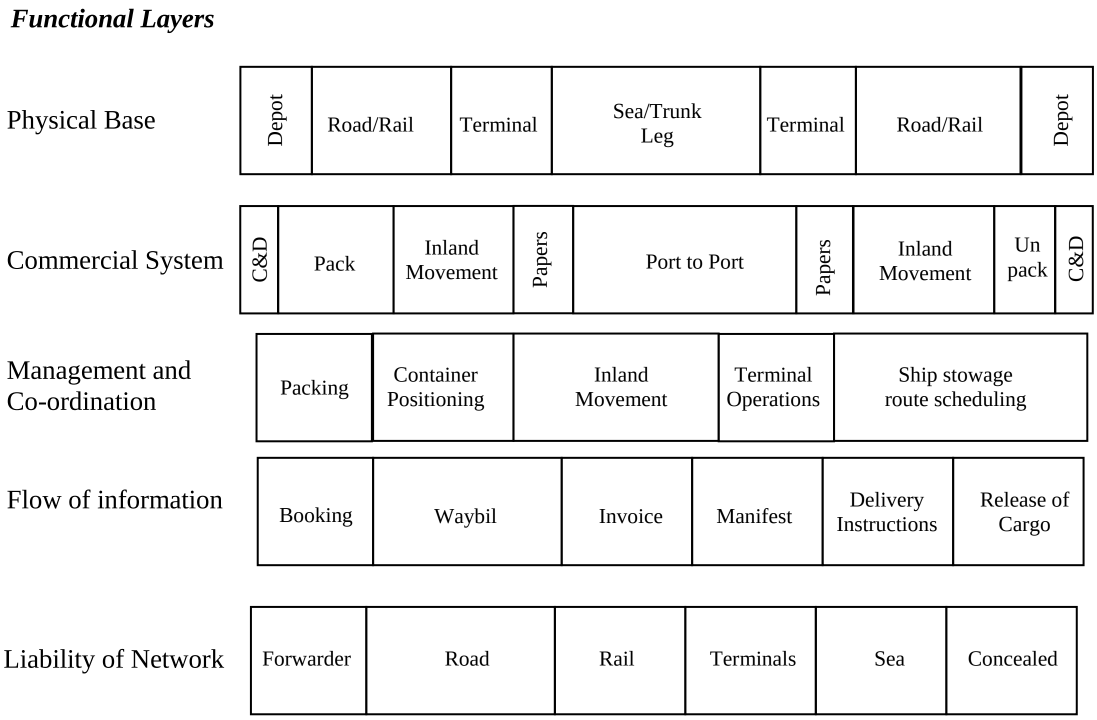
[62] Accordingly with the source, the association Lloyds of London's model had a sixth layer corresponding to the positioning of the intermodal freight transport service in the logistical chain (D'Este, 1996, pp 5).

The first two layers, physical base and commercial system, correspond to the physical transport of the goods and to the costs of each business function, respectively. The remaining three layers (management and co-ordination, flow of information and liability of network) "comprise the 'hidden' and intangible aspects of the business of intermodalism" (D'Este, 1996, pp 5). The management and co-ordination layer corresponds to the management of the system. The flow of information layer corresponds to the exchange of information between the transport agents. And the liability network corresponds to the liability of each transport agents for damage and delay (D'Este, 1996, pp 4-5). Finally, a measure is proposed for each layer, being (D'Este, 1996, pp 4-5):

- Physical base: measured in terms of transit time;
- Commercial System: measured in terms of price charged;
- Management and Co-ordination: measured in terms of management time and effort;
- Flow of information: measured in terms of time and cost associated with information processing;
- Liability network: measured in terms of relative risk.

Some years later, D'Este (1996) used an event-based approach to propose a conceptual framework of intermodal freight systems (D'Este, 1996, pp 8). The author considered that "at its most basic level, the passage of the consignment through an intermodal freight system is equivalent to a sequence of logistic events. Each event takes the goods from one logistic state to another by performing a logistical activity" (D'Este, 1996, pp 8).

The characterisation of an intermodal freight transport service is based on four concepts: *state*, *activity*, *event* and *conformability*. A *state* is "the minimal set of key characteristics that identify the condition of a freight consignment", whereas an *activity* is defined as "anything that takes time or costs money". An *event* occurs when there is a change in the state of the transport service. Events that are compatible are defined as being *conformable* (D'Este, 1996, pp 9), that is, the output of one state must be identical to the input of the following one.



Source: D'Este (1996, pp 4)

Figure 2.4 - Lloyds of London's conceptual framework

The conceptual representation of the intermodal freight transport service is done through a sequence of conformable events that transform the initial of the service into its final state. The performance of the intermodal freight transport service is assessed through the measurement of the activities. The measures can be either deterministic or stochastic and it may involve diverse dimensions, such as: costs, delays, availability, or qualitative service factors (D'Este, 1996, pp 8). A relevant feature of this conceptual representation is that all four concepts can be quantified. As such, the conceptual framework is prone to mathematical translation and formulation and, thus, it can be incorporated in any modelling or other analytical exercise.

This author then presented an example where he put forth a tentative list of state variables and events. The state variables were: product (that refers to the properties of the goods), location (that refers to the current location of the goods in the transport chain), unit (that refers to how the goods are being shipped, namely: bulk, pallet, etc), mode (that refers to which mode of transport is conveying the goods) and status (that refers to the type of contract and other commercial arrangements) (D'Este, 1996, pp 8).

In what concerns the events, this author identified the following ones: warehousing, processing, linehaul, parking, intermodal transfer and document transfer. The state variables and the events should be chosen so that in each event only one state variable is affected. Such property would allow, accordingly to this author, for a simple but effective representation of the intermodal freight transport service (D'Este, 1996, pp 9).

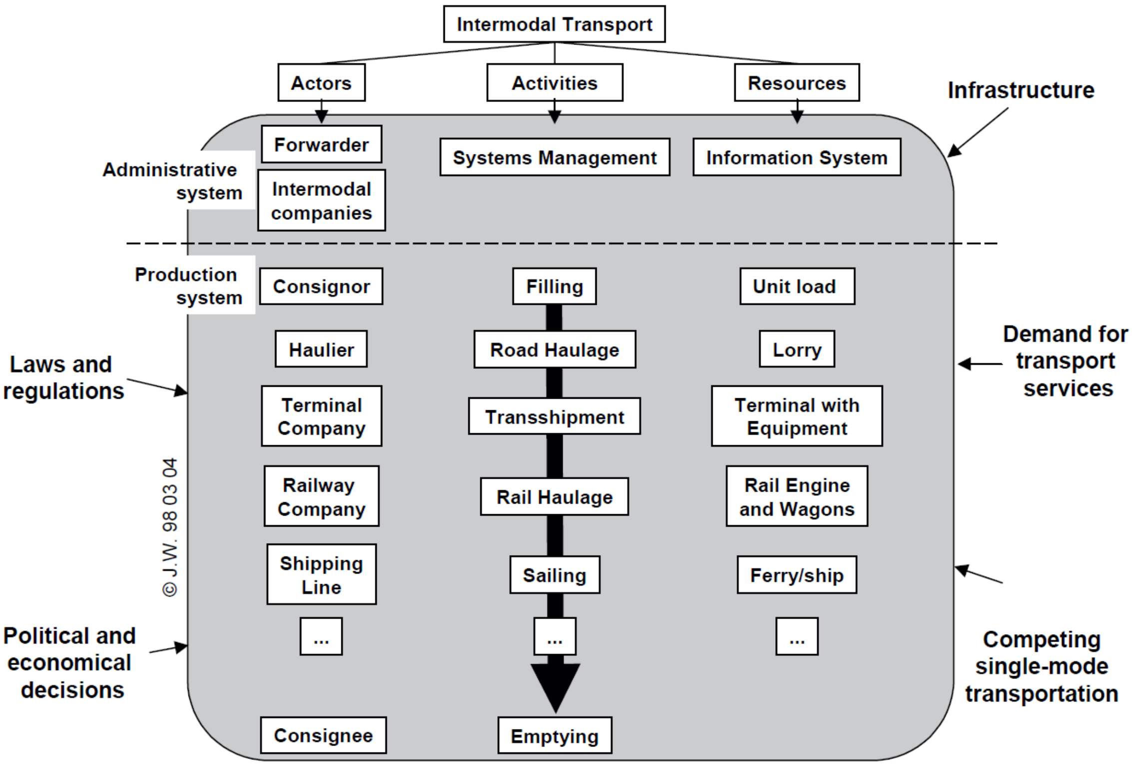
As final note, we may write that this conceptual framework is focussed on the production (that is, overall behaviour) of the intermodal transport operations and it does not explore the inner relations, in particular, between transport agents and modes.

A final conceptual framework was proposed by Woxenius (1998, pp 95-96). The model is depicted in Figure 2.5. Woxenius develops an hybrid conceptual framework of intermodal freight transport services based on four perspectives:

1. Division between administrative and physical subsystems (Jensen's perspective);
2. System perspective;
3. Network perspective;
4. Chain perspective.

The first perspective is based on Jensen's conceptual framework and the division of the intermodal freight transport service into two layers: physical - production system - and administrative - administrative system. The second perspective adopts a systems approach to the intermodal freight transport service. Accordingly with this perspective an intermodal freight transport service may be characterised through six interrelated variables, being: objective (e.g.: how to transport the goods), environment (e.g.: external forces constraining intermodal operations), resources (e.g.: equipment and people), transport agents (e.g.: road carriers, terminal operators, etc.), management (e.g.: freight forwarder), shippers, decision-makers (e.g.: freight forwarders) and planners (e.g.: freight forwarders) (Woxenius, 1998, pp 84).

The third perspective considers that an intermodal freight transport service is a set of links and nodes. In this perspective, the nodes are the transport agents and the links are the business relations amongst them. So, the network perspective is essentially concerned with the administrative dimension of the intermodal freight transport service (and not with the physical transport of the goods). It assumes that, firstly, the relations between transport agents are dynamic (that is, they change over time) and interdependent (that is, the change in one is likely to affect the others); secondly, a transport agent's behaviour is to a large extent the response to the others' behaviour; and thirdly, the relation can be of either competition or cooperation (Woxenius, 1998, pp 54). The fourth and final perspective is also designated as pipeline perspective (Woxenius, 1998, pp 74). In this perspective the intermodal freight transport service is seen as a pipeline, but instead of liquids we have goods flowing. The flow is materialised through the accomplishment of a sequence of activities, namely: transport, unloading, storage and loading.



Source: Woxenius (1998, pp 96)

Figure 2.5 - Woxenius's conceptual framework

This model provides a complete explanatory framework of the (internal and external) structure of the intermodal freight transport service, as well as, the structure of the relation between the components (actors, activities and resources). It is not however meant to be used in "deterministic studies" (Woxenius, 1998, pp 96), but instead to provide a conceptual description.

In summary, Jensen's framework identified the multidimensional nature of the intermodal freight transport, by establishing a division between the physical and the non-physical transport functions. This division is based on the assumption that an intermodal transport entails more than the physical transport of goods. Moreover, this framework defines that the performance of an intermodal freight transport service is function of both dimensions (and not only of the physical transport of goods). The Lloyds of London's porposal introduced some important developments: firstly, by making a detailed identification and characterisation of the dimensions (five in total); and, secondly, by proposing a first assessment of the relevance of each component in the service's performance. D'Este brought further advancements by proposing an analytical framework that could be formulated in mathematical terms. Finally, Woxenius presented a rather complete systematisation of most features and properties of an intermodal freight transport service.

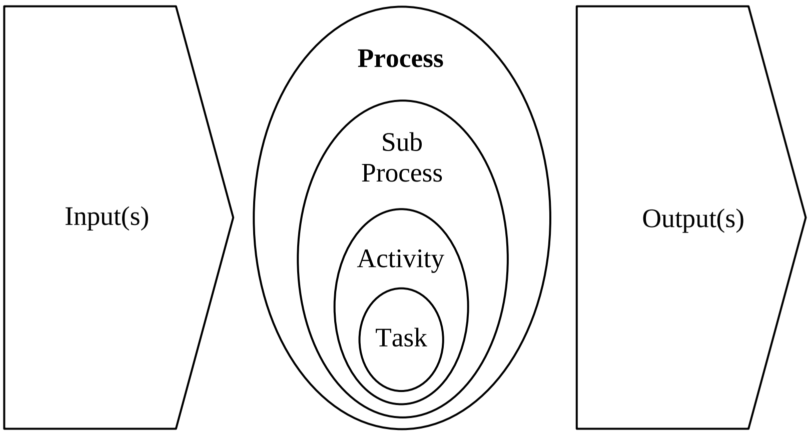
These conceptual frameworks, albeit grounded on different perspectives and developed with different purposes, exhibit some common properties, which allows us to evidence some of the specificities of the intermodal freight transport services. Firstly, the production of such service entails much more than the conveyance of the goods from origin to destination. Other dimensions (such as: administrative and managerial, or liability) have to be taken into consideration. Yet, the exact number and nature vary between perspectives. Such multidimensional nature renders that the production of an intermodal freight transport service is inherently more complex than the production of a single-modal transport service. Secondly, with the exception of the Lloyds of London's proposal, an intermodal freight transport service can be fairly represented through a set of flows (along the various dimensions). The flows add a dynamic nature to the production of this transport services. Thirdly, in the production of an intermodal freight transport service there is a web of interactions between transport agents. Such interactions can be either between transport agents and freight forwarder or between transport agents. This property is more visible in Jensen and Woxenius' representations.

2.2.2 Intermodal freight transport as a process

2.2.2.1 Definition of Process

Sharp and McDermott (quoted in Portougal and Sundaram, 2006, p. 2) defined process as “a collection of interrelated works tasks, initiated in response to an event that achieves a specific result for the customer of the process”; while Davenport, T. H. (1992, p. 5) considered process as “a structured, measured set of activities designed to produce a specific output for a particular customer or market” and as “a specific order of work activities across time and place, with a beginning, an end, and clearly identified business and outputs: a structure for action”; and Pall (quoted in Riley, 1999, pp 6.1) referred to a process as being “the logical organization of people, materials, energy, equipment and information into work activities designed to produce a required end result (product or service)”. Recently, the ISO 9001:2008 (International Standard Organisation, 2008) standard defined process as a set of interrelated activities that transform inputs into outputs.

Process can thus be understood as a set of interrelated, coordinated and sequential tasks whose purpose is to produce a determined *output* or o*utputs* from a given *input* or *inputs*. Such act of transformation consumes a certain amount of resources: labour, equipment or materials. It requires the exchange of information and it is done based on a set of rules (Figure 2.6).



Source: author

Figure 2.6 – Scheme and hierarchical organisation of a process

The basic unit of a process is the *task*. A task represents an individual and well-defined work conducted by a person, equipment or set person-equipment, through which a set of inputs are converted in outputs. Thus, tasks consume time and resources. The inputs and outputs can be of any kind and nature (tangible or intangible), like for example: technology, equipment, information, financial resources, etc.

In order to reduce the complexity inherent in managing or coordinating a high number of isolated tasks, these may be hierarchically organised in several echelons (Figure 2.6). In this way, a set of interrelated tasks form an *activity*; while a set of activities form a *sub process*. The set of sub processes form the *process*.

Both the number of units within each level as well as the number of levels itself - process designing - depends upon each specific case. Process designing is a process by itself whose purpose is to reach a balance between higher detailing (by increasing the number of sub-process) and manageability (by clustering tasks into fewer sub-processes)[63].

The successive passage of output(s) of preceding tasks to input(s) in subsequent ones generates flows. These flows cross the entire process and represent all kind of movements, such as: products, information, capital, etc.

Tasks' positioning within a process is not random, instead they follow a certain sequence, often there are time windows for their beginning (and ending). Furthermore, certain tasks may be ran in parallel. Therefore, the same process may be designed in multiple configurations. Bearing in mind that a task consumes time and resources, different arrangements of tasks, although yielding identical effectiveness[64], may lead to different efficiency levels[65].

A process is thus the schematic representation of how a company's product or service is actually produced. It draws all parties involved, the relationships amongst them, the resources consumed by each one and the tasks allocated to each one. Therefore, the

[63] There are various techniques for the identification and classification of processes see for example: Portougal and Sundaram (2006, p. 6-19), Azevedo and Alves (2002, p. 24-26) or Davenport (1993, p. 27-33)

[64] A process is effective when its outputs meet perfectly the customer's needs.

[65] A process is efficient when it is effective at the lower possible cost.

behaviour and evolution of an organisation can be accessed through the monitoring and evaluating of her processes.

2.2.2.2 Process of intermodal freight transport

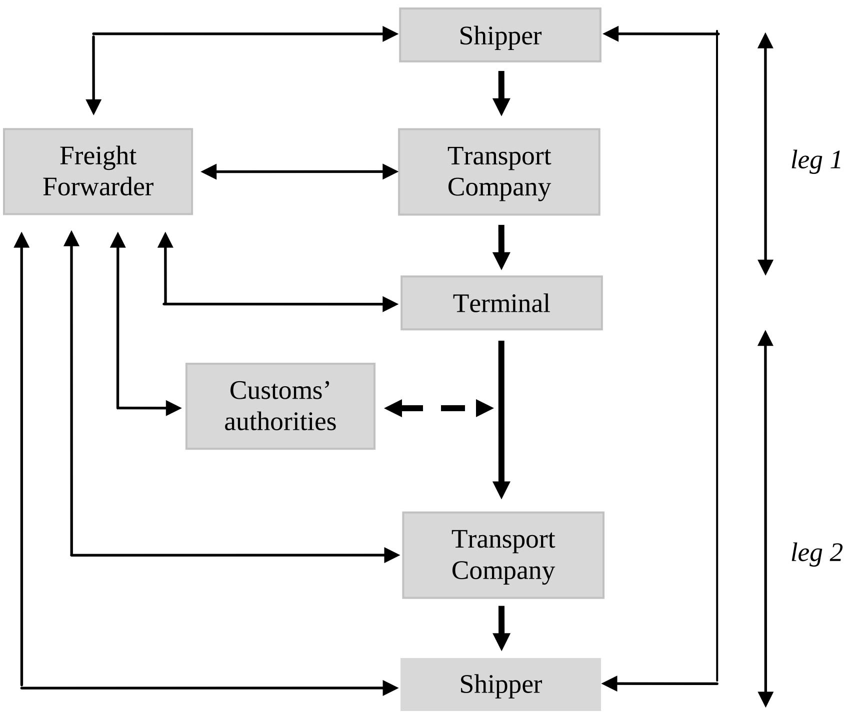
The mechanisms underlying the production of an intermodal freight transport service have every ingredient to be studied on the grounds of the theoretical concepts of processes: firstly, there is a sequence of individual and identifiable tasks and activities; secondly, every task is quantifiable in terms of resources and time consumed; and thirdly, there are inputs (demands and goods), outputs (physical transport of goods) and resources (transport agents).

The utilisation of the concept of process to analyse the intermodal transport allows, on the one hand, to shed some light over the web of relationships within an intermodal freight transport service helping on the clarification of the position and role of each agent; while on the other hand, to depict the mechanisms and relationships involved in this kind of transport solution, promoting the identification of the various tasks, activities and sub processes.

Indeed, the abovementioned conceptual frameworks (Chapter 2.2.1) already make use of the concepts of process and flow. For example, both Jensen (1990) and Woxenius (1998) decoupled the intermodal freight transport service in two major sub-processes: physical and administrative; while, D'Este characterised the intermodal transport in a set of conformable events, or in other words, in a set of flows (D'Este, 1996, pp 8).

The intermodal transport is, as defined in Chapter 2.1, a concept of transport in which multiple modes of transport are brought (temporarily) together to deliver a tailored transport solution. The final configuration of an intermodal freight transport service is function of both shipper’s demands (which is the very reason for the existence of the transport service) and the freight forwarder’s own assets, know-how and positioning within the market. Consequently, different forwarders may deploy different transport processes to fulfil a same transport service. This does not mean that the intermodal freight transport processes entirely differ amongst each others; by the contrary, the bulk of the tasks are similar, only differing a few of them (likely designed to fulfil specific demands).

In this chapter, a general intermodal transport solution is presented along with the common tasks, activities and sub processes. The archetype of an intermodal freight transport service is depicted in the following scheme (Figure 2.7).

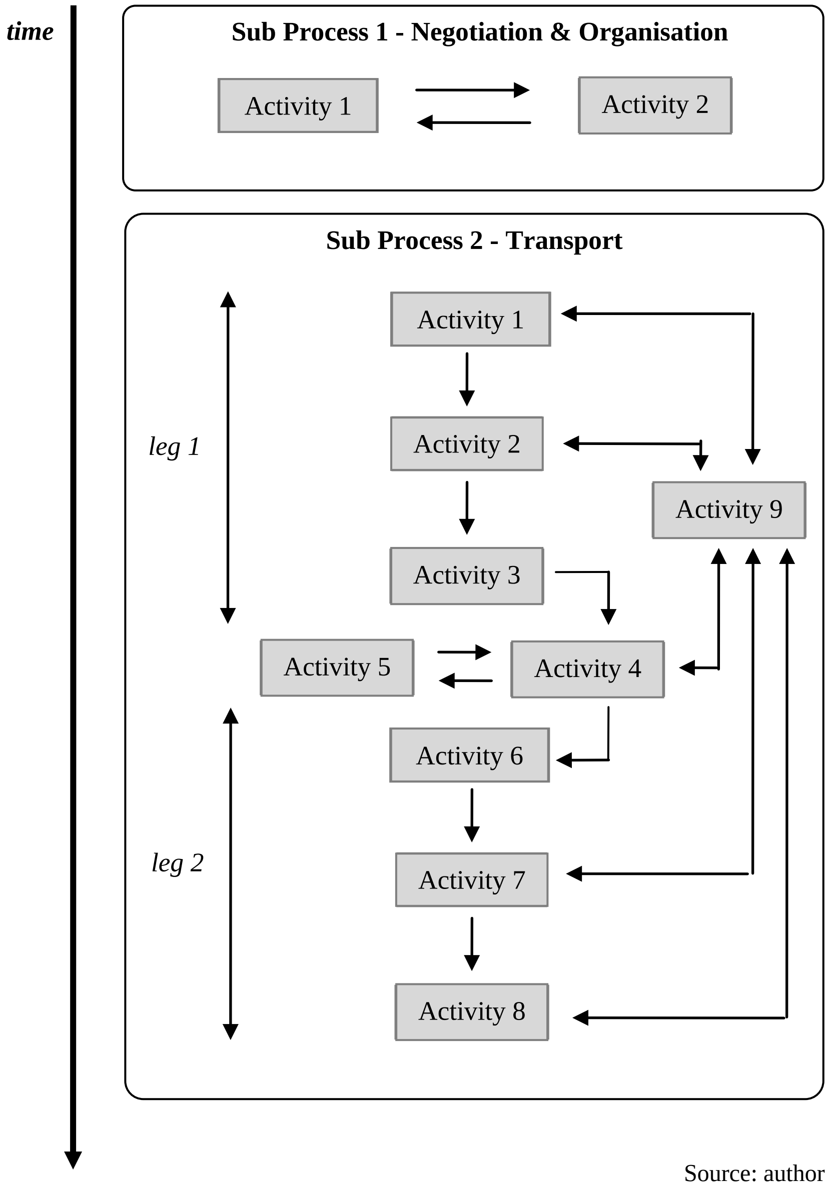


Source: author

Figure 2.7 – Intermodal Transport Service

Owing to space restrictions, the service is represented with two legs. No rigor is nonetheless lost because the activities involved in an intermodal freight transport service with two legs repeat themselves in every extra leg. The client of this chain is a shipper that intends to transport some goods between two locations. To accomplish this, a freight forwarder is hired, which in turn hires transport company agents for supplying those services for which she does not own resources. If the freight forwarder owns no assets, then she has to hire all services to other agents; by the contrary, if she owns all assets, then no agents are needed to be hired. For the sake of clarity, the services are considered always to be conducted by independent parties. By keeping all parties separated, the flows are better presented and described.

Figure 2.8 depicts the usual *sub-processes* and *activities* identifiable along an intermodal transport chain. It should be noted that the length of activities do not represent execution time. The actual duration of each one depends upon each real case situation.



Source: author

Figure 2.8 - General sub processes and Activities of an Intermodal Transport Process

In a typical intermodal transport chain like the one presented in Figure 2.7, it is possible to identify two main sub-processes (also identified by Jensen, 1990, Woxenius, 1998, pp 81, 96), each one compound of several activities:

- Sub process 1: Negotiation and Organisation;
- Sub process 2: Transport.

Sub process 1: Negotiation & Configuration

This sub process embraces the administrative procedures conducive to the assemblage of the transport chain and the establishment of a contract of transport between the shipper and the freight forwarder. This sub-process consists in negotiations amongst the various transport agents. It occurs before any physical transport activity to take place.

Sub process 1 is compounded by two main Activities:

- Activity 1: Freight Forwarder and Transport Agents negotiation;
- Activity 2: Freight Forwarder and Shipper negotiation.

The commencement of a transport service occurs in the moment that the shipper contacts one or more freight forwarders requesting for bids. All the necessary information to assemble the transport service is conveyed at this moment, namely: origin and destination locations, time windows for the pickup and the delivery, amount (volume and weight), nature of cargo or any other condition. If more than on service is required, the shipper also details the schedules of transport.

Based on this information and upon her knowledge on both the operational and technological properties of each mode of transport, and the portfolio of services, performance and quality (namely: reliability, trustiness and safety standards) of the transport agents, each freight forwarder draws a few viable architectures for the transport service (each one having either a different combination of modes of transport, or the same combination but used at different extents) (Activity 1). At last, she chooses one (or more) solutions that best fits into shipper’s demands. The decision process tends to be a semi-conscious process based on both rational and non-rational factors[66]. Activity 1 involves significant negotiation between the freight forwarder and every transport agent of the transport services’ conditions (e.g.: pricing, timing, etc.).

In those cases, where the freight forwarder owns some or all assets (vehicles, warehouses, etc.), Activity 1 is consequently reduced. This situation is likely to happen when the freight forwarder is a so-called freight integrator (like the FEDEX, DHL or UPS), because they own (or control) the entire transport chain.

[66] Modal choice process will be discussed in Chapter 2.4.

Afterwards, in Activity 2, the freight forwards conveys one solution[67] or more solutions[68] to the shipper. In the latter case, the freight forwarder may have to renegotiate conditions with transport agents. This is the reason for interaction (arrows on both ways) between Activities 1 and 2 in Figure 2.8. After the transport solution being chosen and all intervening agents are contacted and the transport chain is put into motion.

Sub process 2: Transport

This sub process corresponds to the effective transport of goods, embracing all the necessary administrative and operational procedures to move the goods between the origin and the destination. The agents engaged in the transport operations are managed and coordinated by the freight integrator, which stands above the transport chain.

Sub process 2 entails the following Activities:

- Activity 1 and 6: Loading;
- Activity 2 and 7: Transport;
- Activity 3 and 8: Unloading;
- Activity 4: Storage;
- Activity 5: Customs' Clearance;
- Activity 9: Management;

If the chain had more legs, there would a repetition of the activities mentioned above. Each extra leg would entail four new activities corresponding to Activities 1, 2, 3 and 4. For each time goods had to be cleared, one Activity 5 should be added. Therefore, any intermodal transport chains with three or more legs is a simple extension of a chain with two legs.

The transport service (Activity 1) starts with the loading of the vehicle, at the origin location. The specificities (techniques and duration) of the loading process depend of several factors, like for example: type of vehicle, type of containerisation (container, trailer, cistern, wagon), or nature of the goods (bulk, pallets, liquids, fragile, etc.). With

[67] When the customer has no intervention on the definition of the transport solution.
[68] When the final decision is jointly taken by the shipper and the freight forwarder.

the goods totally loaded into (or onto) the vehicle, the transport company may notify the freight integration.

Activity 2 corresponds to the actual displacement of the goods in-between locations (in this case, in-between the origin location and terminal). At the moments of starting, ending and in intermediary points, transport agents may notify freight forwarder on the status of the transport. At terminal, goods are unloaded from within (or onto) the vehicle (Activity 3). Once again, the precise procedures deployed depend on the type of goods and vehicle involved. At the end of this activity, either the transport company or the terminal agent may notify the freight integrator. The unloaded cargo can then be either, immediately moved to the next mode of transport - cross docking operations[69], or stored - Activity 4.

Cargo meant for (or proceeding from) international destination may require customs' clearance - Activity 5. In these situations, cargo is retained (stored) until the duly authorisation to be obtained. Freight forwarder is also responsible for the customs clearance of the goods (although she naturally may hire out this service). During this activity customs authorities may require a physical verification of the goods to certify that the declarations presented match with what is actually being transported. In this way, during this activity goods remain within the terminal, which is the reason for presenting Activity 5 directly linked with Activity 4 (Figure 2.8).

After the customs clearance the goods may move forward. From this moment onwards, the activities involved in the transport service start repeating themselves. Goods are firstly loaded into (or onto) a vehicle (Activity 6). This activity may end with the notification of freight forwarder. Afterwards, goods are transported to the final destination (Activity 7). Once again, messages may be sent to the freight forwarder, for updating the progression of the transport service. Finally, at destination, the goods are unloaded from the vehicle (Activity 8). Ending this activity, the transport service ends. The transport company then notifies the freight integrator, which in turn notifies the shipper that goods have arrived to their final destination.

[69] Cross docking operations take place when cargo is simply shifted between vehicles, with no storage taking place.

The freight forwarder, during the transport service, may manage the transport service aiming to ensure that the transport agents are performing accordingly to the plan and that the goods are being conveyed within the conditions of the transport contract (Activity 9). The tracking is carried out via the messages sent by the various transport agents. In case of non-compliance (either delay or damage), the freight forwarder may take appropriate steps to either mitigate or solve the problem (which, for example, in case of delay may comprehend hiring other transport agents). Conversely, for any reason, such as: lack of available technology for supporting real time communication amongst transport agents (which is still often the case) or lack of technological interoperability, Activity 9 may not be possible to carry out, in these situations, any problem becomes visible only at the end of the transport service.

Also included in this activity are the functions related with the payments and, in case of delay or damage, the determination of the liability and, if required, the payment of indemnities. These functions may occur after the completions of the service.

As a final note, it should be emphasised that the sub processes, activities, or the tasks abovementioned may not occur or, alternatively, occur in a different order in real case situations. This happens because there is an almost endless variety of situations and cases, which cannot be documented. The example presented herein represents what the author believes to be a typical chain.

2.2.3 Intermodal Freight Transport as a set of flows

An intermodal transport can also be interpreted as a set of flows. Recalling the description of intermodal transport as a process, we have that a task's inputs may be the outputs of precedent ones and, in turn, its outputs will be the inputs of the following ones. The successive passage and conversion of outputs into inputs results in the flows. From this perspective the flows depend upon the architecture of the process. The flows can also be interpreted as the outcome of the interactions between transport agents. In these interactions there are exchange of different kinds of issues, namely: goods, information, responsibilities and capital, giving ultimately origin to diverse flows.

The utilisation of the concept of flow to characterise an intermodal freight transport service is not new. Jensen considers the existence of three types of flows (being: goods, information and money) along an intermodal freight transport service. And, one the components used by D'Este to characterise an intermodal freight transport service is the conformability of the events (D'Este, 1996, pp 9). Two events to be conformable mean that the output of one must be identical to the input of the following one. The production of an transport service entails the execution of a set of conformable events.

In this research work, the author has identified four types of flows, being: physical flow (Figure 2.9), logical flow (Figure 2.9), liability flow (Figure 2.10) and capital flow (Figure 2.10). The physical flow corresponds to the effective movements of the goods between the origin and the destination. The logical flow corresponds to the exchange of information between the agents[70]. The liability flow corresponds to the responsibility for the goods between agents throughout the transport service. Finally, the capital flow corresponds to the payments for the services carried out by the agents or due to legal obligations (like for example: the customs' clearance).

As the structure of the flows results from the configuration of the process, there is a broad range of possibilities for their structure. In this way, the flows presented in the following sections correspond to the example of intermodal transport chain and respective process described above (Figure 2.7 and Figure 2.8).

2.2.3.1 Physical flow

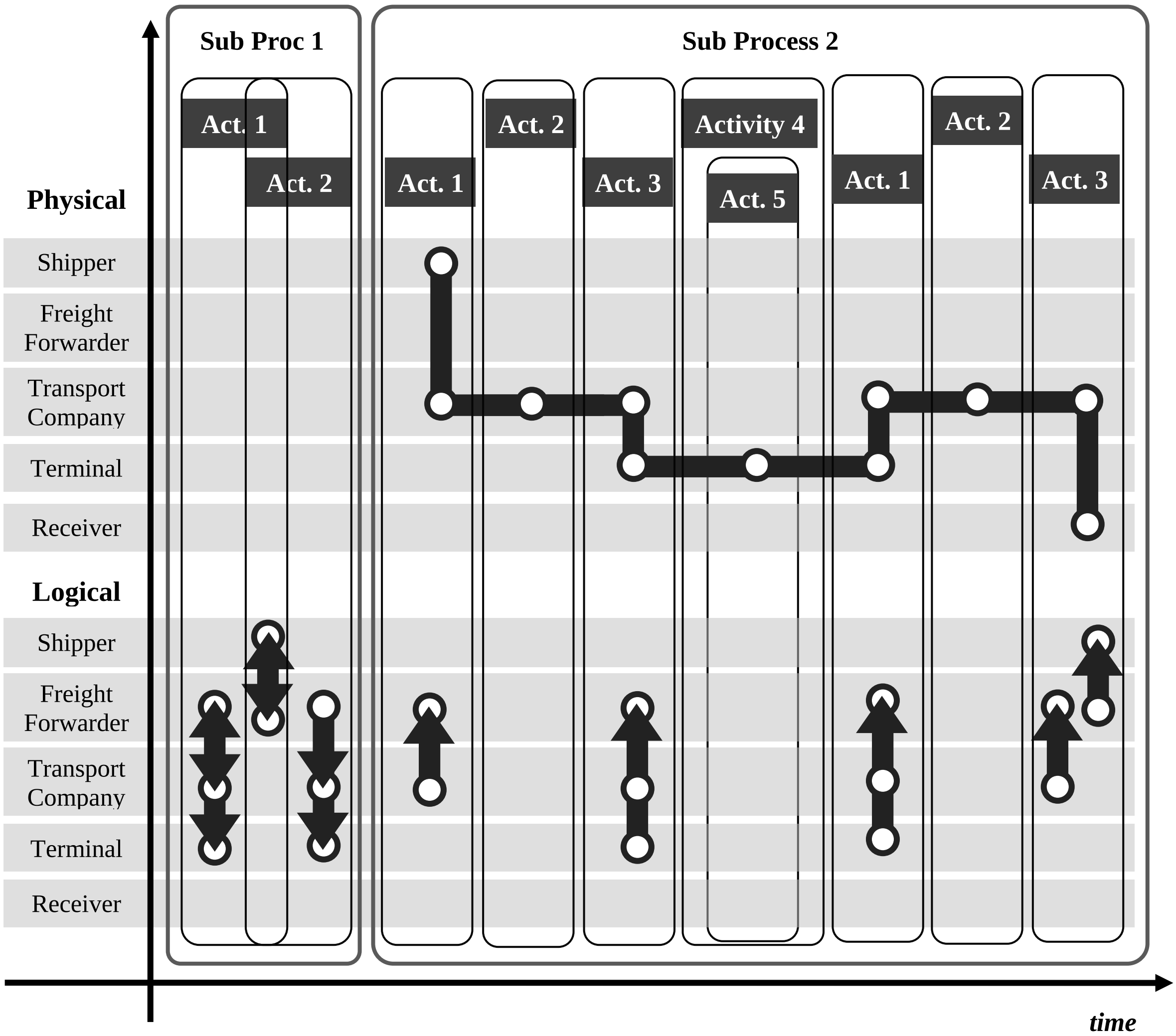
As already mentioned, physical flow corresponds to the production of the various transport service's legs. This flow was already documented during presentation of sub-process 2 and it is depicted in Figure 2.9. In summary, the physical flow on a leg corresponds to the picking-up of goods up at origin location, transporting to the terminal and finally unloading into the terminal. This flow repeats itself for the number of legs.

2.2.3.2 Logical Flow

During the production of an intermodal transport process a great amount of information is exchanged between the transport agents and between the freight forwarder and the

[70] The (paper-based) documentation accompanying the goods is also considered as making part of the logical flow.

shipper. Sub process 1 is entirely based on the exchange of messages; while sub process 2 may also contain a significant amount of information transfer. Indeed, a factor of success of any intermodal transport chain lies on the capacity of the agents to exchange relevant information in a rapid and accurate manner. Robust information promotes transparency and it enables, firstly, the premature detection of deviations from what is established and the implementation of mitigation measures; secondly, the detection of eventual faults or the negligence committed by agents and, thirdly, the monitoring of agents and tasks' performances.



Source: author

Figure 2.9 – Physical (top) and Logical (bottom) flows along an intermodal transport

Figure 2.9 depicts the logical flow of the intermodal transport chain considered herein. During Sub process 1, there is exchange of information between the shipper and freight forwarder, and between this agent and the various transport agents. The logical flow starts when the freight forwarder, on behalf of the shipper, approaches the various transport agents requesting for prices and transport conditions - Activity 1. Upon deciding the final transport chain's configuration, a new logical flow occurs when the freight forwarder notifies all agents about their roles and obligations.

During sub process 2, information may be shared on multiple moments between transport agents and the freight forwarder, namely: loading goods at shipper's premises (or terminal), transport, unloading goods at terminal (or final destination). The finalisation of Activity 3, in leg 1, can be sent either by the transport company or by the terminal.

A caveat should be made on the fact that the actual pattern depends on diverse factors, namely: architecture of the transport service, the technology available or the requirements set by the freight integrator. The involvement of different number of transport agents (like for example: the freight forward provide portion of the transport service) may render the need of less or different messaging.

The level of technology is also relevant, as the existence of real time tracking results in flows practically continuous between the various agents and the freight forwarder; whereas in case of absence of a real time tracking system, the transport agents have to rely on mobile communications (or fixed communications at fixed locations) to periodically communicate with the freight forwarder. Moreover, on a same transport service the various transport agents may be at different technological development, which may force the freight forwarder to make use of various types of communication solutions. Finally, the freight forwarder's decision on the moment and content of messaging may render different type of patterns. In any case, the example herein provides a typical snapshot on the logical flow.

2.2.3.3 Liability Flow

During a transport service, goods are prone to damage or even destruction, as a consequence of mishandling, accidents, or deterioration caused by natural sources (like sun or rain exposition, etc.). Furthermore, delays may occur either during transport (owing to, for example: congestion, bad weather conditions or negligence) or at terminal (owing to, for example, misplacement, misunderstanding or incorrect labelling). Damage or delays may bring significant economic losses depending of the goods' intrinsic value and the purpose they were meant for.

It is then necessary to define an adequate mechanism, so that, if such situation occurs the owner could be compensated from the losses. These mechanisms are laid down in the contract[71] established between the owner of the goods and the agent in charge for the transport - the freight integrator. The contract also defines the liability of this agent. The precise details of the contract vary from service to service, although due to the action of international bodies there are also standardised contracts (for transport services that involve lower risk).

In an intermodal freight transport service, two types of contracts are established: one between the shipper and the freight forwarder, and other between the freight forwarder and the transport agents. The ultimate responsible for the goods is the freight forwarder, because it is this agent that establishes a contract with the shipper. Yet, who actually handles and transports the goods are the other agents, which have to bear the responsibilities in case of damage or delay. Therefore, a contract is established between each of these agents and the freight forwarder, where they assume the responsibility for the goods. It should be noted that this contract is not visible for the shipper, whom only perceives as full responsible the freight forwarder[72].

Figure 2.10 depicts the liability flow of the intermodal transport chain considered herein. The liability flow occurs in Sub process 2 during the physical transport of the goods. It thus parallels the physical flow. From this results that during the transport service the responsible for the shipper is the freight integrator - Sub Process 2. Yet, for the freight forwarder, the responsibility is assumed by the agent that in each moment

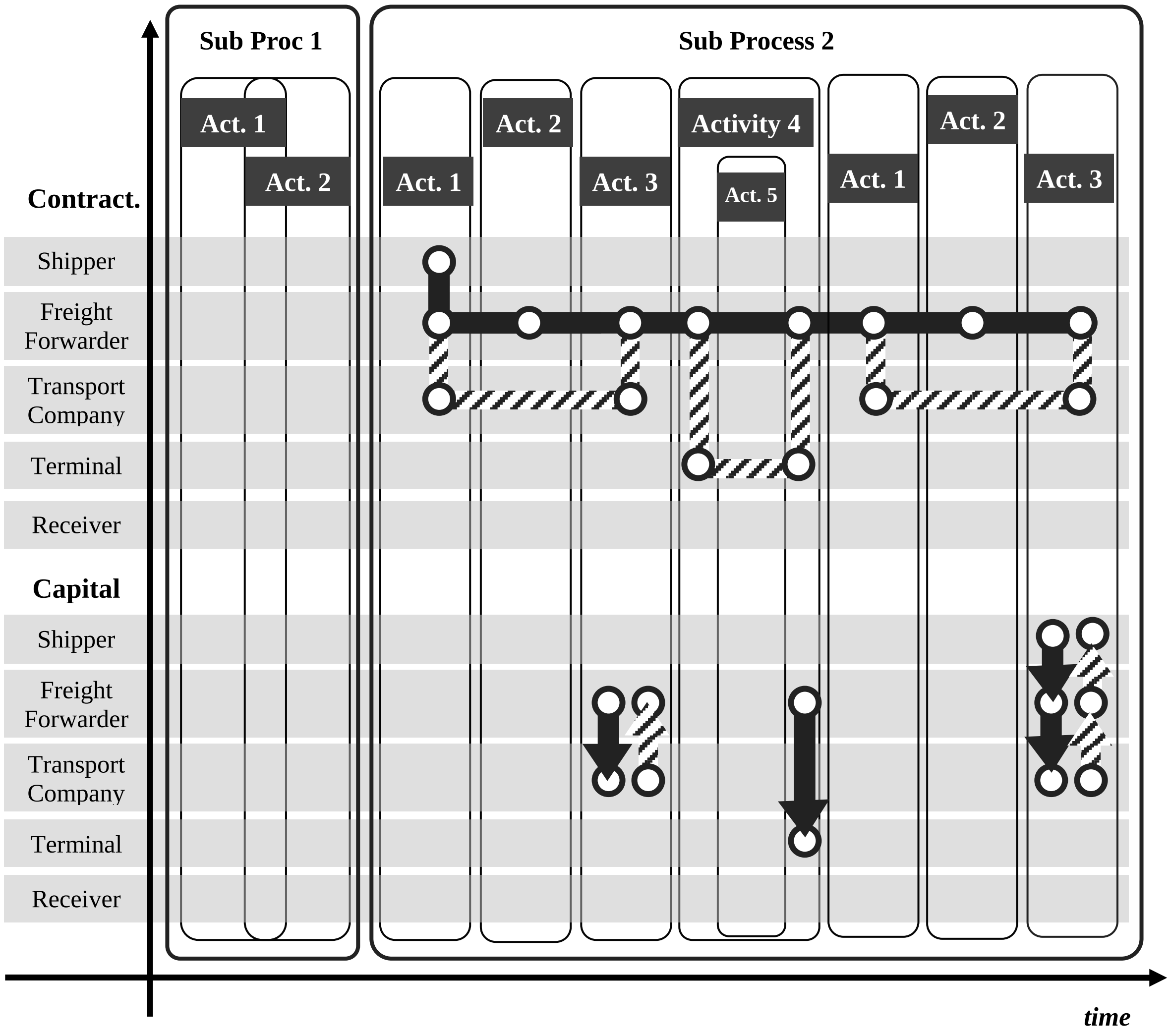
[71] Contracts are established between shipper and providers lying down all the rules and conditions of the service, namely: due payments and indemnities in case of any non-compliance. The definition of indemnities or compensations for faults is of particular relevance in case of a transport service.

[72] A caveat should be made on the fact sometimes freight forwarders make visible these contracts by establishing them directly between the shipper and the transport agents. The freight forwarder's purpose is to put herself aside of any liability. In case of a problem, the shipper to be compensated will have to identify the responsible, which is often difficult and bureaucratic. In any case, this type of transport services should not be considered intermodal freight transport services, since in this situation there is a contract for each leg and not a single contract ruling the entire transport chain. Recall the definition of intermodal freight transport service in Chapter 2.1.

has the goods, which may be the transport company - Activities 1 to 3 - or the terminal agent - Activities 4 and 5.

2.2.3.4 Capital flow

Capital is the raison d'être of any economic activity. The very existence of companies is based upon the goal of profiting from their activities. The transport sector is no exception and, in any intermodal freight transport service capital flows amongst agents due to three main reasons: payment of services, indemnities or compensations and customs duties.



Source: author

Figure 2.10 – Liability (top) and Capital (bottom) flows along an intermodal transport

In what concerns the payment of services, the capital, firstly, flows from the shipper towards the freight forwarder and, secondly, flows from this agent towards the transport agents (namely: transport company and terminal) and authorities (customs).

The pattern of the capital flow depends upon the contracts established both between the shipper and the freight integrator, and between the freight integrator and every other agent. The contracts define the moment or periods of payments. Some contracts foreseen that the payment should occur before the production of the transport service, while others establish a period for payment after the completion of the service. Naturally, each situation results in a different pattern.

In case of any non-compliance (for example: delay or damage) of the terms of contract, the responsible is due to pay an indemnity to the shipper. In an intermodal freight transport service, the compensation is a two level mechanism. Firstly, the freight forwarder compensates the shipper for all liability, as the former is from the latter's point of view the only responsible of the transport service. Secondly, the freight forwarder demands a compensation from the agent or agents (transport or terminal agent) responsible from the non-compliance. While the first level is typically immediate, the second level is considerably harder to carry out since the identification of the responsible implies the unequivocal determination of the cause and moment, which is often difficult (or impossible) to determine with accuracy. The reasons for this situation include: progressive damage of cargo along several agents, lack of inspection or non-external damage (only visible upon visualisation of goods).

The final type of payment corresponds to the customs duties, and only occurs when cargo need to be cleared. Commonly, the payment is done by the freight forwarder.

Figure 2.10 depicts the capital flow for the intermodal transport chain under analysis. It is assumed that the payment occurs as soon as an agent fulfils her service and that the customs duties are paid immediately. As a result, there is capital flow only during sub Process 2 or after the completion of the transport process. Under this assumption, the first payment is made after the completion of the transport service (activity 3). The following payment is made upon completion of the customs' clearance (activity 5). The next payment is to terminal agents (activity 4). Finally, the transport service of leg 2 is paid. The dashed arrows correspond to the possible indemnities.

2.3 Depicting the performance of an intermodal freight transport service

The Oxford dictionary has several entries for the noun *performance* (Wehmeier, 2000, pp 873), namely:

- How well or badly something works, or someone does something;
- The act of performing a play concert or some other form of entertainment;
- The way a person performs in a play, concerts, etc.
- The act or process of performing a task, an action, etc.

Thus, the noun *performance* evaluates the skill of an entity when doing a certain task or process (if more than one task is involved). An entity is the responsible for the work[73] and can be either an individual or a group. Consequently, the performance can be used to form a judgment of the entity in doing one or more tasks.

Since performance is a noun, it does not conveys in itself any value or attribute. Therefore, so that a judgment could be made possible, it is necessary to associate a factor (adjective, variable or indicator). If an adjective is associated than the performance is eminently qualitative[74] (like for example: good, average, bad, well, poor, etc). Otherwise, if a numerical factor is associated than performance is quantitative.

Performance is also an absolute concept[75], in the sense, it does not need to be compared with any other entity to be determined. Thus, the value of performance of an entity is always the same regardless the environment and the properties of that environment[76].

The assessment of the performance is therefore of paramount importance for the transport agent, since it enables them to understand how well they are doing their tasks. Naturally, the higher is the performance, the better they are doing the tasks. If they

[73] Like for example: person, organisation or process. The performance of a process refers to how the group of individuals or organizations is doing the tasks at hands. There may of interest to evaluate the performance of the group, instead of each one individually.

[74] Unless, of course, if the adjective refers to a specific quantitative amount.

[75] It should be noted that in case of qualitative performance, the concept may become relative. Because, for example, the performance of an entity can be considered good, if it is better than others.

[76] This does not mean that the performance of an entity is not influenced by external variables. Only that the quantification of performance is independent of the environment.

surpass their competitors' performance, than they will be more competitive[77] and, in principle, they will be able to continue in the market. There is a vast literature indicating and suggesting performance variables and indicators for all types of agents, task and processes in the domain of transport[78].

Let us now consider a multimodal transport made by a set of independent and non-related single-modal transport services. This means that for the point of view of each agent all the others do not exist, which results that each one produces her own transport service regardless the needs, characteristics, etc. of the others. Therefore, in such a case, the overall performance would be the result of the simple summation of the various individual transport services' performances.

In an intermodal freight transport service on the contrary, all agents work together for a common goal: each one is aware of the other[79], and each transport service is coordinated and tuned with the remaining ones by the freight forwarder. The freight forwarder organises and manages the various agents, aiming to get the most of each party in favour of the overall performance of the transport service. The role of freight forwarding thus generates[80] synergies that are added to the overall performance and reduces the waste that decreases the overall performance. As such, in these transport services, the overall performance is more than the sum of each individual transport service's performance.

The following picture (Figure 2.11) depicts the performance of a multimodal and an intermodal freight transport services The vertical axis represents the performance

[77] In this research work, the concept of competitiveness refers to a company's ability to conceptualise, produce and market its products and services better than those offered by the competitors. Thus, if a company's competitiveness is lower than its competitors, then it will go eventually out of the market. More information is provided in Footnote 37.

[78] In what concerns freight transport, the interested reader is referred to Cottrell (2008), Janic (2008), Blauwens et al (2007), Lai et al (2002), OECD (2002a), Morash (2000), Ferreira and Sugut (1992) or Boisjloy (1979). Some measures of performance were already indicated in the D'Este's conceptual representation of the intermodal freight transport service (Chapter 2.2.1).

[79] Or at least it is aware of the freight forwarder.

[80] The author follows Ackoff's (1994, pp 181) definition about synergy as being "an increase in the value of the parts of a system that derives from their membership in the system, that is, from their interactions with other parts of the system. […] Put another way, synergy requires an increase in the variety of behavior available to the parts of a system".

(measure in some unit[81]). It is considered a transport service with three dual systems[82]: DS1, DS2 and DS3, and one freight forwarder (FF)[83].

If this set of dual systems are involved in a multimodal transport service then, accordingly to the above assumption, the overall performance would be obtained by the summation of each dual system's performance (left bar in Figure 2.11). If those same dual systems are now involved in an intermodal freight transport service, then the overall performance will be higher due to the synergies created by and the reduction of waste obtained by the freight forwarder.

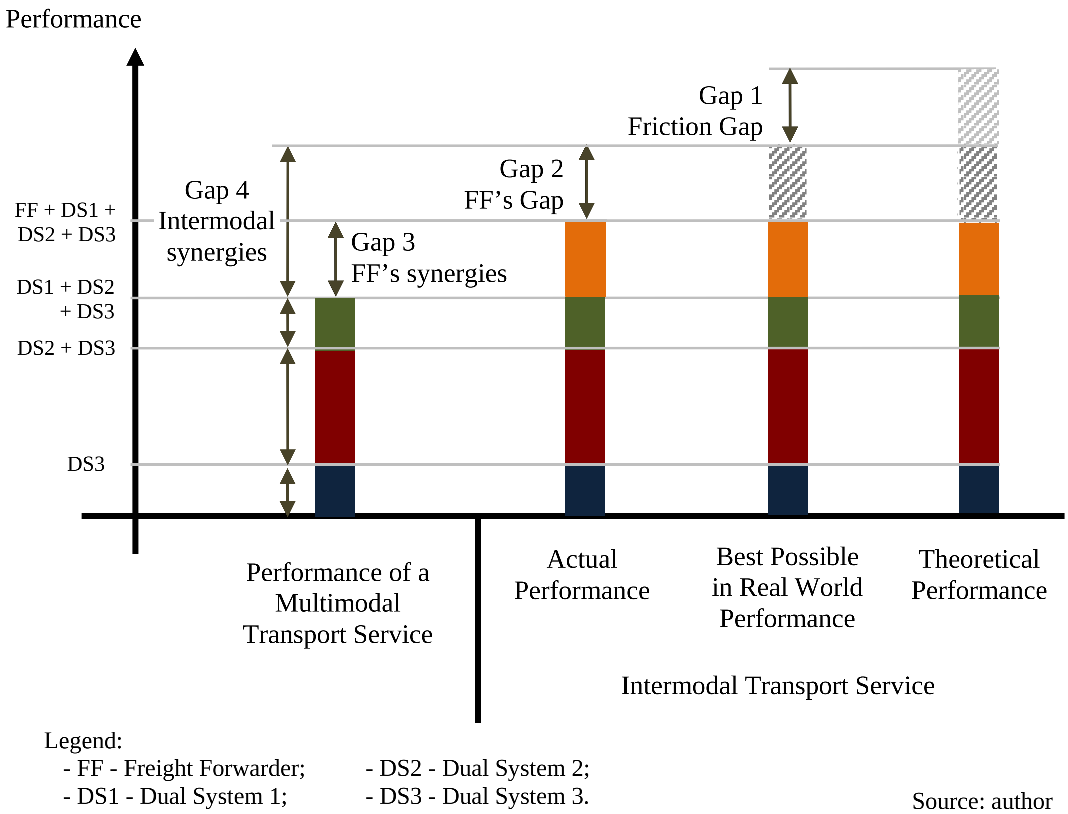


Figure 2.11 – Depicting the performance of intermodal freight transport services

[81] The unit depends on the specific case, but it could be: time, reliability, flexibility or capacity.

[82] Dual system is a set compound by the transport agent and the mode of transport. If the same transport agent operates more than one mode of transport, than she forms several dual systems (one for each different mode of transport).

[83] The performance of DS1 is represented at blue, the performance of DS2 at red, the performance of DS3 at green and the performance of the FF at orange. The dashed bars represent losses of performance.

Let us now assume that, first, each dual system is being deployed at the maximum of its performance, second, the synergies are maximised and, third, the waste (inefficiencies) is reduced to zero (or to the minimum). Such assumption would consubstantiate a situation where that set of dual systems would be delivering the maximum possible overall performance. Let us call this performance the *theoretical performance* (right bar in Figure 2.11). The theoretical performance corresponds thus to the maximum performance attainable by an intermodal freight transport service.

Yet, diverse real world reasons[84] may originate losses of synergies or waste between the dual systems' profiles[85] and, in this way, to preclude the achievement of the theoretical performance. Therefore, the maximum performance attainable in the real world could be inferior to the theoretical performance. Let us call this performance as the *best possible in the real world performance* (second right bar in Figure 2.11). A gap may thus occur between the theoretical performance and the best possible in the real world performance (Gap 1 in Figure 2.11). This is the so-called *Friction Gap*, which corresponds to the amount of waste or, in other words, the level of friction between dual systems. The best possible in the real world performance is therefore the maximum performance attainable by a non-fit intermodal freight transport service[86].

The friction gap is not eliminable by the freight forwarder because it is generated by properties that are intrinsic to the dual systems and, thus, outside her scope of influence. In order to reduce the friction gap the dual systems should work together to eliminate the sources of friction[87].

---

[84] These reasons include factors such as: lack of schedule coordination, reduced physical interoperability, different procedures and cultural habits, or non-willingness of transport agents in working together. These are factors that the freight forwarder cannot eliminate because they are internal to the dual system and are thus outside her scope of influence.

[85] Let us assume, for purposes of presentation, that these are internal frictions and they may correspond to either a decrease of the synergies or an increase of the waste. And that eventual external factors (such as: congestion, bad weather conditions, etc) do not influence performance. This simplification does not affect the validity of this reasoning. The external factors would influence in equal terms the performance of the dual system either they are operating in multimodal or in an intermodal freight transport services. Therefore, the inclusion of external factors would lead to an offset (positive or negative) of all performances (bars) by the same amount.

[86] It should be noted that the Friction Gap affects in equal manner the multimodal transport service. Indeed a similar figure to Figure 2.11 could be constructed for the multimodal scenario. However, since the scope of this research work is intermodal transport chains only this scenario is analysed. The inclusion of the multimodal transport services is only for purposes of benchmarking.

[87] Like for example: investment in interoperable equipment, alignment of processes, etc.

Looking now into the freight forwarders, they are certainly not equally skilled. Indeed, different freight forwarders would follow different processes of production of intermodal freight transport services and, as such, they are likely to obtain different performances from a same set of dual systems. So, the actual performance achieved by a set of dual system ultimately depends on the capabilities of the freight forwarder, and it could be below the real world performance (if the freight forwarder is not able to manage the dual systems in the best possible way). Let us calls the actually achieved performance by the intermodal freight transport service as the *actual performance*. The actual performance should lie between the performance of a multimodal transport service and the best possible in the real world performance (second left bar in Figure 2.11). On the one hand, the actual performance should be higher than the performance of a multimodal transport service because of the synergies created by the presence of the freight forwarder; whereas, on the other hand, it is at best equal to the real world performance (because this performance is the maximum attainable by a transport chain). Moreover, to reap the maximum synergies and eliminate all the waste could be hard to a freight forwarder.

A second gap may thus occur between the real world performance and the actual performance. This is the so-called *Freight Forwarder's Gap* (Gap 2 in Figure 2.11) and corresponds to the inability of the freight forwarder in extracting the most from the dual systems and, ultimately, the transport service.

A third gap may also be identifiable between the actual performance and the performance of the multimodal transport service. This is the so-called *Freight Forwarder's synergies Gap* (Gap 3 in Figure 2.11) and corresponds to the added valued brought by the freight forwarder.

A final gap can be identified and corresponds to the difference between the real world performance and the performance of the multimodal transport service. This is the so-called *Intermodal synergies Gap* (Gap 4 in Figure 2.11) and corresponds to the full potential of intermodality over multimodality (that may not be entirely explored due to the incapacity of the freight forwarder).

From this reasoning, the author argues that the performance of an intermodal freight transport service is function of three factors, being:

- Performance of the dual system: transport agent – mode of transport;
- Freight forwarder’s capabilities of managing;
- Friction gap.

The assemblage of high performance dual systems does not necessarily entail that the outcome will be a high performance intermodal freight transport service, because of the interplay of forces between the performance factors: either there may exist high friction amongst the various parties (friction gap) resulting in low performance transport chains; or because the freight forwarder may not be able to reap all the possible synergies from the resources or to eliminate the waste (high freight forwarder’s gap).Herein lies a possible explanation of why some high performance modes, when brought together are not able to yield a high performance intermodal transport chain.

Therefore, the utilisation of high performance dual systems does not necessarily entail the production of high performance intermodal freight transport services, if there is friction gaps, because the existence of friction gaps reduces the *best possible in the real world performance* and it may preclude the achievement of high *actual performance*. In this sense, lower performance dual systems may achieve higher *actual performance* if they are fit (zero friction gap).

2.4 Modal choice: literature review

Modal choice is the process whereby the transport decision maker decides upon the mode or modes of transport and the transport agents required for producing a transport service. The process remains to some extent not well understood and an evidence is the vast amount of literature dedicated to the subject, particularly, in what concerns the identification of the decision makers' key attributes or factors for modal choice.

An important feature of the modal choice process is the identification of the requisites for freight transport services. The requisites do reflect the shippers’ benefits from the transport service (higher benefits yield higher requisites). The requisites are commonly divided into qualitative or quantitative. Quantitative requisites refers to cost and, commonly, to transit time; while qualitative requisites refers to all others. The qualitative requisites define the minimum quality of the transport service[88]. Yet, a full identification of the requisites is hardly viable both because not all are known as well as because there are many possible combinations that makes virtually impossible to catalogue all of them (Witlox and Vandaele, 2005, pp 78, Jeffs and Hills, 1990, pp 42). Nonetheless it is possible to identify those attributes that are generally taken into consideration or, at least, that there is some consensus around their relevance. In this sense, the vast body of literature addressing the problem of modal choice process has already shed some light on this matter. Follows a brief review on this topic.

In its work in 1990, later on updated by Paul Murphy and Patricia Hall in 1995 (Murphy and Hall, 1995), McGinnis compares twelve studies on modal choice process, in the United States, before and after the 1980 transport deregulation process (McGinnis, 1990, pp 13). Deregulation in the United States brought a growth in competitiveness and complexity, as both freight transport suppliers began competing against each other, and freight shippers began imposing new requisites and conditions for their transport services. Nonetheless, McGinnins acknowledges that shippers' priorities have not changed with this process (McGinnis, 1990, pp 17).

In his literature review, McGinnis identified six key attributes in modal choice process, being: freight rate, reliability, transit time, safety, shipper market considerations and carrier considerations (McGinnis, 1990, pp 14). The author does not rank these variables, nevertheless, he refers that freight rates, although being important, are often surpassed by the other qualitative attributes (McGinnis, 1990, pp 17). Paul Murphy and Patricia Hall went a little further and ranked the McGinnis' attributes, being: first, reliability; second, freight rates; third, carrier considerations; fourth, transit time and shipper market considerations; and sixth, safety (Murphy and Hall, 1995, pp 35).

In their work, Jeffs and Hills (1990) analysed the modal choice process in the industrial category of paper, printing and publishing sector, in the region of West Yorkshire (United Kingdom). The purpose was the identification of the key influential variables in that process.

---

[88] Quality may also be perceived from the transport operators' perspective, which not always coincides with shippers'. In this research work, the perspective is upon the shippers' side.

These authors found out evidences of bias in the process: firstly, they identified some sort of loyalty to either transport supplier or mode of transport (either because of inertia to change or actually good service); and secondly, they found out that there is a cut-off point for the process of searching for alternative transport solutions (because it is a costly process) (Jeffs and Hills, 1990, pp 33). Both situations introduce some lack of transparency and rationality to the process.

The study comprehended one hundred interviews, in which it was asked to identify the most relevant attributes influencing modal choice. Using factor analysis technique, the authors identified the most significant variables in explaining the modal choice process, being: reliability, monitoring, safety, security, transit time, flexibility, length of haul and size of shipment (Jeffs and Hills, 1990, pp 44). The costs of transport were not found to be significant in these industrial sectors.

Paul Murphy, James Daley and Patricia Hall published a new study in 1997 (Murphy et al, 1997) in which they identify and compare the key attributes in the modal choice process between freight shippers and freight suppliers (Murphy et al, 1997, pp 67). Through a mail survey, the authors inquired some 350 shippers and 360 transport suppliers operating within the United States. The rate of response was respectively of twenty and seventeen percent. In the survey, the authors asked the respondents to evaluate the relevance of eighteen attributes in their current modal choice process. From the analysis of the responses, the authors concluded that both shippers and suppliers valuated as most important the attribute reliability and secondly the attribute equipment availability. Freight shippers valuated in third the transit time attribute, in fourth pick up and delivery service attribute and in fifth the freight suppliers' financial stability. On the other hand, freight suppliers valuated, respectively, operating personnel, transit time, pick up and delivery service (Murphy et al, 1997, pp 70).

Matear and Gray (1993) have conducted a survey to shippers and freight transport suppliers operating within and in-between Ireland and the United Kingdom. The purpose was to identify the criteria of modal choice of sea and air transport services (Matear and Gray, 1993, pp 26). In what concerns the freight shippers, the most relevant criteria for modal choice were: fast response to problems, safety and on-time collection and delivery. For the freight suppliers purchasing sea transport services, the key attributes were: availability of freight space, punctuality and high frequency of service; while for the air transport services, the key attributes were: frequency, punctuality and availability of freight space (Matear and Gray, 1993, pp 28). The authors refer that the reliability factor, which is usually top ranked amongst quality factors, was not so valued in the survey (Matear and Gray, 1993, pp 28) and, even, lost for others attributes, like for example: punctuality. However, it is the understanding of the author of this research work that Matear and Gray have evenrually misunderstood the concepts, because punctually refers to the arrival on schedule of the goods, and reliability refers to the transport provider's capacity on fulfilling transport scheduling; so, both terms refer to rather similar qualitative properties (as also argued by Witlox et al, 2005, pp 79). In this sense it is possible that the respondents might have been valuing reliability. Nonetheless, the regional specificities of the Ireland-United Kingdom market should be taken into consideration and reliability might turn out to be not so relevant.

Cullinane and Toy (2000) conducted an extensive literature review to some seventy five bibliographic references on route and mode choice (with a geographical focus in Western Europe). The emergence of stated preference techniques and the need of offering respondents a manageable array of alternatives have led the authors to identify the major attributes in the modal choice process (Cullinane and Toy, 2000, pp 41). Following the content analysis method[89], they have identified five key attributes influencing modal choice process, being: cost, speed, transit time reliability, characteristics of the goods, and service[90] (Cullinane and Toy, 2000, pp 49).

Norojono and Young (2003) conducted a stated preference experiment to a set of freight shippers of Java Island (Indonesia) to determine the most relevant modal choice criteria for road and rail transport. Reliability, safety and flexibility were ranked amongst the top three (Norojono and Young, 2003, pp 207). On the other hand, cost and transit time were not seen as much relevant as expected. These situations have to do with market geographic specificities. In what concerns the former, in Indonesia, the transport costs

---

[89] Content analysis is a method for analysing the contents of messages, such as texts. The interested reader is referred to Downe-Wamboldt (1992).

[90] Service is by itself a variable that may embody a number of other attributes, which may vary between respondents and depends upon the transport decision maker's perspectives or expectations (Cullinane and Toy, 2000, pp 49).

are passed on to the consumers and cost structure is rather similar across industry; while concerning the latter, in Indonesia, there is a great tolerance towards time (Norojono and Young, 2003, pp209).

The European Commission founded project Intermodal Quality (IQ) was carried out with the purpose of improving the quality of intermodal transport within European Union (INRETS, 2000, pp 5) and ultimately fostering this type of transport solution. IQ acknowledges that qualitative attributes may vary in function of the nature of goods, type of freight shippers and length of the transport service. In this way, twenty three freight transport market segments have been identified (INRETS, 2000, pp 20). Nonetheless, IQ identified a core group of quality attributes that tend to be present in the modal choice process, albeit the relative weight of each one to differ amongst segments. The attributes are: time indicators, reliability, flexibility, qualification, accessibility, monitoring, and safety and security (INRETS, 2000, pp 13-14).

The LOGIQ project was developed to identify the main actors in the decision-making process and to provide information on the underlying criteria and constraints in the use of intermodal transport (GRUPO Clas, 2000, pp 6). In order to identify the key modal choice variables, LOGIQ has carried out with a set of interviews to some transport decision makers, namely: freight forwarders, freight shippers and shipping lines (GRUPO Clas, 2000, pp 37). The group has been segmented in function of the type of the decision orientation, namely: cost oriented, quality oriented, and specific group. The cost oriented group has on price its main decision attribute. Any change on price has significant consequences of modal choice process. Quality is perceived as a by-product and therefore not fundamental for transport decision. On the other hand, for the quality oriented group both qualitative factors and cost are equally evaluated in the modal choice process. The key quality factors are: reliability, flexibility, safety and frequency. Finally, on the specific group the cost and the quality play different roles depending on the type of specificity (GRUPO CLASS, 2000, pp 40).

Table 2.2 and Table 2.3 gather the attributes found in the just reviewed literature and adds some few others. Although being aware that the herein review to the state of the art is by neither extensive nor exhaustive, the author nevertheless considers that these tables may bring some insights into the modal choice process's criteria. Assuming that the quantity of references reflects the attribute's universality on the modal choice process[91]. First, there is a consensus on the importance of the same (and few) modal choice attributes, being: reliability, transit time, safety, flexibility or price. Second, there is reference to (many) other possible modal choice attributes. The identification of these attributes may likely have been due to specificities (of, for example: goods, region or market) of the respective research's case-study.

Table 2.2 – Modal choice attributes (part 1)

Attribute	**Authors**	**Attribute**	**Authors**
Reliability	• Norojono and Young (2003), • Shinghal and Fowkes (2002), • Culliane and Toy (2000), • GRUPO Clas (2000), • INRETS (2000), • Murphy et al (1997), • Jovicic (1996, quoted by De Mayer and Pauwels, 2003, pp 27), • Jeffs and Hills (1990), • McGinnis (1990, updated by Murphy and Hall, 1995), • McGinnis (1989), • Oum (1979).	Transit Time	• Garcia-Menéndez et al (2004), • Shinghal and Fowkes (2002), • Culliane and Toy (2000), • Murphy et al (1997), • Jovicic (1996, quoted by De Mayer and Pauwels, 2003, pp 27), • Jeffs and Hills (1990), • McGinnis (1990, updated by Murphy and Hall, 1995), • McGinnis (1989), • Oum (1979).
Safety	• Norojono and Young (2003) • GRUPO Clas (2000) • INRETS (2000), • Matear and Gray (1993), • Jeffs and Hills (1990), • McGinnis (1990, updated by Murphy and Hall, 1995), • McGinnis (1989).	Flexibility	• Norojono and Young (2003), • GRUPO Clas (2000), • INRETS (2000), • Jovicic (1996, quoted by De Mayer and Pauwels, 2003, pp 27), • Matear and Gray (1993), • Jeffs and Hills (1990).
Price	• Garcia-Menéndez et al (2004), • Culliane (2000), • Jovicic (1996, quoted by De Mayer and Pauwels, 2003, pp 27), • McGinnis (1990, updated by Murphy and Hall, 1995), • McGinnis (1989).	Frequency of service	• Garcia-Menéndez et al (2004), • Shinghal and Fowkes (2002), • GRUPO Clas (2000), • Matear and Gray (1993).

[91] Universality understood as the attribute's presence in any modal choice process. The point here is that specific type of goods (or market conditions) may render some attributes as being important, while in most situations are not taken into consideration (like for example: in markets highly unbalanced the availability of containers (equipment) may be a key issue). A universal attribute is thus an attribute that is always taken into consideration in the decision making process.

Table 2.3 – Modal choice attributes (part 2)

Attribute	Authors	Attribute	Authors
Service level	• Culliane (2000), • Jovicic (1996, quoted by De Mayer and Pauwels, 2003, pp 27).	Shipper's market considerations	• McGinnis (1990, updated by Murphy and Hall, 1995), • McGinnis (1989).
Monitoring	• INRETS (2000), • Jeffs and Hills (1990).	Security	• INRETS (2000), • Jeffs and Hills (1990).
Length of haul	• Jeffs and Hills (1990)	Punctuality	• Matear and Gray (1993)
Size of Shipment	• Jeffs and Hills (1990)	Availability of freight space	• Matear and Gray (1993)
Equipment availability	• Murphy and Hall (1997)	Pick up and deliver service	• Murphy and Hall (1997)
Freight transport supplier's financial stability	• Murphy and Hall (1997)	Operating personnel	• Murphy and Hall (1997)
Qualification	• INRETS (2000)	Characteristics of the goods	• Culliane and Toy (2000)

Looking now towards the domain of research, the literature concerning modal choice on air cargo transport is relatively scarce. Indeed, all studies abovementioned refer to either land based modes (road or rail) or water transport (sea and fluvial).

In what concerns air cargo research, recently, Park published a study on the shippers' modal choice attributes for freight integrators services on the South Korean market (Park et al, 2009, pp 322). The freight integrators taken into consideration were: DHL, FedEx, UPS, TNT, EMS (Park et al, 2009, pp 323). Based on a survey and on an analytic hierarchic process, the authors identified and ranked twenty six attributes clustered into six groups, being:

- *Accuracy* – reliability of pickup and delivery windows times (the shorter, the better);
- *Promptness* – necessary time in advance to book a service;
- *Safety* – reliability level and accountability of the transport provider;
- *Convenience* – easiness of booking and track and trace, and geographical coverage of the transport service;

- *Economic efficiency* – price and price structure;
- *Dependability* – image and reputation of the carrier.

Table 2.4 presents the ranking of these attributes. The study points out *accuracy* as being the most relevant factor, followed by, *promptness*[92]. Bearing in mind that this study concentrated on freight integrators that focus on express cargo, it is somewhat natural that these two factors appear in first place. Price (incorporated on the factor *economic efficiency)* appears in fourth place. Once again, understandable, since express cargo is commonly high valuable, thus price tends to play an inferior role. Although being an important study, it refers to express cargo which is out of the scope of this research work.

Table 2.4 – Weight of modal choice attributes

Attribute	**Weight**
Accuracy	0.32
Promptness	0.27
Safety	0.17
Convenience	0.11
Economic Efficiency	0.09
Dependability	0.04

Source: Park et al (2009, pp 325)

In another study developed by Hsu and her colleagues aimed to evaluate a new forecasting model for the air cargo market, the authors simulated the shipper's behaviour using the concept of total logistics cost[93] (Hsu et al, 2009, pp 1). In this concept the best transport solution is the one with minimum total logistics cost. The decision factors were: price, frequency, transit time and product characteristics (Hsu et al, 2009, pp 2). These factors correspond to the various components of the concept total logistics costs.

[92] Promptness may also be understood as flexibility since it refers to the transport company's adaptation capacity.
[93] A good review and explanation on the concept of logistics costs is provided by Blauwens et al (2006).

The authors concluded that the importance of each attribute is dynamic, depending on the market's industrial structure and product characteristic (Hsu et al, 2009, pp 1). This conclusion is relevant because it points to the likely non-static nature of the modal choice factors. Besides the two variables (industrial structure and product characteristics), other factors such as: economic environment, demand for the shipper's products or market competition, were identified as also playing a role on the valuation of the modal choice factors. If this assumption is held true, further complexity is added to the modal choice behaviour, raising even further the burden of simulating this process.

Hong and Jun studied the differences between service quality priorities of air cargo providers and shippers (Hong and Jun, 2006, pp 55). Once again the market is South Korea, and the quality of service is analysed towards five companies: Korean Airlines, Japan Airlines, Lufthansa and Northwest Airlines. For the identification of the quality attributes, the authors carried out a set of ten interviews with specialists and chose the most often mentioned. They end up with eighteen attributes clustered in four groups, being (Hong and Jun, 2006, pp 61):

- *Supply capacity* – refers to the existence of infrastructure to provide transport services;
- *Service accountability* – refers to the commitment of transport provider in solving and assuming responsibility for eventual problems occurring during the transport service;
- *Competitiveness of service fees* – refers to the price structure;
- *Management capability* – refers to the transport provider culture and equipment.

The outcomes of this study are not relevant for the current research work, since they focus on perception quality gaps. Interestingly, however, it is the fact that against to what is traditionally considered, these authors consider price as a quality attribute. No explanation is put forth for such fact.

Another interesting conclusion is that, with the exception of the attribute *supply capacity*, the remaining quality attributes herein considered are similar to those identified by Park et al (2009), although using a different designation. Since both studies use the same market (South Korea), the similarities between attributes may evidence that shippers from express cargo and non-express cargo may follow an analogous modal choice structure (although it is not possible to infer on the relative importance of each factor). Certainly, further studies should be carried out before such assumption could be proved or refuted.

Albeit the vast body of literature has shed some light over modal choice process, it still remains considerably unclear and not well understood. Firstly, not all decisions variables as well as their relevance are entirely depicted. Secondly, non-rationality tends to play a role in the decision making process. Thirdly, the wide range of decision making situations renders almost impossible to identify and have common reference frameworks. Nonetheless, looking into the literature a core number of attributes consistently appears and it is always ranked amongst the top, namely: price, transit time, reliability, safety and flexibility. Such situation evidences the possibility of existing a few number of attributes that regardless the specificities of the case always make part of the equation; however, the weight and relevance of each one varies from case to case.

Although not being the purpose to question the veracity of the outcomes of the body of research, the author does have some reservations on the freight forwarders' actual consideration of modal choice factors besides the cost and the transit time. This perception was built, throughout the research period, from direct observations of operations of the freight forwarders and interviews with various agents, and supported on the literature.

During the doctoral research period, the author has had the opportunity in the training period at the airport of Oporto to observe the daily operations of a freight forward. Typically, upon receiving the shipper's demands, employees chose a set of transport agents and inquired them for prices and transit time. The final choice was apparently done upon these two factors, with no other being considered. When questioned on this topic, employees invariantly answered that they only worked with trusted partners (transport companies, terminal agents, etc.), and that therefore all other quality attributes were inherently fulfilled.

Indeed, it looked like they had ranked the transport agents in terms of trustfulness (basically, partners with more quality of service would be ranked higher than others with lower quality of service). Then, in a situation of difficult (or demanding) requirements they would limit the choice to the highest ranked transport agents; while in a situation of less difficult requirements they would enlarge the choice to more agents. When questioned if the higher quality partners would not have higher prices, employees answered that not always (but sometimes).

From the interviews carried out throughout the research period, those with relevance for this topic were held with Mr. Amilcar Horta, Ms. Helena Rosa, Mr. Thilo Schmid, Mr. Mário Sousa and Mr. Alberto Silveiro[94]. All the interviewees agree that currently the shippers' modal choice attributes are essentially price and transit time.

Mr. Amilcar Horta evaluated cost as accounting for as much as eighty percent on shipper's weight decision, while Mr. Thilo Schmid judged cost as accounting for seventy five percent. The time factor would weigh the remaining percentage. The others did not put forth any valuation but agree on the higher importance of cost over time.

When inquired about the relevance of other quality variables on the modal choice process, interviewees answered the transport agents have evolved towards similar levels of quality and that any transport operator below a certain threshold was condemned to go out of the market. Therefore, although acknowledging differences amongst transport agents, these are not so different as to be taken into consideration in the shippers' decision process. It seems that qualitative attributes are used for elimination purposes (if the transport agent's quality is above a certain threshold it can used, otherwise no); and not explicitly taken into consideration along with price or transit time.

Mr. Mário Sousa was also convinced that shippers having to decide upon similar transport options (in terms of price and transit time) would predominately choose the option offered by the transport agent with which they normally work the most (as long as that transport agent provides a good service). And this even, in the case, that the others transport agents were presenting better qualitative attributes. Once again, the factor of trust and knowledge seems to play a relevant important, and shippers are likely

[94] The interviews with Mr. Mário Sousa and Mr. Alberto Silveiro were done in the context of road and sea transport. They are nonetheless of relevance for understanding modal choice behaviour.

averse to risk their goods with unknown transport agents (although having potentially better quality). When inquired in which circumstances a shipper would change transport agent, Mr. Mário Sousa said that first the new comer has to offer better prices or transit time. Upon change, the shipper would take some time (of several months) to realize the better quality of service and, eventually, become captive of this transport agent. And, only after this trial period, the transport agent could try to raise prices.

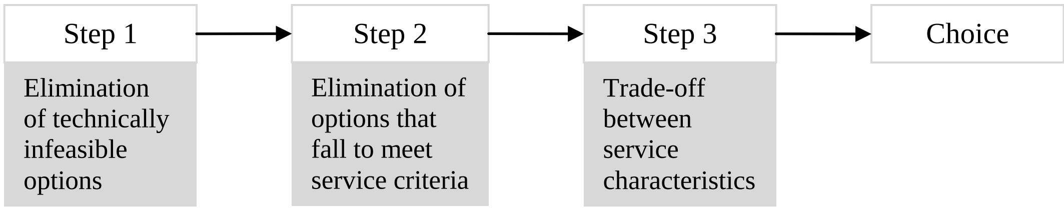
One can argue that the interviewees' perceptions are only valid within the current economic environment, however, the same argument can be applied to all the above studies, since they were not carried detached from real world conditions.

In line with the author's perception, other authors have also been claiming that the modal choice is a simple process and not necessarily grounded in strict rational principles (Beuthe et al, 2008, D'Este, 1996, Evers et al, 1996, pp 13, Jeffs and Hills, 1990, pp 35). The point is that typically modal choice process is carried out by middle level employees that multiple times on the working day and in very short periods of time, have to assemble the intermodal freight transport service. As such, they tend to choose either those transport solutions that they know that have been successful in the past, or those transport agents that they usually work with. For example, Beuthe et al (2008, pp 159) stated that "it is not obvious that a competent transport manager thinks in terms of maximising a utility value. They likely rather try to minimise some measure of the total transport logistic cost that integrates many internal and external logistic factors. These factors are functions of the transport attributes, and may naturally include some subjective judgment as to risk taking […]".

D'Este (1996, pp 10) also considered that the modal choice was a simple process based on a simple reasoning (Figure 2.12). Accordingly to the author, the modal choice is a three step process. In the first step, the decision maker discards all the non-feasible transport services[95]. In the second, she discards the transport agents that do not offer the minimum quality levels. That is, the transport agents that do not meet the minimum standard level in one or more of the qualitative factors is also put aside. At the end of

[95] Various reasons may be pointed out, like for example: non-compatible schedules, non-adequate vehicles, lack of available capacity, etc.

the second step, the decision maker has a set of transport agents that meet the minimum quality levels and that are provide feasible services. In the last step, the transport agents are chosen based on quantitative properties, such as: transit time or price.



Source: D'Este (1996, pp 10)

Figure 2.12 - D'Este's modal choice process

Reinforcing that the purpose of this reflection is not contradicting the knowledge on modal choice behaviour, from the observations of the real world, the author believes that the importance ascribed to certain quality attributes might be overemphasised. In practical terms, decision making process seems to be far more simpler and straightforward than the transport studies claim[96], based on very few attributes. Moreover, the quality attributes seem to be used on shipper's perception and trust of the transport agents, and consequently used for selection purposes or alternatively as elimination of non-acceptable transport agents. In any case, what the author claims here is not that only time and price matter, but that there is a lexicographic ordering system where other attributes enter first as acceptability filters, and that time and price criteria are applied only on those offers who passed those filters.

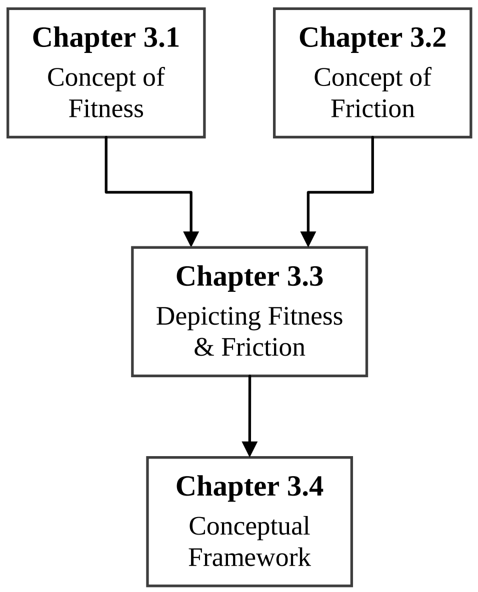
Finally, it should be noted that this reflection only applies to daily operations. Understandably, on long term or very important transport services the modal choice process is certainly the outcome of a thoroughly process where many attributes are taken into consideration.

[96] Henry Mintzberg (2001), in a different context, also claims that decision making process is often non-rational and simple.

3 CONCEPTUAL FRAMEWORK

This chapter presents the conceptual framework developed in this research work. The conceptual framework depicts the mechanisms of integration in an intermodal freight transport service. It is meant to be the instrument to help the combination companies to deploying the strategic option of intermodality.

The structure of the chapter is outlined in the following scheme (Figure 3.1).



Source: author

Figure 3.1 – Structure of Chapter 3

The first two chapters are dedicated to the theoretical presentation of the two core concepts of the conceptual framework, being: the concept of fitness in Chapter 3.1, and the concept of friction in Chapter 3.2. The Chapter 3.3 applies these concepts to the context of an intermodal transport service. Finally, in Chapter 3.4, the conceptual framework is described.

3.1 The concept of Fitness in Intermodal Freight Transport Services

3.1.1 A review of the concept of Fitness

The utilisation of the term *fitness* is not new in scientific research. In the domain of evolutionary biology, Charles Darwin[97] in his seminal work about the evolution of the species applied the term fitness and some derivatives (*fit, fitter, fittest)* to express the level of matching between the individual properties of the individuals (of a given species) and the characteristics of the environment[98].

In his research, Darwin observed more or less marked variations in the properties of the individuals of a same species (Darwin, 2007, pp 33-36). He also observed that in function of the specific characteristic of the environment, some properties could provide the individuals with a competitive advantage in their permanent competition for surviving and reproducing (Darwin, 2007, pp 50). He then claimed that those individuals whose properties were more aligned or fit with the characteristics of the environment would have higher rates of survivability, and thus higher rates of reproduction, than those whose properties were less adapted or less fit (Darwin, 2007, pp 62-68). Darwin designates this mechanism as the Natural Selection or Survival of the Fittest (Darwin, 2007, pp 60).

Ariew and Lewontin (2004, pp 348) provided a further explanation about the utilisation of the term fitness in Darwin's work. They referred that the "different individual

---

[97] Darwin, Charles (1859) "The Origin of Species by Means of Natural Selection, or The Preservation of Favoured Races in the Struggle for Life", London (United Kingdom), John Murray

[98] Environment understood as the spatial-temporal region where the species lives (Rosenberg, 1983, pp 458). It includes for example: the geographical properties of the land, the existence of other predators or competitive species, the nature of the weather, etc.

members of a species [...] *ft* into the environment to different degrees as a consequence of their variant natural properties, and those that made the best *fit* would survive and reproduce their kind better than those whose *fit* was poorer. The word *fit* (*fittest*, *fitness*) is a metaphorical extension of its everyday English meaning as the degree to which an object (the organism) matches a pattern that is pre-existent and independently determined (the environment)".

Darwin's concept of *fitness* presents some features of interest for this research work. Firstly, fitness presupposes the existence of two entities (in the case of Darwin's studies, they are the individuals and the environment)[99] (Rosenberg, 1983, pp 458). Secondly, fitness has a continuous nature[100] (Fisher, 1999, pp 35, Cohen, 1985). Thirdly, fitness has a multidimensional nature because the individuals and the environment are described in terms of their properties or characteristics (not to a single property of each one) (Ariew and Lewontin, 2004, pp 352, Rosenberg, 1983, pp 459). And, fourthly, fitness is a measure of the individuals' (and by extension the species') level of competitiveness, since the higher is the fitness of an individual, the higher is the probability of surviving and reproducing.

The utilisation of the concept of fitness was though not constrained to the domain of Natural Sciences. Recently, Richard Richards (2004) proposed the extension of the concept of fitness to the domain of Arts with a framework for evaluating the aesthetic of artwork. The author defended the relative nature of the concept of fitness by stating that "a property of an organism contributes to the fitness of that organism only relative to a

[99] It is important to mention that discoveries in the reproductive mechanisms of species and in the field of genetics, after Darwin's works, have brought new meanings to the concept of fitness (Cohen, 1985, pp 716). Currently, one meaning of the term fitness is the *reproductive fitness* that is "the probability of survival of a genotype from egg to adult" (Ariew and Lewontin, 2004, pp 353). In this interpretation the fundamental property of fitness is the individual, whereas in the *Darwinian fitness* the emphasis is placed on the relation between the individual and her environment. This interpretation denotes that fitness may either refer to the properties of a single entity or the nature of the relation of two entities. Other nomenclatures were proposed. For example: Matthen and Ariew (2002, pp 55-56) make use of the terms *vernacular fitness* and *predictive fitness* to designate the *Darwinian fitness* and *predictive fitness*, respectively. In this dissertation as it will be explained later in this chapter the author follows the Darwinian interpretation of fitness.

[100] Whether referring to the level of matching between the properties of two entities – Darwinian fitness, or whether referring to the intrinsic properties of individuals – Reproductive Fitness (Footnote 99 presents the definition on Reproductive Fitness).

functional context" (Richards, 2004, pp 265). He defined the functional context at two levels: an internal context that refers to how the properties of the individual interact among each others[101], and an external context that refers to how the properties of the individual interact with the environment (Richards, 2004, pp 265). The author then claims that "an artwork is good insofar as it is *fit* – functions well in a specified context, and a property is good insofar as it contributes to the overall fitness of the work. And like evolutionary fitness, aesthetic fitness is relative to an internal context – the correlation of parts, and an external context – those who experience and use the artwork" (Richards, 2004, pp 265).

Although not being the intension of the author of this dissertation to draw comments on this proposal, this exercise brings nevertheless some additional interesting features. Firstly, Richards emphasises the relational nature of fitness and the importance of the context in the level of fitness, when writes that "there is no value independent of, or in isolation from these contexts!" (Richards, 2004, pp 269). This feature leads to a second conclusion which is the absence of a unique and absolute value for the value of fitness, because it is function of the specific context (Richards, 2004, pp 270). And, thirdly, Richards acknowledges the multi-dimension of fitness because any artwork exhibits multiple properties and it can therefore be assessed from different perspectives - or dimensions of fitness (Richards, 2004, pp 268). Finally, it should be mentioned that no analytical tool to measure the level of fitness is proposed (neither a discussion on this matter is made). As such, Richards's concept of fitness remained essentially conceptual and qualitative.

In the domain of Social Sciences, the term fitness has identically been used for some time. In 1950, George Homans[102] published a work where he analysed the behaviour of society and the "behaviour of men in group" (Homans, 1975, pp xviii). In his work this author concluded for the existence of several elements influencing the emergence and the stability (or not) of different types of social clusters, such as: families or friends.

[101] Darwin refers that the change in some properties of an individual would result in changes in other properties, since they are all correlated (Darwin, 2007, pp 67).
[102] Homans, George (1950) "The human group", Routledge & Kegan Paul, London (United Kingdom)

One type of these elements corresponds to *factors of integration* between people (Homans, 1975, pp xix, 252). The author enumerated several factors of integration, such as: activity, sentiment, interaction and norm (Homans, 1975, pp xix, 24-48). The factors of integration have a dual nature: attraction or repulsion. In this context, *integration* can be understood as *fitness* between people.

In parallel, developments in the domain of Sciences and Social Sciences resulted in the emergence of novel research approach[103] so-called *systems thinking*, which is a philosophy of research based on the General Systems Theory formalised in 1968 by von Bertalanfy (Von Bertalanfy, 1968). Systems thinking[104] scholars defend that the fully understanding of real world complex systems[105] can only be achieved through a holistic perspective (i.e.: by studying the system as a whole and not looking to its constitutive elements[106]). Systems thinking brought a new perspective of tackling and researching organisations and organisational problems, and the vision of regarding an organisation as a complex open social system emerged (Ackoff, 1994, pp 179, Katz and Kahn, 1978, pp 17-35).

From the systems thinking perspective, an organisation is the system and its internal divisions and units are the elements. These elements are interconnected and continuously influencing each others. Therefore, the successful understanding of an organisation (and, of its problems) can be achieved by considering it as a whole (Nadler, 1993, pp 86).

This new vision provided new tools for other authors to apply the concept of fitness in a different approach than Homans had done. In the following decades authors, such as: James Seiler (Seiler, 1967), Paul Lawrence or Jay Lorsch (Lawrence and Lorsch, 1969 or Lorsch and Lawrence, 1972) embraced the systems theory and developed theories

[103] The author defines research approach as a body of theories, methods, techniques and tools.

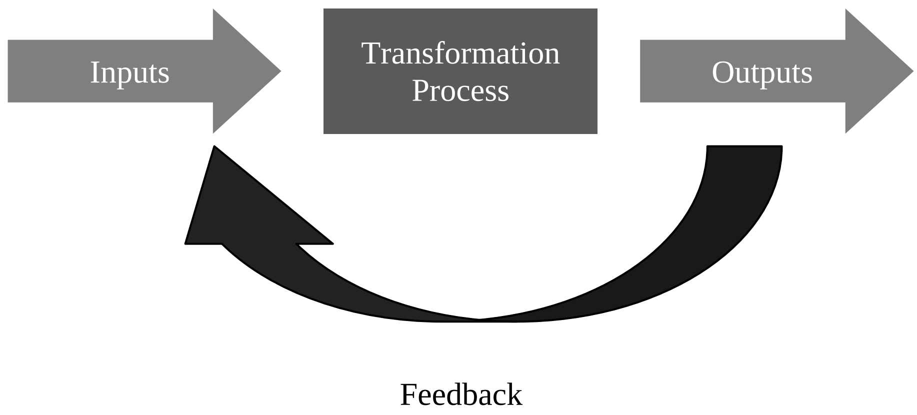
[104] A thorough review to the concept of systems thinking can be found in Richardson (1999).

[105] Ackoff (1994, pp 175) defines complex system as being a “whole consisting of two or more parts (1) each of which can affect the performance or properties of the whole, (2) none of which can have an independent effect on the whole, and (3) no subgroup of which can have an independent effect on the whole, In brief, then, a system is a whole that cannot be divided into independent parts or subgroups or parts”. The notion of complex system is further elaborated in Chapter 4.2.

[106] The point is that being a system more than the sum of the parts, the understanding of every constitutive element is not enough to understand the whole system (because the properties related with the interaction of the various parts are lost when breaking down the system).

and tools to apply the concept of fitness to organisations. These authors adopted a process[107] view of the organisation. They considered an organisation as a process that converts some set of inputs into a set of outputs, and with the capacity of evolving over time by changing or improving the inputs through the analysis of the outputs. In other words, they added a feedback interaction to the process of organisation. The following figure (Figure 3.2) presents the schematic view of a company.

With systems thinking the concept of fitness gained a holistic dimension, since it was now applied to the entire organisation, and a dynamical dimension, since it could evolve over time through the feedback loop.



Source: Oliver Wyman (2003, pp 4)

Figure 3.2 – Basic representation of the organisation

In 1975, Bowers and his colleagues (Bowers et al, 1975), using concepts of social systems theory and medical science pathology (Bowers et al, 1975, pp 391), proposed a model of organisational development. Within this context they put forth the *principle of congruence* and the *principle of predisposition.* The principle of congruence was defined as follows: “for constructive organizational change to occur, there must exist an appropriate correspondence of the treatment (action, intervention) with the internal structural and functional conditions of the organization for which change is intended. Since by definition these internal conditions pre-exist, this means that treatments must be selected, designed and varied to fit the properties of the organization” (Bowers et al, 1975, pp 393). The principle of predisposition was defined as follows: “there are certain

[107] Process is defined in detail in Chapter 2.2.

points in organization space where change will enjoy its greatest likelihood of success; these points are, at least in terms of the change strategy, boundary points, and change starts at that boundary and works inwards" (Bowers et al, 1975, pp 393-394). The authors identified four main points – *determinants of behaviour* – in an organization, being: information, skills, values and situations (Bowers et al, 1975, pp 396).

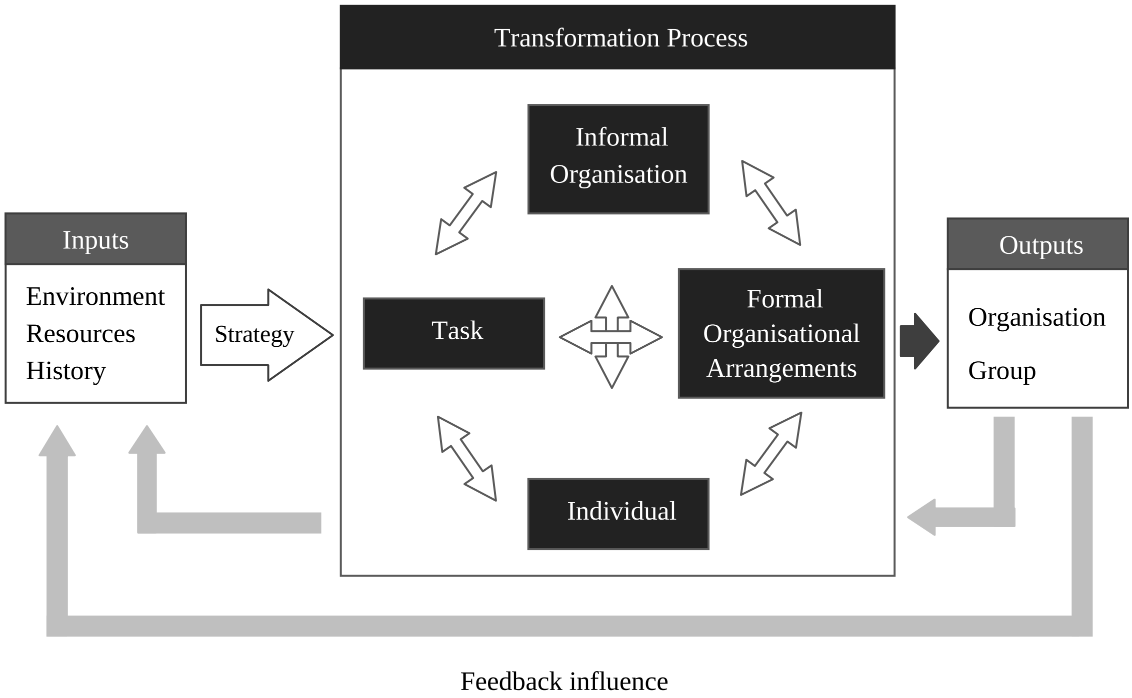
From the first principle, these authors defended that purposeful evolution depended from an adequate match – *fitness* – between the internal structure and the actions. From the second principle, they defended that purposeful change only required to intervene in some aspects of the organization (and not in all of them). These concepts will be used later in this chapter.

In 1980, David Nadler and Michael Tushman, based on the work of Bowers and his colleagues (Bowers et al, 1975), published theirs "congruence model for organisation analysis" (Nadler and Tushman, 1980). The authors used the concept of fitness to develop a model aimed to help managers to improve organisational performance (and, therefore, market's competitiveness) from within. The model is meant to be applied at the strategic level of an organisation (although, it can be easily applied to lower levels of decisions) (Nadler and Tushman, 1980, pp 45).

The authors made use of the term *congruence*, but acknowledged that it has similarities to the term *fitness*, because they define congruence "a measure of how well pairs of components fit together" (Nadler and Tushman, 1980, pp 45). The level of congruence is defined as "the degree to which the needs, demands, goals, objectives, and/or structures of one component are consistent with the needs, demands, goals, objectives, and/or structure of another component" (Nadler and Tushman, 1980, pp 45). The basic hypothesis was that "other things being equal, the greater the total degree of congruence or fitness between the various components, the more effective[108] will be the organization" (Nadler and Tushman, 1980, pp 45).

[108] The authors define effectiveness as "the degree to which actual organization outputs at individual levels are similar to the expected outputs, as specified by strategy" (Nadler and Tushman, 1980, pp 45).

The congruence model is presented in Figure 3.3, and exhibits a high degree of similarity with the conceptual view of Figure 3.2 as all of the components of the process view of the organisation are presented plus the feedback loop.



Source: Nadler and Tushman (1980, pp 47)

Figure 3.3 – Nadler and Tushman’s congruence model

These authors considered four dimensions of fitness (Nadler and Tushman, 1980, pp 46):

- *Task* – refers to how tasks and internal processes fit into the overall strategy of the organisation;
- *Individuals* – refers to the nature and characteristics of the members and employees of the organisation;
- *Formal organisational arrangements* – refers to how the internal structure of an organisation (such as: divisions, working units, hierarchical structure) fit into the overall strategy of the organisation;
- *Informal organisation* – refers to the internal culture of the organisation.

Meanwhile, Nadler and Tsuhman's congruence model has been extended to analyse the fitness of alliances of organisations (Douma et al, 2000, Douma, 1997, Niederkofler, 1991). Accordingly, the number of types of fitness increased from four to five. The fifth type corresponds to the fitness between the strategies of the organizations (of the alliance) (Figure 3.4).

Marc Douma, in his doctoral disertation (Douma, 1997), defined that "there is strategic fitness if the partners' strategies and objectives are mutually dependent and compatible, and the alliance is of strategic importance to the partners' competitive position". This author identified five factors for defining the level of strategic fitness, being (Douma, 1997, pp 21):

- Importance of the strategic alliance;
- Compatibility of strategies and objectives;
- Common vision about the market and the consequences for their own company;
- Degree of mutual dependency of the partners;
- Amount of added value for the partners and buyers.

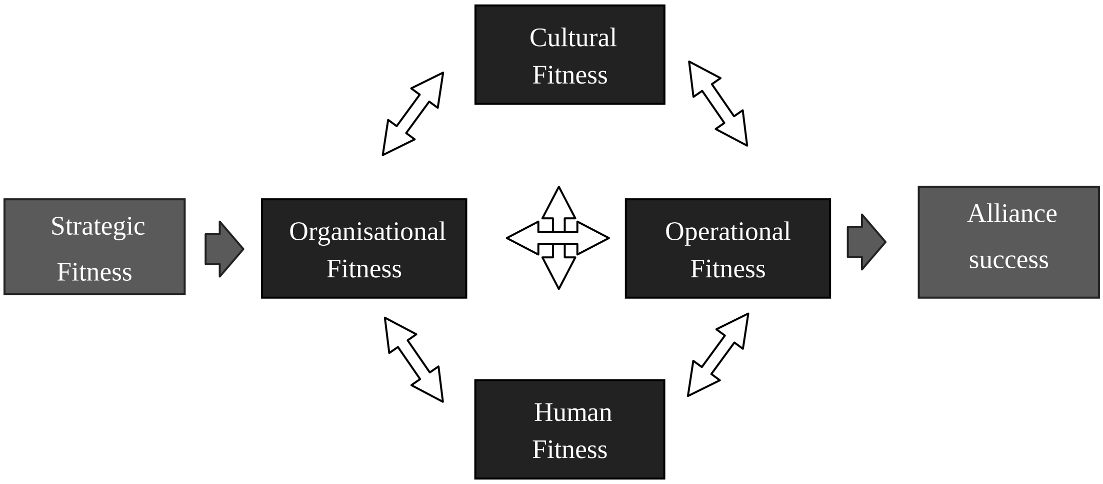
Also in the domain of Management, Michael Porter (1996) applied the term *fit* in his work on business strategy. The author[109] argues that a company can obtain a competitive advantage through either a high operational effectiveness or an adequate strategic positioning (Porter, 1996, pp 61). Yet, a competitive advantage largely based on operational effectiveness will hardly prove to be sustainable because of imitators. The point is that a company's activities are more or less easily emulated by other competitors, which will progressively lead to the erosion of its initial advantage (Porter, 1996, pp 62).

Conversely, a competitive advantage largely based on a strategic positioning will likely deliver sustainable competitive advantage because it is hardly emulated by other competitors. Three key principles sustain a company's strategic positioning: firstly, the

---

[109] This following description is naturally a simplification and superficial view about Porter's work. The purpose is however not to discuss his ideas but to frame the context of usage of the term *fit*. Porter's literature is rather vast; the interested reader is referred to one of his most well known works: Porter (1985).

development of a strategy, secondly, the choice of a market positioning and, thirdly, the creation of fit among the company's activities. A company's strategy is "the creation of a unique and valuable position, involving a different set of activities." (Porter, 1996, pp 68). And, the essence of strategy lies in either to chose to perform the activities in a different way or to perform different activities than the other market competitors (Porter, 1996, pp 64).



Source: Douma et al (2000, pp 582)

Figure 3.4 – Douma's congruence model

In parallel with its strategy, the company will also have to decide its market positioning. The various market segments tend to exhibit unique features (in terms of for example: marketing, quality, customer service, etc.), which naturally are likely to require unique set of activities often non-compatible amongst them. As such, the choice of market positioning entails to trade off the various market segment[110] (Porter, 1996, pp 68).

Finally, he then adds that a company's "competitive advantage comes from the way its activities fit and reinforce one another. Fit locks out imitators by creating a chain that is as strong as its strongest link. [Moreover,] fit drives both competitive advantage and

[110] A typical example occurs in the passenger air transport market between the Networked Companies (e.g. TAP) and the so-called Low Cost Companies (e.g.: Ryanair). The market positioning of the Networked Companies is different of the Low Cost Companies. Yet, not rarely the Networked Companies, in face of an increase competition from the Low Cost Companies, attempt to enter in their market segment (typically by lowering the fares). This is condemned to failure, as various real world examples demonstrated it. There is a considerable amount of literature dedicated to this topic like for example Morrell (2005).

sustainability” (Porter, 1996, pp 70). Porter argues that the fit is what ultimately makes unique a company’s strategic positioning because it is hardly emulated by competitors.

Porter’s concept of fit is linked to the nature of activities (to how they influence and determine each other), and to the processes (to how the activities are coordinated and sequenced). It is achieved when the activities are coordinated and when they complement one another. Moreover, fit entails to consider a company as a system of interconnected activities (with all influencing all) and not a simple collection of them. Thus, fit is fundamentally linked to the nature of the interactions among activities and not so much to their intrinsic nature (Porter, 1996, pp 70). So, fit is related with the internal properties of the company that typically are not observable or known to the outsiders.

Finally, Porter identifies three levels of fit: consistence between activities, reinforcement between activities and optimisation of effort between activities (Porter, 1996, pp 71-73). Each level denotes higher fit and “it enhances a position’s uniqueness and amplifies trade offs” (Porter, 1996, pp 71).

In summary, the basic properties of Porter’s fit are: fit refers to the relation between activities, fit is dynamical and reinforced over time, and fit promotes competitive advantage. However, the explanation of Porter presents some shortcomings as he does not explain on how, firstly, to achieve the fit between activities (he only explains the benefits accruing from fit) and, secondly, to measure the fit of a company.

This brief review on the evolution of the concept of fitness enables the drawing of some conclusions. Firstly, the concept of fitness seems to refer to the degree of matching between a pair of entities. Secondly, fitness has an inherently dynamic behaviour. Thirdly, although not being new in the domain of Social Sciences; the concept of fitness has neither been explored nor extensively applied in its lifetime. Fourthly, there seems to be a lack of metrics for measuring the fitness. Although Nadler and Tushman (1980,pp 46) state that fit can be measured, they fail in provide any kind of measuring. Douma et al (2000, pp 585) has made an attempt by doing a lexicographic visualisation of fitness. This absence may either evidence an impossibility to quantify measuring fitness or, simply, the lack of knowledge for the development of appropriate tools.

In what concerns this research work, the model with most relevance was the congruence model of Nadler and Tsuhman (and later on extended by Douma). The main reasons are now presented. First, the systems theory was the theory used to develop the congruence model. The domain of intermodal transport also presents the properties of a system and, therefore, the conditions to be researched following this theory[111]. Therefore, the congruence model can thus be applied to the study of intermodal transport. Second, the concept of fitness is multi-dimensional. There is no limit to either the quantity or the nature of factors to consider in the analysis of fitness (Nadler and Tushman have identified four dimensions, while Douma has identified five dimensions). And, third, the concept of fitness is dynamic in nature, which denotes memory and persistence over time; and it considers both internal and external factors (to the organisation). All of these properties are important in the freight transport market, as it will be proved subsequently in this chapter.

However, the concept of fitness and the congruence model exhibit some insufficiencies that preclude its immediate application in the current research work. These limitations are detailed below.

- The concept of fitness and the congruence model are applied at strategic level of planning and control[112] of either a single organisation or alliances of organisations. The deployment of intermodal freight transport services is done at tactical level.
- The concept and the model were developed for and applied in the domain of management; yet, in the case of intermodal transport other domains may influence the fitness and the performance, such as: technology, liability or economic (which by themselves introduce constrains in the domain of management).

[111] Evidences that intermodal freight transport services present properties of systems are detailed in Chapter 4.2.
[112] There are three levels of decision: strategic, tactical and operational. Their definition is provided in Footnote 44.

- Few metrics or methods have been offered to measure fitness, which poses some limitations to its applicability. Additionally, the author, to the best extent of his knowledge, was unable to find any reference or application in the domain of transport (so, there is no reference to how apply fitness to this field).
- There is no detailing in the theoretical aspects underlying the development of the concept of fitness and the congruence model. The abovementioned authors claim that the model was based in the systems theory; however they fail to explain the mechanisms linking the concept of fit and the organisation's overall performance[113].

3.1.2 Defining Fitness

The fitness is the maximum amount of performance that is possible to obtain from the integration of a set of dual systems.

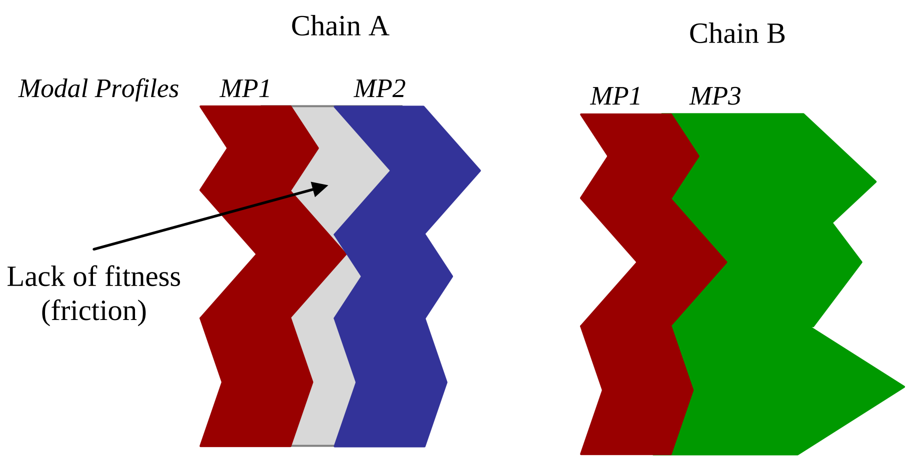
In the discussion about the performance of intermodal transport in the Chapter 2.3, the best possible in real world performance was defined as the maximum performance attainable by a set of dual systems in an intermodal freight transport service. Moreover, the difference between this performance and the performance of a multimodal transport service was designated as intermodal synergies gap (Figure 2.11). This gap represents the fitness, or in other words, the maximum increment in the performance of a multimodal freight transport service due to the integration of the dual systems.

The gap between the best possible in real world performance and the theoretical performance corresponds was designated as friction gap (Figure 2.11). The friction gap corresponds to the lack of fitness or, as it is defined in the next chapter, to the level of friction.

---

[113] It should be noted that this gap does not necessarily reflects the non-validity of the concept or the model, but simply an evidence of the precision paradox. The precision paradox may be defined as the ability to "achieve precision in prediction without any knowledge of how the predicated outcome was produced" (Dubin, 1978, pp 23). Alternatively, the authors may simply have decided to undisclose this information.

In graphical terms, the fitness is a concept that represents the degree of matching of the profiles[114] of two successive dual systems in a transport chain. The following picture presents the concept of fitness in a schematic way (Figure 3.5). Three profiles are represented: Profile 1 in red (MP1), Profile 2 in blue (MP2) and Profile 3 in green (MP3). The configuration of each profile depends of the constituent variables. The profiles are combined in two chains: Chain A (left) and Chain B (right). When Profiles 1 and 2 are brought together, it is visible that they do not match (gray region). The profiles are not compatible – this situation reflects the existence of friction that will be analysed in the following chapter. On the other hand, Profiles 1 and 3 have a perfect match. They are thus entirely compatible. Consequently the (level of) fitness of Chain B is higher than the (level of) fitness of Chain A.



Source: author

Figure 3.5 – Concept of Fitness

Other way to look the concept of fitness is through the analysis of the flows along an intermodal freight transport service. Recalling that along an intermodal transport chain, four types of flows may be identified[115], being: physical flow, informational flow, liable flow and financial flow. The fitness determines the easiness or smoothness that those flows move between dual systems. The higher is the fitness, the higher is smoothness of

[114] The profile of a dual system (or of the freight forwarder) is the set of relevant characteristics that influence the performance of the intermodal freight transport service. The characteristics are described in Chapter 3.3, during the presentation of each dimension of fitness.
[115] Chapter 2.2 describes the various flows of an intermodal freight transport service.

the flows. This means that, at operational level, the fitness refers to how seamlessly are produced the intermodal transport operations.

3.2 The concept of Friction in Intermodal Freight Transport Services

The friction represents the waste or the inefficiencies that occur in the production of an intermodal transport service. Therefore, the friction defines the limits to the integration in an intermodal freight transport service. It is inherent to the dual system and it cannot be changed by the freight forwarder. To reduce the friction changes in the dual systems (including the freight forwarder) are required, such as: change in technology, alignment of processes or compatibility of cultures. These changes may done at the various dimensions of fitness[116].

Recalling again the discussion about the performance of an intermodal transport service in the Chapter 2.3, the friction corresponds to the friction gap that is, to the difference between the theoretical performance and the best possible in real world performance. Thus, the friction of an intermodal freight transport service determines its fitness.

The knowledge of the level of friction is arguably of greater interest than the level of fitness, because it provides information on the amount of performance that it is being lost and that could be recovered. Furthermore, the knowledge about the less fit variables is fundamental to define the investment programmes to improve the performance.

The author encountered no definition in the literature to designate this kind of loss of performance. The solution was to resort to the well known physical concept of *friction*. There are various advantages in choosing this concept. Firstly, it is a well known concept in physics, with the behaviour clearly defined. Secondly, its behaviour and mechanism are rather similar to those produced by the sources of loss of performance. Thirdly, it is sufficiently generic and broad to embrace under the same umbrella all potential sources of loss of performance.

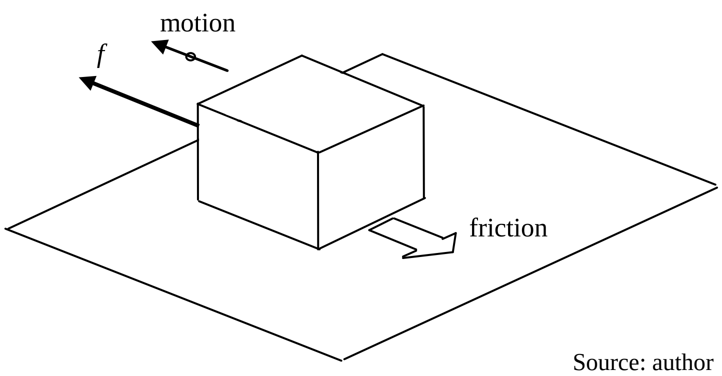
In Nature, when an object moves or attempts to move on another object, as a consequence of external forces, there is a force of resistance opposite to its (Figure 3.6).

[116] The dimensions of fitness are analysed in the following chapter.

Because surfaces are more or less rough; they contact only at few points - the peaks on the roughness. At these locations, physical and chemical interactions occur: on the one hand, the peaks of one body block the motion of the others; on the other hand, chemical attraction between molecules also introduce resistance to the movement (Serway and Jewett, 2004, p.131-133). Such resistance force is called as *force of friction* or simply *friction*. Friction arises on the surface of contact and it has the direction contrary to motion. So, friction acts in such a way of neutralising those external forces responsible for the object’s motion or attempt of motion.

Therefore, if one needs to put an object in motion, either one increases the external force (to counterbalance friction), or one reduces the friction (by for example: cleaning or polishing the surfaces). So, reducing the friction is an effective way to reduce the external force necessary to induce motion in an object.

Looking to the intermodal freight transport services, there are similarities between the physical concept of friction and the process of loss of performance. First, in nature, the friction occurs at the surface of contact of a pair of objects. The pair of objects corresponds to the pair of dual systems. The surface of contact can be considered as being the interactions between pairs of dual systems.



Source: author

Figure 3.6 – Mechanical representation of the concept friction

Second, in nature, friction results from the interactions between surfaces that have a physical and a chemical nature. In a transport chain, the friction results from incompatibilities or issues between the variables of the dual systems' profiles. Third, in nature, there is more than one type of friction. In an intermodal transport chain a similar phenomenon may be identified. The concept of fitness is dynamic and, hence, it is expectable to observe an evolution on the type of friction over time between a pair of transport agents. Fourth, in nature, friction counterbalances or reduces the force that attempts to move or keep the object in motion. In an intermodal freight transport service, the friction creates waste and inefficiencies.

Concluding, there is a considerably degree of similarity between the concept of friction in the nature and the mechanisms responsible for the loss of performance in an intermodal transport chain. Thus, the author is confident about the utilisation of the concept of friction.

3.3 Depicting Fitness and Friction

3.3.1 Types of Fitness

The inherent multidimensionality of the concept of fitness is laid down in its definition. The fitness was defined as the degree of matching of the profiles of two dual systems. Since the profile contains a set of relevant variables, then we may conclude for the existence of multiple types of fitness.

The question now is how to assess those type of fitness. In Chapter 2.2, the intermodal transport was represented through a set of four types of flows, being: physical flow, logical flow, liability flow and financial flow. Again, the notion of flows were used in Chapter 3.1 and Chapter 3.2 to present the concepts of fitness and friction. It was considered that is the higher the are smoothness of the flows, the higher is the fitness (and the lower is the friction). Thus, using the flows as a departure base, we may conclude that there are at least four types of fitness, each one corresponding to a type of flow.

However, the author found insufficient these four types. The reason is that the four flows only occur during the production of an intermodal freight transport service, which implicitly entails that the various transport agents are willing to participate in such transport solution. Yet, this may not be the case. Indeed, an important factor in the production of an intermodal freight transport service is linked to the commitment and predisposition of the transport agents to engage in intermodal transport operations with others. The point here is that transport agents that are direct competitors may be called to cooperate in an intermodal transport chain. Such situation may give raise to some resistance in their participation[117], which can be felt at several levels: resistance in adapting procedures, resistance in overcoming cultural differences or resistance in solving liability issues. Although a severe resistance may preclude the assemblage of the intermodal freight transport service, lower levels of resistance may lead to the production of the service but it will inevitably introduce friction and, thus, losses of performance. For this reason a fifth dimension of fitness was introduce to represent the nature of the relationship between transport agents, so-called: strategic.

Thus, five dimensions of fitness have been identified (Figure 3.7), being: physical, logical, liability, financial and strategic. The first four flows correspond to the four flows in the process of production of an intermodal freight transport service. The fifth flow corresponds to the nature of the business relationships between transport agents.

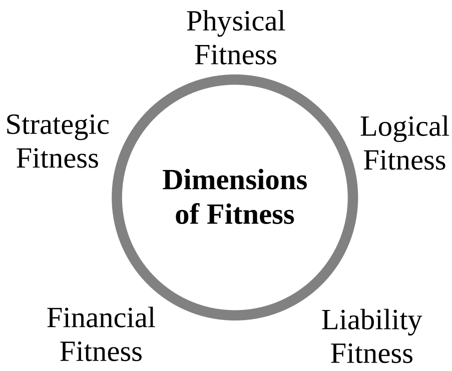
3.3.1.1 Physical Fitness

Recalling the description of the process of an intermodal freight transport service in Chapter 2.2, the physical dimension of fitness refers to the physical flow. Physical friction concerns the waste and resistances that occur during the process of transfer (transhipment) of the freight. Thus, physical fitness is related to the physical interoperability of the modes of transport.

Three factors were found to influence the physical fitness (Figure 3.8). The first factor is related with the *type of containerisation* of the goods. The transport of goods inside (or onto) a container (or pallet) promotes the physical interoperability. This type refers to the compatibility of the containers in the interconnecting modes. The second factor is related with the *type of modes of transport*. The level of interoperability differs between pairs of modes (for example: the level of interoperability between a ship and truck is higher than a ship and an aircraft). The third factor is related with the *type of handling*

[117] This resistance is different from the transport agent's commitment towards intermodality. The resistance is determined by the relation of a pair of transport. The commitment is determined by the agent's own strategy (regardless the others). The commitment determines if the agent participates in intermodal freight transport services; whereas the resistance determine the nature of the business relationship between agents during the production of the intermodal freight transport service.

equipment. The utilisation of non-adequate equipment for handling the goods or the containers may introduce considerable friction in the transfer process.



Source: author

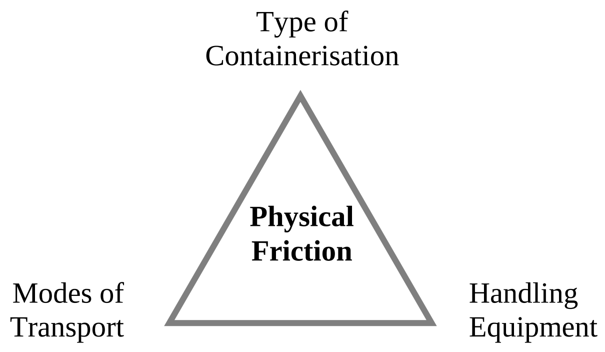
Figure 3.7 – Dimensions of fitness

The choice of the physical fitness resulted firstly from the existence of a relevant stream of research in the domain of intermodality concerning precisely the improvement of transhipment operations (Bontekoning, 2004, pp 8, 14-22, Keller, 2004, pp 43-44, CO-ACT, 2003a, pp 9, TNO INRO, 1999, pp 61). Secondly, from the author's observation of the operations at the cargo terminal in the airport of Oporto. In this airport, cargo arrived in different loading conditions and in different modes of transport, which visibly influenced the transhipment operations.

3.3.1.2 Logical fitness

Recalling the description of the process of an intermodal freight transport service, the logical dimension of fitness refers to the logical flow. Logical friction appears when there are difficulties in the communication between the agents. Thus, logical fitness is related to the compatibility of the communication systems of the agents.

Communication occurs at two levels: physical and virtual. Physical communication refers to the documents and paperwork that accompanies the goods from origin to destination. The physical channel is nowadays completely standardised. There is specific legislation for each mode of transport that defines the documents. The logical friction in this sense refers to some absence (for example: lost during transport, not issued, incomplete information, etc), an error of interpretation, an error in filling in the documents or, even, a deterioration of the documents (due to, for example: bar weather or non-careful manipulation). Since the documentation is required by law, any document missing may result in penalties (like for example: delays or monetary penalties at the customs).



Source: author

Figure 3.8 – Factors determining the physical friction

The virtual communication refers to the information that is transmitted by automatic means. It has suffered major developments over the past decades, with the development of the information and communication technologies and the continuous reduction of both technology and communications' costs. A key advantage of the virtual communication is to introduce visibility in the production of the transport service. This visibility brings important benefits. Firstly, it allows the freight forwarder to track and trace the goods (that is, to know the location of the goods), which allows for an early detection of delays or detours. Upon an early detection of a delay, the freight forwarder can intervene to minimise it. Additionally, it allows the shipper to know where her goods are, which provides confidence and trust on the transport service. Also, it can be helpful in case of dispute between transport agents.

The logical friction depends of the communication channels between the agents. Examples of communication channels include: telephone, fax or e-mail. The better is the type of communication channel (in terms reliability or time of transfer), the lower will be the losses derived from either a bad interpretation or an absence of information. Additionally, the communications network also acts to integrate the “formal and informal networks within the [freight] forwarder’s systems architecture” (Button and

Stough, 2000, pp 298). Communication network promotes the integration and cohesion amongst the companies' employees, reducing the amount of problems when working together.

Two situations should be considered when dealing with lack of (virtual) logical fitness. The first situation occurs when the agents have some sort of equipment of communication but they are incompatible, rendering communication not viable. The rapid pace of technological development of the last decades resulted in the generalisation of technological equipments. Progressively, agents have been using technology for improving their performance (with success). However, these solutions are often non-compatible[118]. A second situation refers to those situations where the agents simply have basic communication equipment (such as: telephone or fax). This may result from either a lack of investment capacity or because the agents do not see reasons for new investments[119]. In any case, the outcome is equal: more or less difficulties of communication between agents. Consequently, the exchange of information become less efficient, takes more time and, often, requires human intervention.

The identification of the logical fitness resulted essentially from the observation of real world, although some literature also acknowledges this issue (for example: Button and Stough, 2000).

3.3.1.3 Liability Fitness

Recalling the description of the process of an intermodal freight transport service, the liable dimension of fitness refers to the liability flow. Liable friction refers to problems arising from the liability transfer between agents. Liable fitness occurs when in case of any non-compliance there are no liability issues and any indemnity is duly paid.

This dimension of fitness shows a latent behaviour, since it only becomes active in case of a non-compliance of the transport service, like for example: damage or destruction of the cargo or delay.

---

[118] In the air transport sector this was overcame by the imposition (by IATA and ICAO) of protocols and standards of communication. Yet, the same has not occurred in the other modes of transport.

[119] Button and Stough (2000, pp 302-303) present an interesting example of a Washington based (United States) freight forwarder.

Liability is conveniently identified in the literature as being a key barrier to the production of intermodal freight transport services (Keller, 2004, pp 43-44, ZLU et al, 1993, pp 56-58, Slack, 1991, pp 149-152). The author also found similar evidences from the real world. A reason for such flaw lies in the lack of an international convention regulating intermodal transport. As such, nowadays, for every legal purposes an intermodal transport is nothing more than a set of independent single modal transports. In this sense, the payment of the indemnities depends upon the unequivocal definition of the responsible which often is not simple or even possible[120] (Asariotis, 1999, pp 46, 1998, pp 4).

The point is that each mode of transport is regulated by different regulations (and, in case of international transport, by different conventions). Each convention foresees different rules and amounts of compensation.

3.3.1.4 Financial Fitness

Recalling the description of the process of an intermodal freight transport service, the financial dimension of fitness refers to the financial flow. Financial friction occurs when payments are not due in time or in accordance with the contracts. Financial fitness occurs when all payments are due in time and in accordance with the contracts.

The financial friction is related with either delays in the payments or incorrectness in the amounts. Some interviewees pointed out, particularly in times of economic recession, that occasionally freight forwarders either allege financial difficulties to not respect the deadlines of payment; or, alternatively, only make partial payments to transport agents.

This dimension of fitness was identified in the interviews with Mr. Mário Sousa, Mr. Alberto Silveira, Mr. Luís Monteiro. No literature was found making reference to this kind of fitness.

---

[120] As an example: a key reason for the failure of the SeaRoad case study were major problems concerning liability. Most of the accidents occurred in the sea, but because the cargo was loaded in road-trailer the transport agents and the insurance companies did not agree in the responsible (the road or the sea transport agent) nor in the convention to apply (the sea or road). This situation created delays in the payment of indemnities with the associated negative image. More information in Baindur (2010).

3.3.1.5 Strategic Fitness

The strategic dimension of fitness refers to the nature of the business relation between the transport agents.

A caveat is important at this moment. An influential factor of the strategic fitness is the transport agent's strategy towards intermodality. If there is strategic interest in intermodality, than actions at all levels of decisions (strategic, tactical and operational) will be taken to improve the business relations and the operations of the intermodal freight transport services. Conversely, if there is no strategic interest in intermodality than most likely the transport agent will scarcely participate in intermodal freight transport services. Yet, the strategic fitness is not defined by the transport agent's strategy towards intermodality. Instead, the strategic fitness is function of the type of the business relationships between the transport agents.

As already mentioned, in an intermodal freight transport service the transport agents are called to cooperate. The nature of the cooperation defines the strategic fitness. Yet, these same agents compete on a daily basis in the freight transport market and, as such, they may not so be willing to cooperate. This resistance to cooperation defines the strategic friction. The strategic friction may be strong enough to dictate the failure of intermodal freight transport services[121].

The strategic fitness is influenced by diverse factors located at the various levels of decision. At strategic level, it embraces for example: the establishment and nature of commercial agreements, the alignment of processes or the investment in interoperable equipment. At tactical level, it embraces for example the coordination of schedules or the agreement of prices. At operational level, it embraces for example the nature of the relationships between the employees[122].

---

[121] Two examples. First, another cause pointed out for the failure of the SeaRoad Case Study was the lack of commitment of freight forwarders. Second, in GLS case study, there was an initial low commitment from the railway operator. In order to overcome this problem, the freight forwarder allocated extra resources to double check the documentation and containers actually transported, and to manage the relationships with this agent.

[122] The production of an intermodal transport chain entails some sort of contact between employees of the agents. As such, the informal web of interactions does play an important role in the production of transport service. The actual importance of this kind of networks is visible in multiple circumstances. For example, in special situations (e.g.: incomplete information, delays or special requirements) the employees of an agent may resort to the employees of the other.

Like the previous one, this fitness also exhibits latent behaviour because it only emergences in particular situations.

Finally, it should be mentioned that the strategic dimension of fitness influences the other dimensions of fitness (for example: a high commitment towards intermodality may lead transport agents in acquire interoperable equipment).

3.3.2 Tiers of Friction

From the previous explanation the latent behaviour of fitness, and thus friction, became apparent. The latent behaviour refers to the fact that in certain situations some sources of friction appear; while in others, they remain non-active with no influence in the overall performance of the transport service. If not appropriately evaluated, such latency may induce in error the evaluation of the fitness, because an apparently fit intermodal freight transport service may turn out to be not fit, if the latent dimensions are not-fit and have never surfaced.

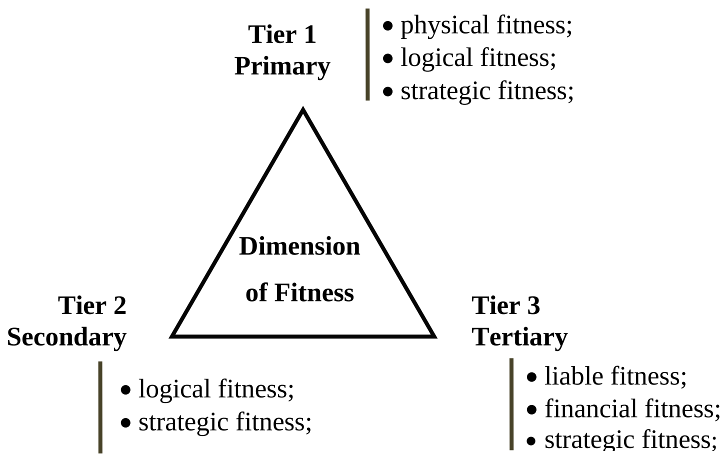
The author concluded for the existence of three tiers of friction, which corresponds at two levels of latent behaviour. Figure 3.9 presents the three tiers of friction along with the dimensions of fitness that are influenced.

The three tiers of friction are:

- *Primary tier* - embraces the frictions that occur during the production of the transport service. It is the first type of friction to emerge.
- *Secondary tier* - embraces two types:
    - Type one - corresponds to the friction that reduces the ability to perceive a non-compliance during the production of the transport service.
    - Type two - corresponds to the friction that reduces the ability to recover from a non-compliance. Even if the non-compliance is detected, the existence of barriers (frictions) may preclude the attempt of recuperation.

One situation that the author had the opportunity to observe at the airport of Oporto was related with the transport of dangerous goods. The transport of dangerous goods in aircrafts is subjected to specific regulation. Often, the road based transport agents requested for help to the handling agent for preparing the packages and documentation. Other situation, also observed at the airport of Oporto was related with delays with the customs clearance. Ohe freight forwarder often warned the handling agent for a delay (but assuring the documents would be released in time); if the handling agent trusted her then it started the processes of containerising the goods.

- *Tertiary tier* - corresponds to barriers that emerge after the production of the transport service, but that prevent it from ending. Two types of friction were identified:
    - Type one - corresponds to the financial friction.
    - Type two - corresponds to the liability friction. It emerges in case of any non-compliance of the initial requirements and if the agents do not agree on how to solve it.



Source: author

Figure 3.9 – Tiers of fitness

The primary tier of friction is a potential source for the inducing a non-compliance in the production of the intermodal freight transport service. The secondary tier is a potential source for the occurrence of difficulties in the resolution of that non-compliance, either because it makes difficult its detection (Type One) or because it makes difficult to devise a solution (Type Two). The tertiary tier may surfaces after the completion of the physical transport, if either one or more transport agents do not proceed with the payments (Type One), or, in case of a non-compliance, there is no agreement about the liable agent (Type Two).

Finally, both primary and secondary tiers occur during the Sub-process 2 (Figure 2.8), while the tertiary tier may occur after the completion of Sub-process 2.

Table 3.1 presents the influence of the tiers of friction in the dimension of fitness. The table evidences that some dimensions of fitness are only influenced by one tier of friction; whereas others are influenced by several. A given source of friction may exist and a given dimension of fitness may be present in more than one tier (like for example: the logical fitness).

Table 3.1 – Influence of dimension of friction in the dimensions of fitness

Dimensions of Fitness	**Tiers of Friction**
Physical	Primary
Logical	Primary Secondary
Liable	Tertiary
Financial	Tertiary
Relational	Primary Secondary Tertiary

3.4 The Conceptual Framework

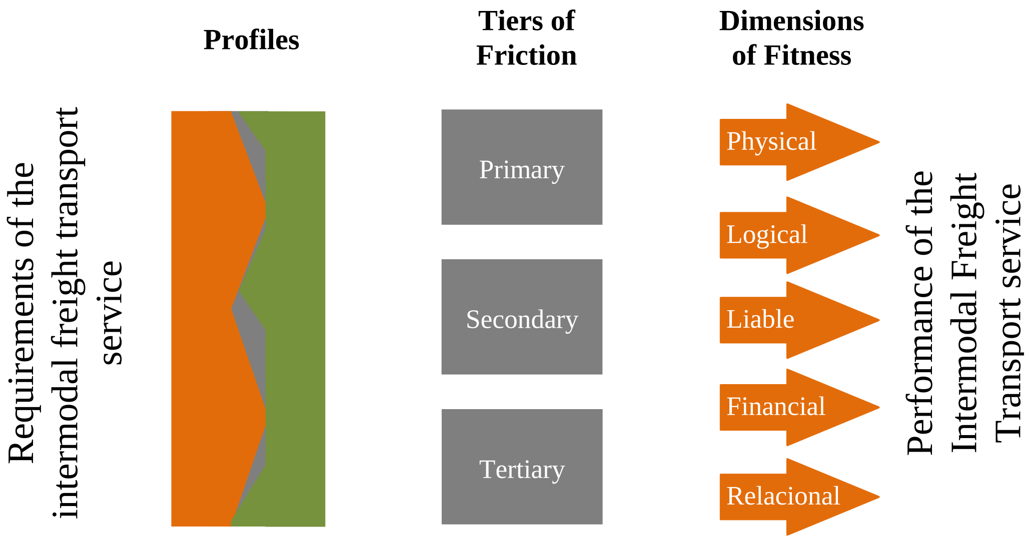
The conceptual framework is presented in Figure 3.10. The framework provides an interpretation of the mechanisms of integration in an intermodal freight transport service. A possible way 'to read' it is as follows: the requirements of the intermodal freight transport service (which are defined by the freight forwarder elaborated on the demands of the shipper) influence the relevance of the variables of the profiles[123] of the dual systems (and of the freight forwarder). Any eventual mismatch between the profiles, in one or more variables, will originate friction, in one or more tiers, resulting in friction, in one or more dimensions. Ultimately, the friction results in losses of performance.

The framework is made of five building blocks:

1. Building block one: "Requirements of the intermodal freight transport service" determines the influence of the variables of the profiles (Chapter 2.4);
2. Building block two: "Profiles" determines the level of fitness between the pairs of dual systems (Chapter 3.1.2);

[123] The profile of a dual system (or of the freight forwarder) is the set of relevant characteristics that influence the performance of the intermodal freight transport service. More information in Footnote 114.

3. Building block three: "Tiers of Friction" determines the nature of the friction of the intermodal freight transport service (Chapter 3.3.2);
4. Building block four: "Dimensions of Fitness" determines the nature of the fitness of the intermodal freight transport service (Chapter 3.3.1);
5. Building block five: "Performance of the Intermodal Transport Service" defines the performance (Chapter 2.3).



Source: author

Figure 3.10 – Conceptual Framework

From the Dubin's (1978) frame of reference of a theory presented in Chapter 1.5, we concluded that there are four basic properties that define a theoretical model, namely: variables, laws of interaction, boundaries and states. The basic properties of the conceptual framework are as follows. The variables are:

- Requirements of the intermodal freight transport service;
- Variables of the profiles;
- Performance of the intermodal freight transport service.

The basic laws of interaction are:

- Integration of the intermodal freight transport service is determined by the minimum level of fitness between the profiles of the dual systems and of the freight forwarder;

- There are five dimensions of fitness, being: physical, logical, liable, financial and strategic;
- The dimensions of fitness define the variables of the dual systems' (and freight forwarder's) profiles;
- The shipper's requirements influence the relevance of the profiles' variables and, ultimately, the level of fitness;
- Lack of fitness between the variables of the profiles originates friction;
- Friction provokes losses in the production of the intermodal freight transport service;
- Friction may occur in different moments of the production and along one or more dimensions of fitness.

The boundaries, or scope, is the intermodal freight transport service. In particular, this conceptual framework is meant for one pair of dual systems (or for the pair: dual system and freight forwarder). As such, the conceptual framework needs to be replicated for each pair of the intermodal freight transport service.

Finally, in what concerns the state, two may be considered:

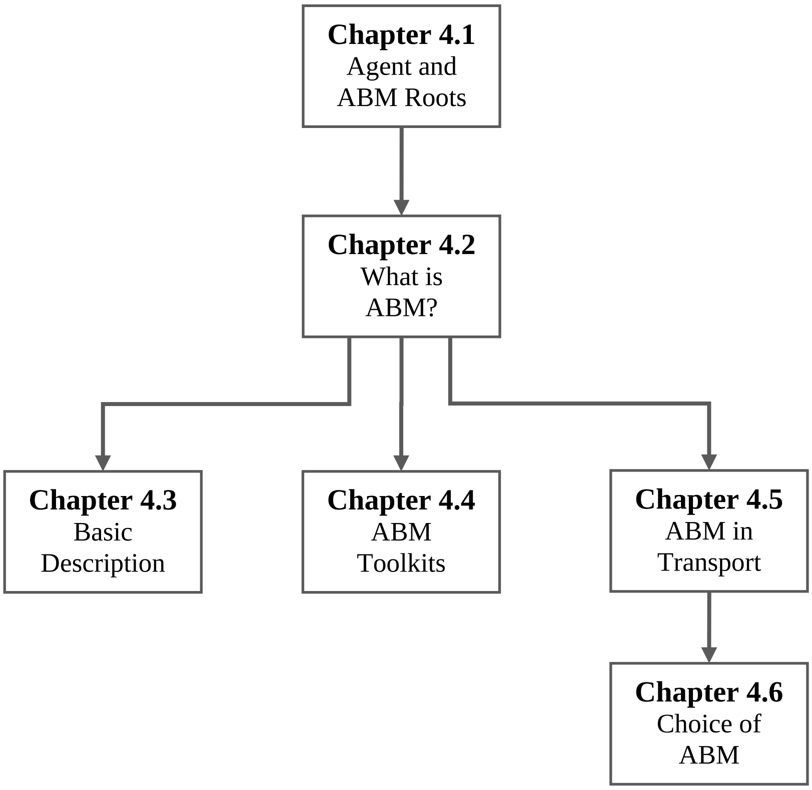
- No friction between the profiles. This state represents the maximum level of fitness of the pair of dual systems (or between the dual system and the freight forwarder);
- Existence of friction between the profiles. In this state, the level of fitness of the pairs of dual systems (or between the dual systems and the freight forwarder) is not the maximum.

4 AGENT BASED MODELLING

The purpose of this chapter is to briefly introduce the modelling framework - Agent Based Modelling (ABM) - deployed in this doctoral research. The chapter is structured into six chapters (Figure 4.1). The first three are essentially theoretical, covering different topics, namely: the origins of the concept of Agent and ABM (Chapter 4.1), the concept of ABM (Chapter 4.2) and the constitutive parts of an agent based model (Chapter 4.3). The following one, Chapter 4.4, provides an overview of the main available software toolkits to develop agent based models. The Chapter 4.5 reviews the literature dedicated to the utilisation of the ABM in the context of transport research. Finally, Chapter 4.6 presents the reasons of the choice of ABM in this doctoral research.

4.1 Agent and ABM's roots

ABM was originally developed within the frame of complexity theory. Complexity theory studies Complex Adaptive System (CAS). The definition of what is a CAS, or what distinguishes a CAS from anything else is still ground for discussion within the research community (Gell-Mann, 1994, pp 17). Bearing this in mind, we will introduce CAS by defining every concept on its name: system, complex and adaptive.



Source: author

Figure 4.1 - Structure of Chapter 4

The notion of *system* can be traced back to the pioneer work of Lotka in 1925, although, the concept would only be formalised in 1968 by the hands of Von Bertalanfy under the General Systems Theory[124]. Von Bertalanfy (1968, pp 56) defined *system* as "a set of elements standing in interrelations. Interrelation means that elements, *p*, stand in relations, *R*, so that the behaviour of an element *p* in *R* is different from its behaviour in another set of relations *R'*. If the behaviours in *R* and *R'* are not different, there is no interaction, and the elements behave independently with respect to the relations *R* and *R'*". From here some conclusions may be drawn. Firstly, a same entity may belong to more than one system, depending upon the type of relations to be considered. Secondly, systems are ephemera, in the sense they depend on the existence of entities to exist (if entities cease existing or exit, the system fades out). Thirdly, since both the entities and the properties (supporting the relations amongst entities) can be of any nature, so can be

[124] For an historical review on the concepts of system and general systems theory, the interested reader is referred to Macário (2005, pp 45-61).

a *system*. Examples include: biological, economic, technological, organisational or philosophical.

The notion of *complexity* is directly linked to the notion of emergence[125]. Complexity occurs when system's individuals "interfere, or cooperate, or compete" (Hoffman and Riley Jr, 2002, pp 319), and are not simply related by cause-and-effect linkages (as in many mechanical systems). In this sense, complexity refers to synergies and dependences among agents that create webs of influences that go beyond the scope of their direct interactions. Simon (1996, pp 183-184) writes that in a complex system "the whole is more than the sum of the parts in the weak but important paradigmatic sense that, given the properties of the parts and the laws of interaction it is not a trivial matter to infer the properties of the whole". A complex system is therefore a system that exhibits behaviours (and properties) that would not be achievable through the simple sum of its constitutive parts. In such systems, the relevance of an individual is higher than what is personalised by herself (Miller and Page, 2007, pp 9) and thus by removing individuals the system could be seriously affected. Complex systems are thus inherently nonlinear.

However, traditional methods are by nature linear assuming that a system's behaviour (or property) arises from the mere combination of each constitutive part's behaviour (or property) (Hoffman and Riley Jr, 2002, pp 313, Holland, 1993, pp 184). These methods reduce a problem into its constitutive parts and study each part individually. The purpose is to reduce the level of difficulty. Later on, the individual findings are re-assembled in order to get the answer. Such approach would be unsuitable on a CAS since the isolation of each component would lead to the destruction of the system itself. Miller and Page (2007, pp 10) write that "the ability to collect and pin to a board all of the insects that live in the garden does little to lend insight into the ecosystems contained therein".

Finally, the concept of *adaptive* refers to the "process whereby a [system's] structure is progressively modified to give better performance in its environment" (Holland, 1993, pp xiii). A CAS is capable of adapting to new stimuli and to changes in the

[125] Definition of emergence is presented in Chapter 4.2.

environment, either through self-organisation or reorganisation of their parts (North and Macal, 2007, pp 45). Adaptation capability may be felt at various levels on a CAS, ranging from the system itself down to an element. It should be noted however that adaptation does not necessarily lead to optimisation. It simply denotes the system is able to change to meet the (new) minimum requirements (or, in case of competition, is better to adapt than its rival systems) (Miller and Page, 2007, pp 81).

In terms of the main properties of a CAS, Miller and Page (2007, pp 233) have recently recognised that there is still no definitive knowledge on this matter. Nonetheless, diverse authors have presented their thought. Holland's list provides a starting point (Holland, 1993, pp 184-185), being:

- All CAS involve a large number of parts undergoing a kaleidoscopic array of nonlinear interactions;
- The aggregate behaviour often feeds back to the individual parts, modifying their behaviour;
- The interactions evolve over time, as the parts adapt in attempt to survive in the environment provided by the other parts;
- In seeking to anticipate to changing circumstance, the parts develop "rules" (models) that anticipate the consequences of responses.

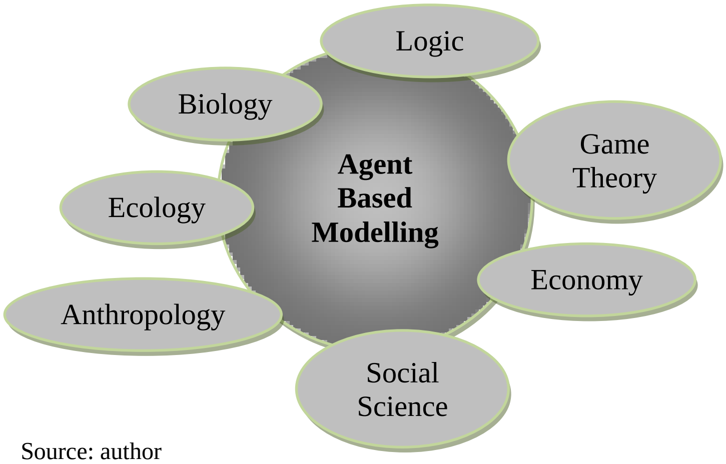
Pascale (1999, pp 84) considers that a CAS exhibits four main properties, being:

- CAS comprises many agents acting in parallel, forming building blocks, and it is not hierarchically controlled;
- CAS continuously shuffles those building blocks and generates multiple levels of organisation and structure;
- CAS is subject to the second law of thermodynamics, exhibiting entropy and winding down over time unless replenished with energy;
- CAS exhibits a capability for pattern recognition and employs this to anticipate the future and to recognise the anticipation of seasonal change.

Looking to these properties, we may conclude that complex adaptive systems are not restricted of particular domain or sub set of the real world. And, indeed CAS have been identified in a wide array of domains (Cowan et al, 1994, Pascale, 1999, pp 85), such as:

biology, ecology, astrophysics, physics, archaeology, anthropology, botany, social science or economy.

ABM was initially developed to study the laws and principles that hold in complex adaptive systems, namely: emergence, self-adaptation and self-organisation. On its genesis lie therefore some of the concepts, principles and beliefs found on the disciplines object of CAS science, as well as techniques and methods of these very disciplines, such as: computational theory, game theory, or logic (Figure 4.2).



Source: author

Figure 4.2 - ABM's influences

4.2 What is ABM?

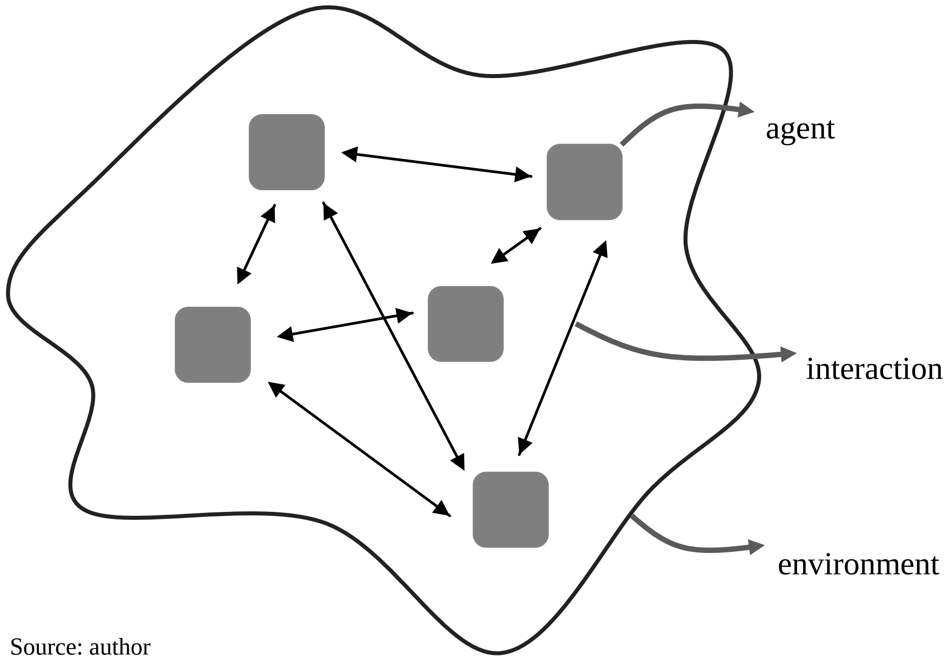
4.2.1 Definition

ABM[126] is more a conceptual mindset than a technique or tool. ABM follows a bottom up approach to understanding real world systems; in this sense, it describes a system by

[126] A caveat is required to mention that there are various terms (and respective acronyms) in use in the literature to what (for all intent and purpose) is essentially ABM, such as: Agent Based Computational Modelling (ABMC), Agent Based Social Simulation (ABSS), Agent Based Computation Simulation (ABCS), Agent Based Modelling and Simulation (ABMS) or Multi Agent Systems (MAS).

In particular MAS has received a lot of attention over the past couple of decades, mainly owing to the advent of Internet. MAS was originated within Artificial Intelligence, to explore the advantage of "massive open distributed systems – such as the Internet" (Wooldridge, 2006, pp xi). There is a vast literature on the subject, and the interested reader is referred to: Bradshaw (1997), Nwana (1996), or Wooldridge (2006).

looking to its constitutive parts (Bonabeau, 2002, pp 7280). It is therefore a micro-simulation conceptual tool for the study of real word system that re-creates, in virtual environment, their essential properties and behaviours. This tool considers that a system is made of a set of entities – *agents* – that *interact* amongst themselves and with an *environment* that supports their very existence (Figure 4.3). The concept of *agent* is the most relevant in ABM. This concept will be detailed later in this chapter, so for the time being is suffice to say that an agent is an autonomous, behavioural and social entity. The system's overall properties and behaviours result from the agents' behaviours and dynamical interactions, which in turn are the consequence of agents either pursing their own goals or reacting to some external stimuli.



Source: author

Figure 4.3 – Conceptual view an agent based model

4.2.2 Scope and conditions of applicability

Over the past decades ABM has been gaining popularity in many domains of research, such as: transportation and traffic systems (Davidsson et al, 2005), animal societies (van der Vaart and Verbrugge, 2008, Grefenstette, 1992), physiological systems (Jager, 2000), social systems (Conte et al, 1998), organisations (Clippinger III, 1999), economic systems (Tesfatsion and Judd, 2006), ecological systems (Janssen and

Ostrom, 2006), physical systems or robotic systems (Reis, 2003), archaeological reconstruction (Brantingham, 2003), biology (Vodovotz et al, 2009), patterns of diffusion (Helbing, 2000) or political sciences (Axelrod, 1997). Applications range from simple academic exercises up to large scale commercial solutions (Castle and Crooks, 2006, pp 41). ABM is primarily used to make analysis and to lesser extent to make predictions and verifications (Davidsson et al, 2007).

North and Macal (2007, pp 93) identified a set of conditions that the real world phenomenon must exhibit to be modelled with ABM:

- When the problem has a natural representation consisting of interacting agents or entities (Weiss, 1999, pp 82), or;
- When agents or entities have a limited range of action[127], or;
- When agents have degrees of freedom to decide on their own reactions (Economist, 2009), or;
- When there are decisions and behaviours that can be defined discretely, that is, with well-defined boundaries, or;
- When decisions are taken locally by individual entities and are not centralised in a single entity[128] (Dannegger and Dorer, 2004, pp 399, Weiss, 1999, pp 82), or;
- When the population is heterogeneous and it makes no sense to consider average (or aggregate) behaviours or properties[129] (Bonabeau, 2002, pp 7287), or;
- When the interactions between agents are complex, nonlinear or discrete (Bonabeau, 2002, pp 7287), or;
- When it is important that agents adapt and change their behaviour (Economist, 2009), or;

[127] This means that, on the one hand, they can only impact surrounding agents and, on the other hand, they have partial knowledge on the real world phenomenon (Wooldridge, 2006, pp 16).

[128] This refers to the notion of decentralised systems, also, referred (or known) as swarming (Shucker, 2008, pp 1405). A system is decentralised when its properties and behaviour (and thus path of development) is the outcome of the individual's decisions (and not from a single entity). A typical example of decentralised system (or swarm) is the flocks of birds. The flocks exhibit complex behaviour although no bird being responsible for it.

[129] For example, people's behaviour depends upon their age, experience, perceptions, goals, etc. Moreover, people does not always behave in rational manner (for example, in extreme situations, such as: life threatening situations) (Economist, 2009).

- When it is important that agents learn and engage in dynamics strategic behaviour (Economist, 2009), or;
- When it is important that agents have dynamic relationships with other agents and agent relationships form and dissolve, or;
- When it is important that agents form organisations, and adaptation and learning are important at the organisation level, or;
- When it is important that agents have a spatial component to their behaviour and interactions (Economist, 2009), or;
- When the past may be a poor predictor of the future, or;
- When scaling up is important, and scaling up consists of adding more agents and agent interactions, or;
- When the process of structural changes need to be a result of the model, rather than an input to the model.

4.2.3 Advantages

Bonabeau (2002, pp 7280) pointed out several advantages of ABM. One of them was the ease of implementation. Indeed, once apprehended the basic concepts, ABM does not offer main difficulties. Other advantages included: to capture emergent phenomena, to provide a natural description of a system, and to be flexible. These advantages are detailed bellow.

ABM captures emergent phenomena

Emergent phenomena refer to behaviours that are observable at system's level but cannot be traced back to agents' levels (Miller and Page, 2007, pp 46, Bonabeau, 2002, pp 7280). North and Macal (2007, pp 276) define emergent behaviour as "system outcomes that are more complicated than the simple sum of the constituent parts". An emergent phenomenon thus exhibits properties that are decoupled from the properties of the parts[130]. Emergence is an inherent property of systems.

[130] An interesting example, albeit heterodox, of emerging behaviour is a photograph (or image). If we look directly into any individual pixel (or dot) on a picture, we can retrieve no relevant information on the overall picture, but, as soon as, our attention moves from the pixel (or dot) to the entire picture (set of pixels or dots) the correspondent image becomes visible (emerges). A more recurrent example of emergence is a flock. Flocks, for example of birds, may exhibit complex behaviour (namely: cohesion,

Complex behaviour also stems from, firstly, the agents' latent behaviours, which are triggered only when special conditions are met (and that cannot be foreseen at the onset); secondly, the learning processes and feedback interactions that makes agents behaving differently in similar conditions (as they have learnt from previous experiences); or, thirdly, parallel actions with cumulative or reductive effects that makes unpredictable the final outcome.

Capturing a system's internal dynamics and non-linearities is precisely a key problem in the study of real-world problems (Miller and Page, 2007, pp 83). Yet, ABM eases the burden of modelling complex behaviours or the real world dynamics because it does not require their formal description. Instead, it only requires modelling the individuals' behaviours (Dannegger and Dorer, 2004, pp 399, Axtell, 2000, pp 3). The real world phenomenon's behaviour is then observed during run time.

ABM provides a natural description of a system

Firstly, in an ABM what is modelled are the agents' behaviours or activities, thus no previous knowledge on the system's properties and dynamics, nor, system's parts' latent behaviours and non-linearities are required (Dannegger and Dorer, 2004, pp 399, Miller and Page, 2007, pp 80). This is in contrast with some traditional modelling tools that require high level of detail on the system's underlying processes. Often such detail is not possible and modellers are compelled to do simplifications or assumption on the real world system' structure. Secondly, ABM makes modelling process more intuitive, because it essentially consists in to identify and to describe the system's parts, in terms of: what do they do?, how do they do it?, how do they communicate?, or what are their goals?.

ABM is flexible

ABM is flexible in the sense that it can incorporate any type of agent's behaviours or quantity and any kind of randomness in events or behaviours, provided availability of

---

pattern or direction). However, this behaviour is not observable looking into each birds in an isolated manner, but instead when the group (flock) is studied as a single entity. In both examples the whole (photograph, in the former, and flock, in the latter) contains information or exhibits behaviour that existent in no individual (pixel and bird, respectively). Thus moving from the individual to the whole, new properties emerge that, although resulting from the individuals, may be not directly related with any of their properties.

computational power (Twomey and Cadman, 2002, pp 58, Miller and Page, 2007, pp 78-79, 85, Castle and Crooks, 2006, pp 12). Randomness may arise from diverse sources, for example: irrational eventual or incompetent human's act or behaviour (Economist, 2009), insufficient knowledge about the situation (resulting in failing to entirely foreseen its behaviour[131]), or uncontrollable forces (such as: bad weather, wild-fires or terrorist attacks).

In what concerns complexity, there is no limitation to the level of heterogeneity that an ABM can incorporate because every agent can have unique properties, which can be designed to emulate any real world behaviour. In the study of social or economic systems, such property is of utmost importance because there is no need to assume that the agents (people, populations, organisations, etc.) behave in a particular way. In what concerns size, ABM has no limits in the number of agents, in practical terms, the only limitation is the lack of computational power[132], and this without the need of introducing any simplification, reduction and homogenisation.

Worth of mentioning is the cumulative nature of the modelling process (North and Macal, 2007, pp 22, Twomey and Cadman, 2002, pp 59). An agent based model can be progressively updated without requiring major alterations or re-drawings. An agent based model is made by set of independent agents that interact following a set of rules. Therefore, as long as those rules of interaction are respected new or more complex agents can be added.

4.2.4 Limitations

As any modelling approach, ABM also reveals some fragilities that should be taken in due consideration.

Some of them are common to every modelling approach. For example, lack of suitable data (both in terms of quantity and quality) may preclude the model's validity, regardless its level of detail or development; or it may render an incomplete

[131] Stock markets' fluctuations are apparently random because no one has the entire knowledge to understand its behaviour.
[132] Current ABM software is able to handle up to several millions agents, and improvements are continuously being made.

understanding of the phenomenon of interest. ABM specific problems include, for example, the ability to capture and translate the essence or real world behaviour, particularly, the potential irrational behaviour, subjective choices or complex psychology. Calibration and validation processes become naturally complex and difficult to carry out, as well as, interpretation of the outcomes (Castle and Crooks, 2006, pp 15, Twomey and Cadman, 2002, pp 59).

Other drawback on ABM is the lack of formal techniques to assess a model's robustness and validity (Axtell, 2000, pp 3). The only method consists in re-running the model under different scenarios. Variables do not necessarily need to be confined to the limits of reasonability. This may pose some problems on the amount of runs to gain confidence on the model, besides consuming time (and computational resources)[133].

At present and despite the existence of software toolkits[134], building agent based models does require robust programming skills. Less skilled scientists (in particularly those with no background on computing or similar fields) may find difficult to model some aspects or carry out conveniently testing procedures (Twomey and Cadman, 2002, pp 59). Furthermore, the level of detail involved in micro-simulation makes ABM a rather computational demanding approach, which may have direct implications on model structure or validity. In case of limited computational resources or modelling time, the amount (or detail) of agents might have to be reduced (or simplified). Additionally, limited modelling time may also reduce the amount of validation tests (Castle and Crooks, 2006, pp 16, Bonabeau, 2002, pp 7287).

ABM lacks prescriptive ability (Twomey and Cadman, 2002, pp 60). Any real world's phenomenon can be caused by different factors, which is a consequence of the complexities and dynamics. Therefore, recreating the same phenomenon does not necessarily mean the ABM's underlying mechanisms are the same to those in the real world[135]. It just means that a possible cause and effect mechanism out of many others (that may exist in the real world and that may be the responsible for the actual behaviour in the real world) has been found. Consequently, utilising ABM for

[133] Validation of an agent based model is detailed in Chapter 5.4.

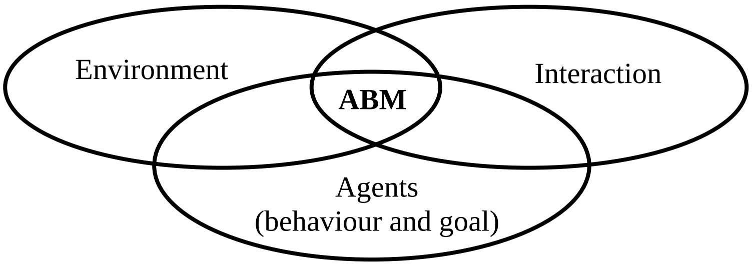
[134] Later in this chapter a brief review on ABM software platforms will be provided.

[135] This is in contrast with some traditional tools (such as optimisation or game theory) that unequivocally link the factors (independent variables) to the causes (dependent variables).

determining courses of action (prediction) or making analysis should be done with carefulness (Castle and Crooks, 2006, pp 16, Twomey and Cadman, 2002, pp 60). Additionally, ABM can establish a causal link between variables, but is not able to provide any insight on the reasons for that consequence.

4.3 Basic description of ABM components

An agent based model is made of three basic components, namely: agents, interactions and environment (Figure 4.4). Of these basic constituents, agents are undoubtedly the most relevant and “the primary focus” (North and Macal, 2007, pp 88); and those who receive more attention and efforts during the modelling process.



Source: author

Figure 4.4 – ABM’s basic components

4.3.1 Agents

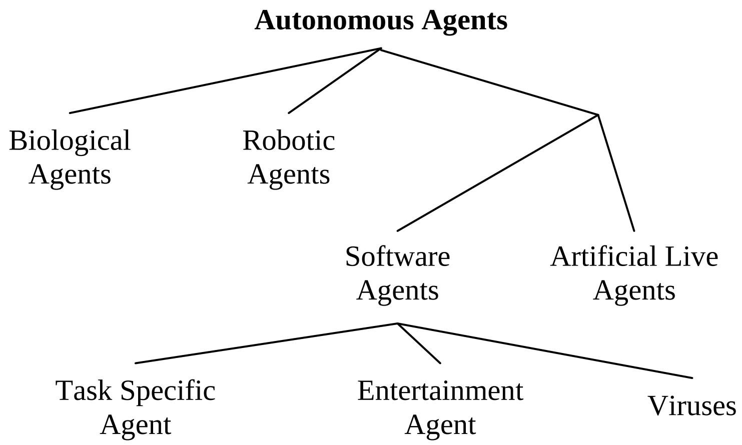
There is no single universally accepted definition of agent on the literature (Wooldridge, 2006, pp 15, Truszkowski, 2006, pp 5, Dannegger, Dorer, 2004, pp 398). An initial definition on artificial agents was brought forward by Hewitt (1977, pp 131) that refers that an agent is “a computational agent which has a mail address and a behaviour. Actors communicate by message-passing and carry out their actions concurrently” (cited in Nwana, 1996, pp 206). More recently and also concerning artificial agents Wooldridge (2006, pp 15) defines that agent is “a computer system that is situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives”. In the CAS field, North and Macal (2007, pp 88) consider that the agent is a “discrete entity having its own individual characteristic and behaviours". Truszkowski (2006, pp 6) considers that the agent "exists in an environment and, in some cases, may itself be considered to be a contributing part of the environment [...]. The agent operates based on some precepts and it generates "actions" that could affect the environment". Or even, Jager (2000, pp 27) writes that "an agent is being considered as a system that tries to fulfil a set of goals in a complex, dynamic environment, and 'agent' thus may refer to e.g., bacteria, plants, insects, fish, mammals, humans households, firms and nations".

Bradshaw (1997, pp 5, 8) acknowledges the lack of all-embracing definition, but enumerates characteristics an agent may exhibit:

- Reactivity – ability to sense and act;
- Heterogeneity – ability of embodying unique properties (there is no need to develop typical or mean individuals) (Castle and Crooks, 2006, p 8);
- Autonomy – ability to pursue a goal by itself. Wooldridge (2006, pp 15) refers that autonomy is the only property universally considered as being central to the concept of agent;
- Collaborative behaviour – ability to concert, namely: cooperate, coordinate and negotiate (Wooldridge, 2006, pp 3) with other agents to achieve a common goal;
- Knowledge level communication ability – ability to communicate with other agents or people (using more resembling human like language);
- Inferential capability – ability to use past information and abstract reasoning to generate novel ways (methods, behaviour, etc.) to achieve goals or perform tasks;
- Temporal continuity – ability of maintaining an identity or state over time;
- Personality – ability to reveal unique attributes of a believable character such as emotion;
- Adaptivity – ability to learn and improve with experience;
- Mobility – ability to decide a direction and move along it.

Aiming to introduce some order into the field of research on agents, taxonomies have been developed by different authors. For example: Nwana created seven categories (Nwana, 1996, pp 211-213), being: collaborative, interface, mobile, information, reactive, hybrid and smart; Gilbert classified agents along three dimension, namely:

agency, mobility and intelligence (Bradshaw, 1997, pp 9), or Franklin and Graesser created the following taxonomy tree (Bradshaw, 1997, pp 11) (Figure 4.5).



Source: Bradshaw (1997, pp 11)

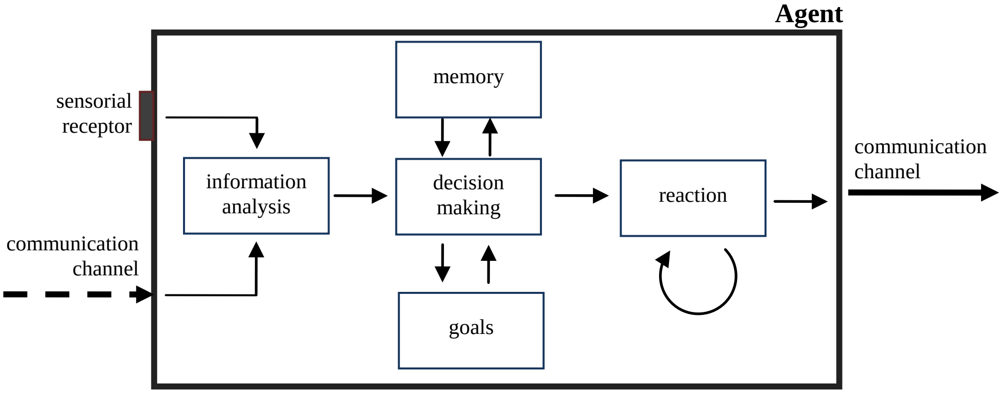
Figure 4.5 – Franklin and Graesser’s agent taxonomy

In face of the absence of a widespread definition, the author of this research work has adopted the following definition of agent. An agent is an independent entity, with precise boundaries, that exhibits autonomous behaviour and with both sensorial and communicational capabilities.

This definition requires some further explanations. So, firstly, an agent should have a clear boundary, therefore, when examining an agent based model, the agents should be easily identified. Secondly, other agents (or external entities) should not have access to the interior[136] of the agent but to their reactions and communications. Thirdly, an agent should be able to interact with her surroundings in at least one of two channels, either capturing information from the environment – sensorial capability – or via direct communication with other agents – communication capability. Fourthly, an agent should exhibit autonomous behaviour, which entails that she must be embodied with some sort of internal mechanism to enable her interpreting and reacting to external information in the pursuit of one or more goals.

[136] Interior understood as the agent’s reasoning mechanism, goals (if any) or other individual information.

Having presented the definition of agent, we now describe the basic architecture of an agent. The internal functions of an agent are depicted in Figure 4.6, being: information analysis, decision making, goals, memory and reaction. Only for purposes of clarity, each function is presented separately.



Source: author

Figure 4.6 – Basic architecture of an agent

The first function – *information analysis* – refers to the ability to translate the information received or captured through the sensorial receptor, into a format understandable by the other building blocks. The information is thereafter conveyed into the next function – *decision making*. This function is responsible for taking the actions. It is done upon information (either recorded or learned), desired goals, and a code of conduct and ethic rules[137]. It is therefore the generator of the agent's behaviour. Diverse techniques and methods have meanwhile been developed to emulate either realistic or specific behaviours[138]. The function *goals* encompasses the agent's goals. Goals may be of either short-, medium- or long-term. Moreover, new goals can be generated from intermediary results or achievements. In social sciences, or whenever the object of modelling is either people or private companies, goals tend to play an important role. This because agent's actions and decision are driven on the pursuit of her goals.

[137] The code of conduct and ethic rules define the agent's *personality* and, ultimately, her positioning within environment and relationships with others.

[138] Like for example, application of game theory principles. More information in Tesfatsion and Judd (2006).

The function – *memory* – concerns the body of information of the agent, which is built over time depending upon her interactions (representing her experience) with the other agents and the environment, and it is used in the decision making building block. The information kept in memory can be of either static nature (if it does not change over time, like for example, a vehicle's capacity) or dynamic nature (if it may change over time, like for example, the number of transport services accomplished). Dynamic information is updated regularly or whenever a new decision is taken. This building block recreates an agent's learning capability, by gathering information over time and enabling the agent to take decision on a progressively large amount of past information.

The final function – *reaction* – translates the decision made by the decision making building function into action. The action can either imply a communication with other agent or agents, or to solely concern the agent itself (for example: moving from one position to another).

The decision making function may require inputs from other agents. As such, this function could generate a reaction (materialised through an action of the agent or in communication with other agents) and stay on hold for the other agent's reactions. And several loops may be required until the completion of a decision making process.

The specific architecture of an agent (that is, the way the functions are grouped and organised) depends upon the complexity of information to handle, the number of tasks or decisions to make, the goals to achieve and their complexity, or the type or nature of actions to take. Furthermore, for modelling purposes, such as to increase the model's legibility or to reduce the computing time, other functions could be added. The final architecture is the result of the specific nature of the problem, the purposes to attain, and the modeller's personal experience. Of paramount importance is to ensure a fast and reliable model.

We may discuss if the presence of every of these functions is necessary to label an entity as agent; or if, conversely, the absence of one or more is reason enough not to label an entity as agent. From the author's point of view as long as the entity fits into the definition above, it should be considered an agent (regardless the type and amount of building blocks). An entity that only presents some of the properties of an agent should be called as proto- or pseudo-agents (or even entities).

4.3.2 Interactions

The next component of an agent based model refers to the interactions. Interaction refers to an agent's ability to exchange information with another specific agent. It is a temporary linkage between a pair of agents, through which information flows in one direction. An interaction is temporary because it is only established during the strictly necessary period of time to transmit the information. It is unidirectional because it flows from the sender towards the receiver. In this sense, a conversation can be understood as an ordered sequence of interactions amongst agents (where interactions are established back and forth amongst the pair of agents). Agents may establish simultaneously more than one interaction with the same or different agents.

So that agents can understand each other, two types of protocols[139] have to be implemented in the model: communication protocols and interaction protocols. Communication protocols define how agents should exchange and understand messages. Weiss (1999, pp 79) provides some example on communication protocols, being:

- Propose a course of action;
- Accept a course of action;
- Reject a course of action;
- Retract a course of action;
- Disagree with a proposed course of action;
- Counter propose a course of action.

Interaction protocols define how agents should structure the exchanges of messages, or in other words, how agents should converse (Weiss, 1999, pp 79). Examples of interaction protocols include, negotiation, coordination or auctioning. Protocols have to be established and defined during the programming stage[140], and their specific design depends on the real world's problem.

[139] Protocol is a set of fixed rules about a topic that every agent respects.
[140] Many ABM software toolkits are based on object oriented programming. In these cases, the protocols for interaction normally consist in defining a set of Classes. During run time, an interaction consists in instantiating one or more Classes with the necessary information and sending it (or them) to one or more agents.

A major property of ABM is the scalability. Such a feature is only possible as long as agents share the same communication protocols. The concept of interaction is thus the basis for such property. This also means that new functionalities could be added to or removed from an ABM without major difficulties; or complexity could be progressively added without changing the model.

4.3.3 Environment

The final component of an agent based model is the environment. The environment consists in all the properties exterior to the agents. An agent is able of either to capture information from the environment or to receive messages from the other agents. The environment also provides support to the interactions amongst agents.

At a given moment, the specific value and nature of the properties along with the arrangement of agents configure the environment’s state.

An environment is built to recreate properties similar to those found on real world conditions, such as: time dimension (for example: second, hour, day, or year), geographical dimension, eventual barriers to the agents’ movement or interactions (for example: rivers or lakes; or walls, stairs, or elevators), or limit values (for example: vehicle’s maximum speed, or weight and volumes always non-negative values).

Russell and Norvig (2003, pp 40-42) have proposed a taxonomy for classifying environments based on six dimensions. Each dimension is defined in terms of its possible extreme value (Table 4.1).

The dimension concerning the level of observations refers to the amount of knowledge an agent has about its environment. In a fully observable environment, an agent can retrieve complete and accurate information on the environment’s state; while in partially observable environment, an agent can only access some of the information. Most real world systems refer to the latter, as often there is some sort of barrier (or barriers) that hinder the full apprehension of the environment (like for example: information is geographically inaccessible, or it is privately held by some agent, or it is simply not understood or not retrievable). Sterman (2000, pp 23) points this very clearly by stating that “we experience the real world through filters”. Thus agents are able of capturing only part of the information on the system.

Table 4.1 – Russell and Norvig's taxonomical dimensions

Dimensions
fully observable vs. partially observable
deterministic vs. stochastic
episodic vs. sequential
episodic vs. sequential
discrete vs. continuous
single agent vs. multigent

Source: Russell and Norvig (2003, pp 40-42)

The dimension concerning the random nature of the environment is related with the level of uncertainty of the outcome of an action. In a deterministic environment there is no uncertainty on that outcome, since a given action will always produce the same result. On the other hand, a random environment is not predictable, and the course of action is unknown (this means that a same action may lead to different outcomes). Randomness nature is simply the expression of agents' incomplete information about the system. Randomness exists because there is information hidden, non-accessible or otherwise outside the agent's scope. Consequently, she is not able to accurately predict the entire range of her actions (Wooldridge, 2006, pp 18). Additionally, randomness may also be caused by unexpected changes in the environment that will condition the agents' behaviours and reactions.

The third dimension refers to level of continuity of the environment. An environment with a short life span is considered episodic; on the other hand, environment that endure throughout time is called sequential[141]. The former type refers to situations where the memory effect does not exist and therefore past actions do not influence current ones. Therefore, an environment can cease existence and be created later on whenever necessary. The latter type occurs when environment is permanent over time as experience plays a role in the state definition. Most real world situations refer to the

[141] The author of this dissertation does not entirely agree with this designation, since 'sequential' may induce the idea that the environment is made of a set of consecutive events, which is not true since there could occur simultaneous events. The author would rather prefer 'permanent'.

latter case, for example: the measure and evolution of time require the persistence of environment; otherwise it would be reseted; and many real world situations are time related.

The next dimension refers to the dynamic or otherwise static nature of an environment. An environment is dynamical in nature when it possesses two properties. Firstly, the environment's properties change by themselves without the intervention of any agent. This means that an environment's properties may differ in two different moments even if no agent takes any action. An environment is static when it remains unchanged unless when an agent performs an action. Secondly, simultaneous actions may occur. This means that in a dynamic environment, diverse agents can act simultaneously influencing the course of actions and the evolution of the environment's properties. This may result in the agent failing to achieve the desired goals because of others' interferences (Wooldridge, 2006, pp 18). Real world environments tend to exhibit both of these properties being therefore dynamic in nature.

The dimension related with the level of discreteness divides environments into discrete or continuous. A discrete environment has a finite number of states; while a continuous environment as an infinite number of states. A typical case of continuous environment concerns a region where agents can freely move around, like for example: animals (agents) moving in the field (environment) or a fire (agent) spreading on a forest (environment). An example of a discrete environment would be a vehicle (agent) moving on a road-network (environment). The vehicle moves along one of a finite set of paths. Another example of discrete environment can be a warehouse (environment), where cargo (agent) is placed on one (or a sub-set) of a finite set of locations.

The final dimension refers to the number of agents in the system. A system with one agent is a single agent environment, while an environment with more than one agent is a multiagent environment. Real world systems normally include several agents and not rarely hundreds or thousands (for example: persons on a city, households on a region, driver on a freeway) of agents, they are therefore multiagent.

4.4 ABM Models and Development Toolkits

Over the few decades of existence, agent based models have been evolving both in complexity and comprehension. Recently, ABM development toolkits have been released which has been opening the door to non-programmer modellers and, consequently, to other disciplines. Some of the most representative models are presented below.

One of the firsts models built on agent based principles was the so called *Game of Life*, developed in the seventies by John Conway[142]. Game of Life is a cellular automata[143] model. A cell can be on one of two possible states: On and Off, every time. The rules for determining a cell's state are:

- A cell will be On in the next update if exactly three surrounding cells (out of eight) are On;
- A cell will retain its current state in the next update if exactly two surrounding cells are On;
- A cell will be Off otherwise.

The initial configuration of the cells' state is randomly generated at the beginning of every simulation. Running a Game of Life, we could observe the emergence of patterns after the initial unordered distribution. Some of these patterns can hold throughout the simulation; and some are capable of self-reproduction. From this very simple model two important conclusions may be drawn: firstly, ordered patterns may emerge; secondly, the patterns are highly sensitive to the initial conditions of the system (North and Macal, 2007, pp 46-47).

Another well known agent based model is *Sugarscape*, developed by Epstein and Axtell (1996). Sugarscape is credited to be the first (computational based) model to study the fundamentals of human societies (Jager, 2000, pp 50). Sugarscape is a cellular automata

---

[142] Gardner, Martin (1970) "Mathematical Games – the fantastic combination of John Conway's new solitaire game 'life'", Scientific American, Vol 223

[143] Cellular automaton is a simple ABM environment. It consists in a two dimensional grid divided in cells. Each cell, at any point in time, assumes one of a set of possible sets. The state is defined in function of predetermined rules. On a periodic basis the state of each cell is updated; each update is called as generation. Normally the new state depends on both the cell's current value and the values of the eight surroundings cells (North and Macal, 2007, pp 46-47).

model. Agents are “living beings” that need sugar to keep alive and moving. Agents consume some quantity of sugar per unit of time, and additional sugar to move around. They can only observe their environment up to a limited range. The environment is made of cells, some of which have sugar while the others are empty (or have other agents). Sugar on cells can be exhausted. The agents’ basic goal is to keep alive; so they are always scanning the environment for cells with higher quantities of sugar. The more sugar an agent consumes, the longer she will survive and move around.

The model starts with a certain number of agents scattered across the environment. Additional, complex behaviours, such as death, reproduction, trade or war, may be incorporated to increase the model’s realism. Such simple model is able to experiment many of the human societies’ behaviours, like: growth or extinction of populations, domination or slavery of populations, inheritance, or cultural background (North and Macal, 2007, pp 53, Jager, 2000, pp 50, Peterson, 1996, pp 332-333).

One of the first model concerning social processes was design by Thomas Schelling in the seventies (North and Macal, 2007, pp 51). Thomas Schelling’s model is based on cellular automaton principles. Each cell represents a person (agent) whose purpose is to be surrounded by a certain quantity of neighbours of the same type. In each update, an agent’s level of satisfaction is measured as being the quantity of surrounding agents of the same type. The rules are as follows:

- If the level of satisfaction is below a certain pre-fixed threshold, the agent is dissatisfied and moves to a cell that satisfy its preference (if possible);
- Otherwise, the agent is satisfied and does not move.

The author concluded that segregation could occur for levels of satisfaction as low as twenty five percent (that is, two of the same type out of eight), and that ghettos could arise spontaneously (North and Macal, 2007, pp 52).

The increase of interest of ABM has led to the development and ulterior release of software toolkits to support the development of agent based models. The most significant are: Swarm, NetLogo, Repast, AnyLogic (Samuelson and Macal, 2006).

Swarm[144] is the first widely available toolkit. It was developed at Santa Fé Institute (United States), by Chris Langton and others (North and Macal, 2007, pp 56). Its initial purpose was the study of biological systems, attempting to infer mechanisms observable in biological phenomena. Over time, it has been applied in other fields such as, computer science, economy or political sciences. Swarm however requires a thorough knowledge on programming.

NetLogo[145] was developed at Northwest University (United States), in 1999, as a variant of an older ABM toolkit: the StarLogo (created at the Massachusetts Institute of Technology, United States), to support the deployment of models over the Internet. It is a straightforward toolkit widely used in disciplines varying from biology to physics to the social sciences. It is especially popular in courses and lectures on ABM, owing to the extensive documentation, tutorials and demonstration models available on-line. NetLogo has a graphical interface and a specific programming language. Images can be imported into the model facilitating the development of spatial models.

Repast[146] stands for the REcursive Porous Agent Simulation Toolkit, it was originally developed at the University of Chicago (United States) in the year 2000, and later on expanded by the Argonne National Laboratory (United States). Repast is a free and open software, available in pure Java or pure Microsoft .NET forms. The toolkit consists in a large library that can be directly imported to any Java program. Repast's latest version can handle up to several millions agents, and three dimensional and geographical based environments. It was considered to be the most powerful and customisable ABM toolkit; however, it requires a thorough knowledge and skills on JAVA (and object oriented programming).

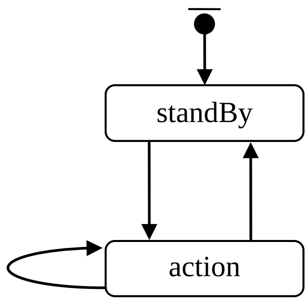
AnyLogic[147] was created and is maintained by XJTek Technologies, a Saint Petersburg (Russia) based company. AnyLogic is a hybrid micro-simulation software that incorporates ABM, system dynamics and event discrete approaches.

---

[144] Official webpage: http://www.swarm.org (5th August 2009)
[145] Official webpage: http://ccl.northwestern.edu/netlogo (5th August 2009)
[146] Official webpage: http://repast.sourceforge.net (5th August 2009)
[147] Official webpage: http://www.xjtek.com (5th August 2009)

AnyLogic is a high-level visual Java scripting software, entirely created upon Eclipse Platform[148]. It has extensive libraries materialised through actions buttons, covering several dimensions, namely: modelling (communication, movement or scheduling), statistics and plotting, or visualisation (texting, basic drawing tools or basic user interface tools). The modelling process consists largely in, firstly, dragging and dropping the action buttons onto the model, and, secondly, programming in Java the specific features.

Agents' behaviour is modelled through one or more state charts. A state chart is made of a set of states (boxes in Figure 4.7) connected by transitions (arrows in Figure 4.7). The state represents the agent's current situation. A transition represents a change in state and, consequently, a behaviour. A transition can be triggered either by internal or external actions.



Source: author

Figure 4.7 – State chart

AnyLogic blends the friendless and easiness of high-level programming (drag and drop) with the completeness and power of pure Java programming. Therefore, AnyLogic is suitable for a wide range of programmers from the one less skilled to the expert. The latest version can handle unlimited quantity of agents, being only limited by the available computational resources (normally, several millions agents). It can handle three dimensional environment and geographic based environments.

The main drawback of AnyLogic is the fact of being proprietary, which requires to be purchased and it is dependent on the company for future updates and improvements.

[148] A software for, among other purposes, developing Java based programs and Java plug-ins. More info on Eclipse website: www.eclipse.org (accessed on 5th August 2009)

As a final note, it should be mentioned the ability of embedding other modelling techniques in agent based models. The point is that ABM is a conceptual modelling approach, therefore the how's and who's of the model is defined upon the specific properties of the problem. This means that ABM can (and is) used along with other traditional modelling techniques and tools to fill in the various components or to simulate specific properties of the real world. Indeed, agent based models are often built with the most diverse tools and techniques to make them more accurate and robust[149].

4.5 ABM in Transport

In what concerns transport-related research, the ABM approach is also being increasingly applied. Gradually, publications have been released covering a wide range of problems and situations. Applications span a wide range of problems or situations, just to mention some fields: traffic control (Chen et al, 2009, Hirankitti et al, 2007, Schleiffer, 2002, Eskafi et al, 1995), air traffic management and control (Iordanova, 2003, Nguyen-Duc et al, 2003, Findler and Lo, 1991), terminal operations (Gambardella et al, 2001), rail or road operations (Böcker et al, 2001, Blum and Eskandarian, 2002), drivers and commuters' behaviour (Yuhara et al, 2006, Rossetti and Ronghui, 2005), drivers and vehicles' scheduling (Douma et al, 2008, Roorda e tal., 2008, Mes et al, 2007), routing (Hunt and Stefan, 2007, Adler et al, 2005), economic analysis (Ozbay and Bartin, 2004), or competition (Dimitriou et al, 2007).

In domains of closer interest of those being researched in this research work, namely, logistics, freight or air transport, ABM approach is likewise receiving growing attention. A recent survey[150] conducted by Paul Davidsson and his colleges concluded that research based on ABM is still in a very earlier stage of maturity[151] and with few (real world) experimental applications carried out (Davidsson et al, 2005, Davidsson et

[149] Many papers have been published coupling ABM and other techniques. For example: Persson et al (2005) explore the connection between ABM and optimization techniques; North and Macal (2007, pp 59-95) explore the possibility of linking ABM with risk analysis, optimization techniques and participatory simulation.

[150] The survey considered a total of 65 bibliographic references, most of them from scientific journals. Other source included: conference proceedings, chapters in books and books.

[151] The authors consider maturity as the level of completeness and validity of the model (Davidsson e tal., 2005, pp 259).

al 2007). The authors also concluded that, firstly, the modes of transport receiving most attention were air, road and intermodal transport; secondly, the main issues of research were planning and scheduling, fleet management, transport scheduling, traffic management and traffic control (Davidsson et al, 2005, pp 260), and, thirdly, the main research problems by mode of transport were (Davidsson et al, 2005, pp 260, 262-264):

- Railways: slot allocation problem;
- Road transport: scheduling and traffic management and control;
- Sea transport: optimisation of container terminal operations;
- Intermodal transport, concerns mainly rail and road transport: scheduling coordination, terminal handling or allocation of transport services;
- Air transport: air traffic management.

From the survey, the authors also concluded that ABM's potentialities are not being explored to full extent. For example, thirty percent of the reviewed papers used centralised control (while ABM is particularly interesting in non-decentralised situations), fifty percent did not make use of the possibility of dynamic structures, or sixty four percent used ABM for decision support systems (Davidsson et al, 2005, pp 263).

Possible reasons for such outcome lie on the overall youth of ABM and on the even more youth of the application of ABM in the transportation domain. In a short period of time, tools, methods or techniques are still likely under development. This assumption is evidenced on another analysis carried out in this survey, concerning the level of maturity of the research. They concluded that thirty percent of the papers are developed at the conceptual level, and fifty three percent use limited or artificial data (Davidsson et al, 2005, pp 264).

Despite the growing interest of ABM approach in transport-related fields, the review to the literature still reveals few publications with relevance to or overlapping with this research work. The following publications were considered of interest for this research work.

An early attempt to use ABM principles for solving transport related problems was conducted by Fischer et al (1995). The purpose of the work was to explore the usefulness of a modelling technique like ABM, and the importance of negotiation and cooperation in road freight transport market. The authors addressed the problem of scheduling orders in the road freight transport market. They claimed that traditional optimisation techniques fail in providing adequate solutions, owing to not only the complexity of the problem (NP-hard) as well as the high level of uncertainty and incompleteness of the freight transport market. The authors presented the MARS model (Modelling a Multi-Agent Scenario for Shipping Companies) that simulates a freight transport market. Demand is generated on a continuous basis and often exceeds the capacities of a single company, forcing the engagement in cooperation with others (Fischer et al, 1995, pp 122).

MARS has two types of agents: shipping company and truck. The former is responsible for processing the orders (determination of transport window times) and, eventually, negotiation with other shipping companies. Shipping companies are primarily selfish, only forming alliances whenever necessary. The latter is responsible for conveying the freight, which entails defining the best suitable scheduling. Each transport company owns a fleet of trucks. The paper incorporates three dimensions of real world: cooperation, negotiation, and task decomposition and allocation. And it explores three types of cooperation: vertical between shipping company and its trucks, and horizontal between shipping companies one with share of information about free capacity and other with share of information and orders (Fischer et al, 1995, pp 128-129).

Cost was the proxy for evaluating the model’s efficiency. The reasoning was the following: system’s costs should decrease with better utilisation of trucks’ available capacity. The authors ran a set of experiments, comparing simulations with no horizontal-cooperation against simulations with horizontal-cooperation. Considerable costs reductions were achieved, in particular, in case of larger shipping companies. The authors concluded on the suitability of ABM approach to overcome the complexity of scheduling problems. Additionally they concluded that negotiation and cooperation can significantly reduced overall transport costs (Fischer et al, 1995, pp 136).

The clear division between the dimension of negotiation and the dimension of transport provided useful insight for the development of the model of this research work. No other aspect was used as both the purpose and problem addresses are different.

Paul Davidsson and his colleagues have been developing a micro-simulation model of intermodal transport chains, inspired on ABM principles (Davidsson et al, 2008, Holmgren et al, 2007, Ramstedt et al, 2007, Bergkvist et al, 2005, Persson and Davidsson, 2005). The model is called TAPAS. Its purpose is twofold: to investigate the transport chain agents' reactions to the implementation of governmental control policies, such as: fuel taxes, road fees or vehicle taxes (Davidsson et al, 2008, pp 2, Bergkvist et al, 2005, pp 236); and to evaluate different production and transporting planning strategies (Holmgren et al, 2007, pp 2).

The model takes a societal perspective, and computes the transport service's total transport costs (both direct and external costs, including environmental costs), society revenues and shippers' satisfaction (as the level of reliability) (Bergkvist et al, 2005, pp 239). The entities on the model are: shipper, producer, transport agents, production planner, transport buyer and transport chain coordinator (Davidsson et al, 2008, pp 3), Bergkvist et al, 2005, pp 239- 241).

It is based on two-layer simulation engines: one concerning the physical transport, other concerning the decision making process (Holmgren et al, 2007, pp 2). The physical engine is based on Davidsson and Wernstedt (2004). It represents both the transport network that is made of links (roads, railways, etc.) and nodes (consumer depot, producer or terminals), and the vehicles (trucks and trains) that convey the goods (Davidsson et al, 2008, pp 2). Every component (link, node and vehicles) is conveniently characterised (e.g.: each transport agent has a set of vehicles which in turn have a maximum speed, maximum capacity and some emissions rate).

The decision making engine is inspired on Persson and Davidsson's (2005) and Bergkvist's et al (2005) early works. The communication protocol conducing to the transport chain management is also provided (Davidsson et al, 2007, pp 4-5, Holmgren et al 2007, pp 10-12). Decision making process is based on costs (Holmgren et al 2007, pp 9). Costs are time-related (e.g.: driver or capital), distance-related (e.g.: fuel or taxes) and link-based (e.g.: road tools) (Davidsson et al, 2007, pp 2).

Some case studies were presented to evaluate TAPAS's applicability. The purpose was to determine the amount of taxes necessary to lead to a shift from road to other modes of transport. More than one intermodal transport route is considered, each one using various modes of transport in different quantity. The overall conclusion was that a modal shift could only be attained after a significant increase of road taxation (Bergkvist et al, 2005, pp 246, Davidsson et al, 2007, pp 6).

The TAPAS model also offered some useful insights for the development of the agent based model of this research work. A first insight was related with the structure of the model. TAPAS, in line with Fisher's et al (1995) early work, has a clear division between management (decision making) and transport operations (physical transport)[152]. Such division introduces transparency in the model and brings it closer to reality. A second insight concerned the quantity and nature of the agents to be considered, and a third insight concerned the structure and contents of the communication protocol.

TAPAS however diverts from this research work on what concerns the target, purpose, and scope. Firstly, TAPAS aims to support the development of public policies, by analysing the effectiveness of different measures. Its target is thus primarily the public authorities (responsible for defining public policies). Conversely, this research work aims providing insights for the assemblage of intermodal (air cargo) transport services. The target is thus eminently the (air) transport companies. Secondly, TAPAS simulates transport corridors, where origin and destination points are determined at the outset. Each corridor may be served by more than one transport solution (involving intermodal and single-modal solutions). This research work simulates a freight intermodal transport market, with a single transport solution: intermodal air transport.

Kequiang Zhu (Zhu et al, 2000, Zhu and Bos, 1999) presented an agent based model specifically developed to support KLM’s cargo services’ intention of reshaping its air cargo transport network. This would be materialised by implementing the ‘pipeline concept’[153], which in general terms means to move towards a multi-hub system with trunk routes connecting the main hubs (Zhu et al, 2000, pp 2, Zhu and Bos, 1999, pp

[152] This division has already been used by some authors in the conceptual representation of intermodal transport services. These representations are discussed in Chapter 2.2.

[153] Pipeline concept “is a set of control principles by which shipments (transport orders with associated charges) are processed through a network of handling and transportation capabilities (with associated cost) at agreed quality and efficiency levels aiming at maximising the system profit” (Zhu et al, 2000, pp 2)

14). The model was not meant for simulation purposes but, instead, to be used in KLM's real time operations.

In general terms the model aimed to optimise KLM's air cargo capacity by diverting low priority cargo from over-loaded into under-loaded routes (or schedules). Although such strategy could result in an increase on the delivery times (of the diverted cargo), it would yield higher reliability levels (in particularly, in what concerns the premium cargo) (Zhu et al, 2000, pp 2, Zhu and Bos, 1999, pp 15). Particularly, it had two main purposes: coordination of orders' allocation process and management of physical transport services.

In terms of structure, two types of agents were considered: company agents (such as: shipper, freight forwarder, transport agent or customs) and resource agents (such as: trucks, aircrafts or containers). The former agents were responsible for taking the decisions, while the latter were somewhat passive serving only to impose restrictions (such as: capacity or productivity).

As the coordination of KLM's operations with other agents is of paramount relevance to deliver high quality services, the communication structure has received a great amount of attention (Zhu and Bos, 1999, pp 2-13). Accordingly, communication is materialised through seven protocols, being: service-requester, service-provider, information-asker, information-reporter, planner, dispatcher and controller (Zhu and Bos, 1999, pp 2-12). No details are presented about an eventual application on KLM, therefore, the validity or usefulness of the model could not be assessed.

Dong and Li (2003) developed a conceptual agent based model to manage intermodal freight transport chains' information (Dong and Li, 2003, pp 2269). This work is similar to those presented previously by Keqiang Zhu's (Zhu and Bos, 1999, Zhu et al 2000), simply extending the focus of the model. Zhu's model was focussed on the air cargo agent, while Dong and Li's works was focussed on the intermodal chain.

Zhu's work's main contribution laid on the object of the model. The author developed a conceptual architecture of an agent based model for the management of an intermodal air cargo. Both the nature and type of agents, and communication protocols were of interest to this research work. Unfortunately, no practical application is made, so the model's validity or robustness cannot be assessed. Furthermore, the focus is entirely made from the airline company's perspective giving little or no attention to the other agents.

4.6 The choice of ABM for this research work

The choice of the method of modelling is a fundamental step in the research work, in order to ensure meaningful and valid outcomes. This choice depends on three factors:

- Purpose of the research project - determines which real world's variables, behaviour or processes have to be conveniently emphasised or studied.
- Specific properties of the real world phenomenon - determines the possibilities and limits of the research project. This includes to determine, for example: the nature of phenomenon (social, mechanical or other), the constraints to experiment or manipulation (owing to ethical, e.g.: experiments on human beings, or the practical reasons, e.g.: private business or lack of data).
- Appropriateness of the method of modelling for emphasising the necessary properties (second factor) to achieve the desired outcomes (first factor).

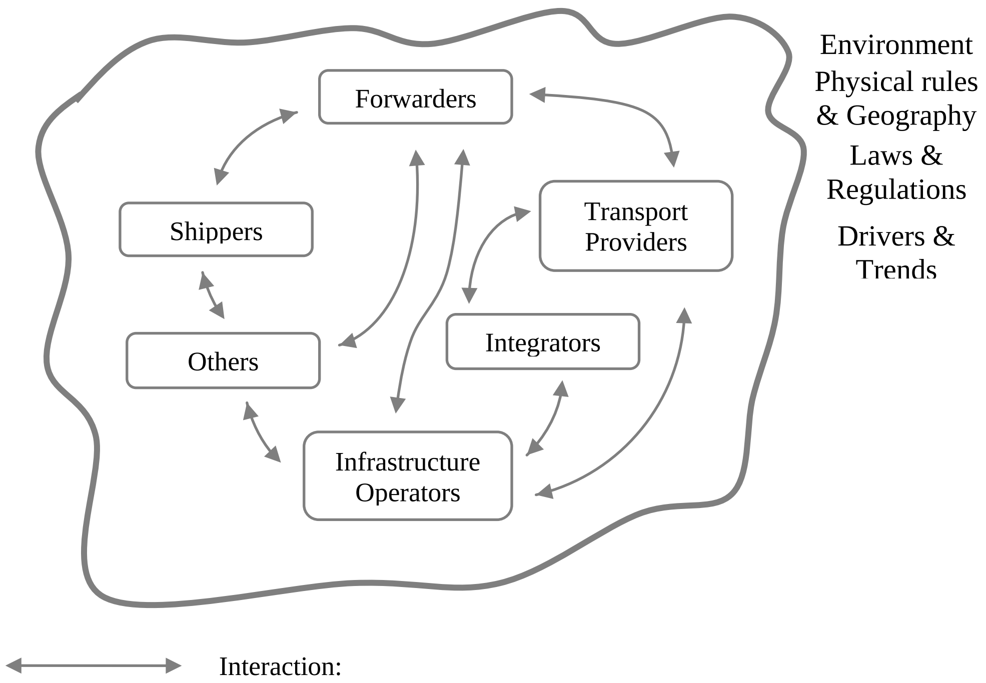
As already mentioned the method of modelling applied utilised in this research work was ABM - Agent Based Modelling. In simple terms, ABM implies formalising a variety of autonomous and behavioural agents that interact within a bounded environment. In order to justify this choice let us first recall the objectives of this research work: first, the overall objective of this research work is to contribute to the competitiveness of the combination companies in the air cargo market; second, the operational objective is to develop a conceptual framework about the mechanisms of integration in intermodal freight transport services.

If not for other reason, freight transport markets exhibit (to some extent) every property of a CAS, and since ABM was originally developed to study CAS, it would be suitable to study freight transport markets. Applying the above mentioned Pascale's (1999, pp 84) conditions to the freight transport market, we have:

- Freight transport market is inherently decentralised, there is no entity that rules and decides what decisions should be taken. Each transport agent is autonomous (or at least partially autonomous, if there is cooperation) and takes its decision upon others' decisions, market conditions and its own goals;

- Freight transport market is highly dynamical, with constantly new comers entering the market, alliance being formed or destroyed and new products released on the market;
- Freight transport market are increasingly complex as drivers and trends introduce news demands and constraints;
- Freight transport agents are highly competitive and dynamic, being constantly looking for innovative services.

Figure 4.8 presents a conceptual interpretation of a freight transport market through the lens of ABM. The market is perfectly recognisable and easy of interpretation. There are no need to introduce simplifications on the quantity and type of transport agents, neither on the rules of market functioning.



Source: author

Figure 4.8 – Conceptual view of a freight transport market

Recalling now the conditions put forth by North and Macal (2007, pp 93), for the utilisation of ABM, we may conclude that the freight transport market fits in most of them (Figure 4.8). A freight transport market can be decomposed into a set of individual entities, corresponding to the various transport agents, like for example: shippers, transport providers, forwarder, integrators, or terminal operators. Each transport agent can be easily identified within the market. Entities are heterogeneous exhibiting different behaviours, performing different tasks or activities and pursuing different goals. This market, as any economically driven market, has become highly competitive and dynamical: constantly new services are being provided, new comers are entering the market defying incumbents, or alliances are being formed (or destroyed). In this environment, a key role of success is the adaptability. Transport agents are required to continuously adapt to the new market conditions, either by changing their strategies (by entering new market or withdrawing other, or offering new services), or processes (doing activities in a different way).

Additionally, transport agents often have partial access to the market information. Privacy and confidentiality are (considered) key factors of success and, consequently, a substantial part of the information is not publically available on the market. There is a wide research on privacy and confidentiality in business[154]; however, no scientific work about the impacts of disclosure of information in the freight transport market has been found.

Also, there is a constant and complex interaction amongst transport agents. The interactions can assume the form of communication, contracts, liability or even exchanging goods. In the current time, timely and reliable communication is of utmost importance on the success of any transport agents and, increasingly sophisticated solutions have been introduced into the market (like for example: track and trace through global positioning satellites, or automatic web based connections). Indeed, the success of Integrators (e.g.: FedEx, UPS or TNT) relied to a great extent on an effective communication network and some intelligence.

Another factor underlying the choice of a method of modelling is related with the very nature of fitness. Fitness is directly linked to the type of interactions between dual systems. Such property requires that the modelling technique could make explicit these

[154] For example: Hannah (2006), Nola (1999) or Kahaner (1998).

interactions, which is synonymous to require a modelling detail to the level of the agents (micro-level). ABM fits into these demands since it is a micro-simulation tool that explicitly models interaction amongst agents.

A key issue faced by the author was the lack of suitable data. Indeed, the author found it difficult to get some data during interviews[155] (namely: about costs, suppliers or shippers' names, performance indicators, or contractual and liability clauses). Even worst was the possibility of interviewees providing not accurate date (or even erroneous). ABM could ease to some extent the problem of the lack of real world information, since it only requires data about the agents, their interactions and the environment, but not about the market (namely: its structure, types and nature of relationships amongst agents, agents' performance), which reduces the amount of information necessary to be collected.

A final reason for using ABM was the possibility of incorporating feedback loops that drive the future development of the market. In particular, there is a feedback flowing from the transport operations into the decision making process of assembling transport chains[156]. ABM allows to make the decision making processes based (amongst others) on the decision-makers' previous experiences. Experience gathered from the production of other transport services, using the same or other transport. Consequently, ABM enables to make the feedback loops explicit, like they occur in the real world and that influences the future course of the decision making process. This ability is of paramount importance for the current research work because the fitness problems occur at operational level (during the transport service), but it will impact on future decision making situations.

For all these reasons, ABM was found suitable for modelling freight transport markets and, thus, to be applied on this research work. This observation has already been claimed by other authors, namely: Davidsson et al (2008, pp 1153), Bonabeau (2002, pp 7282), or Fischer et al (1995, pp 123).

---

[155] In order to circumvent this limitation either questions were put in suppositional terms (in the form: "let's assume that…", or "imagining that…"); or plausible intervals were asked, instead of absolute figures.

[156] After all, miss-performing transport agents or chains are unlikely to be called again for future transport services.

4.6.1 Comparison with other models

However, the decision on using ABM was not done without firstly examining other modelling approaches or concepts. Other modelling approaches analysed were: game theory, optimisation and system dynamics. The utilisation of ABM does not imply that other modelling approaches could not have been used, nor that ABM is better or more capable in every dimension against any other approach. As a matter of fact, other approaches could have been used and certainly relevant insights and conclusions would have been drawn. The utilisation of ABM only denotes the author's conviction on the better suitability of this approach for the task in hands when compared with the others. This suitability is related to ABM's capability of isolating the fitness mechanisms.

Game theory "can be defined as the study of mathematical models of conflict and cooperation between intelligent[157] rational[158] decision-makers. Game theory provides general mathematical techniques for analysing situations in which two or more individuals make decisions that will influence one another's welfare" (Myerson, 1997, pp 1). The overarching purpose of game theory applications is to determine the likely outcome of a game[159]. Game theory was founded in the first half of the twentieth century and since then it has been extensively used on decision support systems either, for predicting and defining strategies, or for analysing players' behaviours and strategies.

Game theory was not chosen as modelling approach for the problem under research for several reasons. Firstly, game theory focuses on the outcome or final configuration of the interaction of parties and not on how that outcome is reached. It is therefore an essentially descriptive science. The path that parties take to reach the final configuration is not of interest for game theory. This is a natural aspiration in the sense that for analysing conflicts the central issue is the final position of the various parties, and not necessarily what moves were required to reach that point. Secondly, game theory is not suitable to tackle operations related problems. Game theory is a behavioural analysis

[157] A decision maker is intelligent if she has access to every publicly available information and takes inferences accordingly (Myerson, 1997, pp 4).
[158] A decision maker is rational is she makes decisions consistently in pursuit of her own objectives (Myerson, 1997, pp 2).
[159] Game is any social situation where two or more parties (the players) interact. Games can be of conflict or of cooperation.

tool, essentially meant to support strategic definition and not to define how those strategies may be achieved. Thirdly, game theory assumes that ultimately some sort of equilibrium is reached amongst parties (an optimal solution may not be found but nevertheless parties will eventually converge to a stable situation or to a domain of stable situations). Yet, stability is rarely the rule in many human or economic situations. This happens as the consequence of multiple tensions and forces that render impossible a static equilibrium to be obtained and maintained.

Optimisation was another modelling approach evaluated. In general terms, it seeks to find the optimal situation (either maximum or minimum) from within a space of possible solutions (North and Macal, 2007, pp 78). The optimisation approach has been developed under the umbrella of operational research domain field. Optimisation approach encompasses a vast set of techniques, of which linear programming is one of the most widely known, others include nonlinear programming, stochastic techniques (which incorporates randomness and uncertainty), multi-objective programming (when there are more than one objective at stake and trade off should be taken into consideration).

Within the freight transportation domain, optimisation tools have been deployed for over the past decades to tackle diverse problems, such as: nodes (such as: ports, airports or warehouses) location, crewing scheduling or timetables design, fleet optimisation, or vehicle routing (Hensher and Button, 2007, McKinnon et al, 2002 or Ortuzar, 2001). Operations research on freight intermodal (or multimodal) transportation is however a comparatively recent field, with the first publications appearing in early nineties (Bontekoning et al, 2004, pp 6). The topics of study are fairly the same as the broader topic of freight transportation, with a special focuses on the modes of transport’s coordination, the terminal design, the ships or train’s load optimisation, or the infrastructure network configuration (Macharis and Botekoning, 2004).

A typical optimisation problem involves an objective function and a set of constraints. The objective function is the mathematical translation of the real-world aim, while the constraints refer to the various real-world limitations (such as, number of daily working hours, or maximum capacity and volume). The purpose would be either the maximisation or the minimisation of the objective function subjected to the constraints[160].

Applying an optimisation technique to the current research problem would be feasible although with some potential difficulties. The first difficulty would concern the very definition of the objective function, owing to transport agents' conflict interests. The ultimate purpose of any organisation is profit maximisation; albeit this goal could be sacrificed in the short run if higher benefits could be attained in the long run. If we solely take the perspective of the air transport company, we would face questions such as: would the company seek for optimising their operations or she should sacrifice it in order to optimise the intermodal air transport service's operations. We should bear in mind that the optimisation of an intermodal transport solution might not be attained by the maximum optimisation of all the transport agents. Similar conflicts of interests could be identified in other agents.

A second difficulty is related with the ability of capturing the non-linear influences and latent behaviour in the market. As already explained, the behaviour of a system is affected by either feedback influences, when past choices influence current ones, or latent behaviours, which are triggered when some conditions are met. These indirect influences do play an important role in the system's behaviour. Two main problems may be pointed out. Firstly, these properties are at best fairly known at the outset and it is not possible to analyse what is not known. Secondly, the translation into mathematical wording and subsequence solving of the problem would be very hard (if not impossible). For example: the fact of some influences only being felt in some conditions would raise major difficulties in the modelling process.

A third difficulty is related with the need of modelling the market's latent behaviours. As an example, let us consider the latent behaviour of *delay* (delays occurs occasionally, for reasons outside the agents' control). In case of no-delay, the freight forwarder will be pleased with the transport agent's performance and she will likely call her in the future. On the other hand, in case of delay, the freight forwarder will not be pleased and,

[160] The literature on optimization and operational research is vast, and further developments lie outside the scope of the present research work. The objective here is only to justify the option for ABM instead optimisation. More information could be found on, for example, Hillier and Lieberman (2004).

besides an eventual monetary compensation, she could not call her in the future. In this situation, the agent may trigger one or more latent behaviour to counteract, like for example: reducing the price of the transport services. In consequence of her decision other agents may also trigger latent behaviours not to lose competitiveness advantage (like for example: provided extra services for the same price or likewise match price reduction). This in turn may lead to trigger other latent behaviours and so on and so forth. Similar dynamics could be developed for any other latent behaviours. From this simple example we may also conclude for the sequentiality of (latent) behaviours, since although their existence depending of the presence of some trigger, the same trigger may give origin to different behaviours.

A final modelling approach investigated was *system dynamics*. Systems dynamics was established in the fifties by Jay Forrester[161] at the Massachusetts Institute of Technology (United States) (Sterman, 2000, pp 4). Accordingly to John Sterman "system dynamics is a perspective and a set of conceptual tools that enable us to understand the structure and dynamics of complex systems. System dynamics is also a rigorous modelling method that enables us to build formal computer simulations of complex systems […] The goal of systems thinking and system dynamics modelling is to improve our understanding of the ways in which an organisation's performance is related to its internal structure and operating policies, including those of customers, competitors and suppliers and then use that understanding to design high leverage policies for success" (Sterman, 2000, pp vii, viii). A caveat should be made. The second part of the definition can be re-written changing the word 'organisational', by 'complex system' without losing its validity.

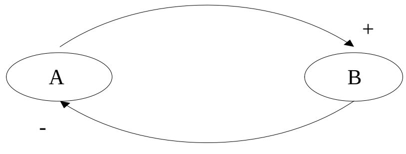
System dynamics models the real world system through key aggregate variables and casual relationships (macro level), this is complementary to ABM which is a micro-level simulation technique. These variables represent groups individuals (or populations), which are taken as homogeneous, and are quantified via an average value. In a model, the system is considered to be made of set of casual (cause-and-effect) loops that induce (or provoke) flows in-between stocks (or variables). Stocks characterise the

[161] Forrester, Jay (1958) "Industrial Dynamics: a major breakthrough for decision makers", Harvard Business Review, Vol. 36, Issue 4, pp 37-66

state and behaviour of the system. Flows define how stocks change over time. The casual loops can also be intertwined[162].

Systems dynamic is one of the schools of systems thinking. The object of analysis of system dynamics is a complex system. The notion of complex system is discussed in detail in Chapter 4.6 during the presentation of the tool for validation of the theory. Also in this chapter, it is made the evidence that an intermodal transport exhibits properties of a complex system; hence, the author could conclude for the applicability of systems dynamics to study intermodal freight transport services and, in particular, of the fitness of intermodal freight transport services. Yet, systems dynamics is focussed on the overall progress of a system, and not on the progress of every individual. Therefore, this method of modelling is not meant to capture the agents' behaviour and, in particular, their adaptive processes (Jager, 2000, pp 25); or, in a transportation context, the logistical processes, such as, transport agents' modal choice, negotiation or strategies (Davidsson et al, 2008, pp 1154). For this sole reason, system dynamics could not be utilised.

[162] The basic tools of system dynamics are the so called casual loop diagrams. More information about the utilisation of system dynamics can be found in John Sterman (Sterman, 2000). Causal loop diagrams are schemes that represent the system's variables, the casual relationships and nature of influence. The following figure represents a simple system. This system is made of two variables: A and B. There are two casual relationships between variables A and B (reciprocal influence). The influence of A over B is positive, meaning that "if the cause [variable A] increases, the effect [variable B] increases *above* what it would otherwise have been, and if the cause decreases, the effect decrease *below* what it would otherwise have been" (Sterman, 2000, pp 139). The influence of B over A is negative, meaning that "if the cause [variable A] increases, the effect [variable B] decreases *below* what it would otherwise have been, and if the cause decreases, the effect increases *above* what it would otherwise have been" (Sterman, 2000,pp 139).

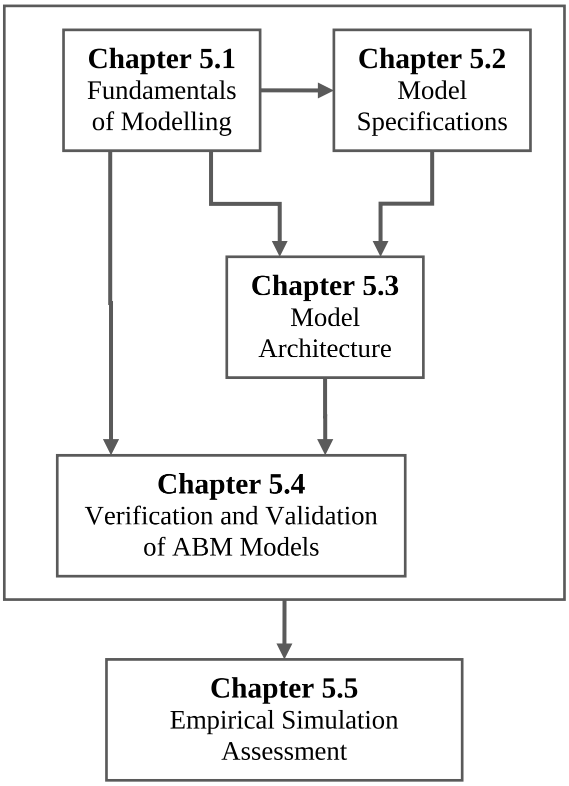


5 SIMULATION ASSESSMENT

This chapter describes the efforts developed to test the hypothesis (presented in Chapter 1.4) and to validate the conceptual framework (formalised in Chapter 3). The efforts were conducted using a simulation model specifically created for this purpose This model is hereinafter designated by *Air Freight Transport Market Simulator* (AFETAS). AFETAS is a generic tool for micro level simulation of freight transport markets. As already explained in the previous chapter, ABM was the modelling framework used to build AFETAS. The implementation of AFETAS was done through the commercial software AnyLogic.

This chapter is organised into five chapters, which can be grouped into two parts (Figure 5.1). The first part comprehends the first four chapters (Chapter 5.1 to Chapter 5.4) and it details the process of the construction of the model AFETAS. Chapter 5.1 makes a brief introduction to the basics of modelling, by addressing three basic questions: "why models?", "what are models?" and "how to build models?". Chapter 5.2 specifies the properties of AFETAS in order to fulfil its purpose. Chapter 5.3 provides the full description of the model, including: variables, assumptions, agents' behaviour, etc. And, Chapter 5.4 describes the steps carried out in the verification and validation of AFETAS.

The second part comprehends a single chapter (Chapter 5.5) and it presents and discusses the set of Experiments carried out with AFETAS.



Source: author

Figure 5.1 - Structure of Chapter 5

5.1 Fundamentals of Modelling

Why models? What are models? How to build models? These are the three questions that will be addressed on this chapter.

For attempting an answer to the question “why models?”, we should firstly recall that theories are meant to explain the mechanisms underlying real world phenomena. Therefore, any theory has to be tested in the real world conditions to be considered accurate and valid. However, for diverse reasons, the utilisation of the real world for testing theories is often not possible. In these situations, alternative methods have to be deployed. One of the possible solutions consists in recreating models[163] of the real world

[163] A caveat should be done for the fact that models can be used for other reasons than theory testing. Wyner (2006,pp 6) points out three reasons for deploying models, being: explanation (where it can be

phenomenon in virtual environment, through the utilisation of computational resources[164].

Looking into detail to one of the objects of analysis in this research work – intermodal freight transport service – further limitations were uncovered. Firstly, no suitable real world intermodal freight transport service was found to serve as test bed. Secondly, no transport companies were found willing to either dedicate resources (namely: vehicles, personal, time) or use their shippers' freight (because of high risk of damaging their image on the market) on a series of experiments. Thirdly, no transport company was willing to provide data about their intermodal transport operations, on grounds of confidentiality. Companies were afraid of revealing data that could be used by competitors to gain some sort of competitive advantage.

After assessing some alternative options for validation, the decision has ended up in the utilisation of a simulation model. Simulation models have been used with success in the domain of freight transport and intermodal services. Moreover, simulation models offer the possibility of recreating multiple scenarios and variations of the world market and, thus, to enable to test theories in ceteris paribus situation[165]. Amongst the various techniques for developing simulation models, the choice was, as explained in Chapter 4.6, for the agent based modelling.

Moving now to the remaining questions "what are models?" and "how to build models?". Bonabeau (2002, pp 7287) addresses these questions in a very consistent way when he writes that "one issue is common to all modelling techniques: a model has to serve a purpose; a general-purpose model cannot work. The model has to be built at the right level of description, with the right amount of detail to serve its purpose; this remains an art more than a science". This sentence raises three central questions that should be conveniently discussed.

---

included theory testing), prediction and decision making support. The primary reason in this research work is theory testing.

[164] Other possibilities include, for example: small scale models or mathematical formulation.

[165] Ceteris paribus situation is fundamental to ensure the causes and outcomes are de facto consequences of a given variable, and not from the mixed influence of multiples variables.

First, every model exists to serve a specific purpose (Sterman, 2000, pp 84, Randers, 1976, pp 417). A model is, as a matter of fact, a metaphor of an object (regardless of being real or imaginary), since it embodies solely those properties that are meaningful for the objective of the research (as we will see later, it makes no sense to incorporate properties that add no value to the proper functioning of the model). If we consider an all-embracing model of real world, it would have to incorporate every property of the real world and it would end up binge so complex as the real world itself and, therefore, useless. So, every modelling development has to be preceded by a careful specification of the requisites of the model.

The second question is related with the previous one: a model should not contain more detail than the necessary to fulfil its purpose. The issue is that a model is the result of a creative process whereby the modeller incorporates the details and properties she thinks are necessary, which means that the amount of detail is entirely discretionary - details can be added indefinitely. Yet, identifying the necessary amount of detail is not straightforward (Carley, 2002, pp 2, Peterson and Eberlein, 1994, pp 170). On the one hand, a model should be as simple as possible. A complex model is prone to errors and more difficult for validation. Moreover, extra details do not bring added-value to the model (as the model is already complying with the initial requisites) and it can be negative as they may create noise or unnecessarily increase the level of complexity. Complexity also reduces the model’s legibility and repeatability, which may be a relevant issue if it is meant to be used and interpreted by other people than the modeller. On the other hand, a model should contain enough detail to represent with sufficient rigour the real world to allow a good perception of the values of the key variable and their influences on the outcomes. The real world is inherently complex, therefore, any model should contain some of its complexity, otherwise it has no meaning. A model emptied from every complex matter cannot be used to represent reality.

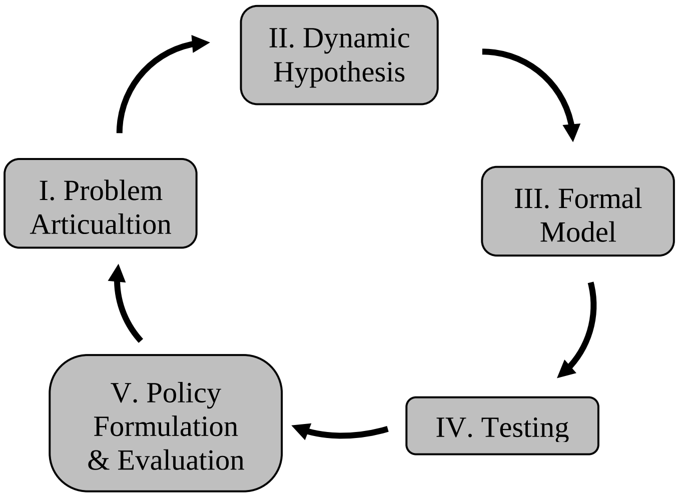
Balancing these two forces, simplicity versus thoroughness, is not an easy task neither a novel question. Hoetjes (2007, pp 1), within the planning domains, for example, calls it as “rigour-relevance dilemma, i.e. how can research be both relevant and scientifically rigours?”, and Sterman (2000, pp 96), within system dynamics domain, writes that “a broad model boundary that captures important feedback is more important than a lot of detail in the specification of individual components”. The bottom line is that there is no right formula for determining the sufficient amount of detail of a model. The modeller has to balance a set of factors, having always in mind the ultimate purpose of the model (and of course its validity).

The third question addresses the absence of methods to support the model development (Sterman, 2000, pp 87, Peterson and Eberlein, 1994, pp 161, Randers, 1976, pp 416). This process largely remains a question of endurance, intuition, and inspiration – *art*; although, experience does play an important role. This is particularly critical in social sciences where the modeller deals with variables that are not easily observed or measured. Model creation is thus a creative and iterative process, whereby the modeller successively eliminates errors and adds details (Sterman, 2000, pp 83).

Despite this absence, considerable efforts have been made on this topic and some authors have brought forward guidelines for the development of models. Sterman (2000, pp 86, 87) considers five main stages (Figure 5.2) on model development process, but he points out that “modelling is a feedback process, not a linear sequence of steps”:

- Problem articulation: it consists in the identification of the problem, purpose and key variables and dynamics of the problem (it is considered the single most important step);
- Formulation of dynamic hypotheses: it consists in the development of the theory for explaining the underlying mechanism of the problems. Theory is laid down through a set of hypotheses;
- Formulation of a simulation model: it consists in the development of a formal model. The model embodies the hypotheses;
- Testing: it consists in subjecting the formal model to various tests and criteria of acceptability. Tests include comparing to reference models, assess robustness under extreme conditions, or carry sensitiveness analysis;
- Policy design and evaluation: consists in applying the model on the design of policies for improvement, specification and evaluation of scenarios, evaluation of interaction of policies[166].

[166] The author of this dissertation does not entirely agree with Sterman's formulation on this stage. The point is that not only a model can serve other purposes than policy design and evaluation, as well as policy design and evaluation is more than what it is written. The author believes that Sterman just meant to transmit the idea that in this stage the model is applied to the real world problem.



Source: Sterman (2004, pp 87)

Figure 5.2 – Model building process

5.2 Model Specifications

The model is meant to support to test the hypothesis and the conceptual framework. The tests are presented and discussed in Chapter 5.5. The hypothesis was formulated in Chapter 1.4 and it claims that the integration of combination companies in intermodal freight transport services can enhance their competitiveness in the air cargo market. The conceptual framework was developed in Chapter 3 and it is meant to explain the mechanisms of integration in intermodal freight transport services. The conceptual framework (Figure 3.10) depicts five dimensions of fitness, being: physical, logical, liability, financial and strategic.

For purposes of testing not all the dimensions were used (Chapter 5.5). The dimensions that were analysed are: physical fitness, logical and strategic. The strategic fitness was assessed through the factor schedule coordination, which corresponds to different transport companies to adjust their transport services’ schedules. The remaining two dimensions (that is: liability and financial) were not analysed. The reasons are now presented. In what concerns the liability friction, Chapter 3.3 claims that uncertainties in the unambiguous determination of the responsibility for some non-compliance (either delay or damage) of the transport service may become a key issue on the production of the intermodal freight transport services.

Nowadays in legal terms, an intermodal freight transport service is a set of individual transport services. Every transport leg has a clear duration: it starts once the transport agent accepts cargo and it ends once the next transport agent (or shipper, in case of final leg) accepts the cargo. The acceptance of the freight by a transport agent (or the shipper, in case of final leg) denotes, in legal terms, that the freight is in good conditions (i.e. there is no damage[167]). Therefore, if damage is detected at the end of the transport service, then the transport agent is the sole responsible for it. In case of damage, the transport agent (or the shipper, in case of final leg) may refuse to accept the freight, or can accept it but with a remark about the existence of damage. If cargo has damage but it is accepted anyway (as being in goods conditions), then the agent (that accepts cargo) is the fully responsible for any ulterior detection of damage.

This situation implies that, at any airport, freight has to be conveniently checked for damage, both externally as well as internally[168]. The air transport agent may even deny boarding the freight if she founds that either it will not bear the stresses of the journey, or the protection (or fastening) of the cargo is not convenient. Consequently, although liability friction may in certain intermodal freight transport services be responsible for losses of fitness, it is not so likely to be relevant in intermodal air transport services and, thus, it is not being considered[169].

In what concerns the financial dimension of friction, it was also fairly solved by the airline industry. IATA, in 1945, implemented a program designated Cargo Account Settlement System (CASS). CASS is a clearing house that manages every financial payment between air transport companies and any other transport agent. In an automatic and transparent way, the CASS processes payments (and any sort of compensations) eliminating any problem resultant from financial friction (IATA, 2009b). Certainly, that for any reason transport agents may delay or deny payments. This situation erodes trust amongst transport agents, and may preclude future assemblages of intermodal transport

[167] Delay related problems are of easier identification since the arrival and the departure times are normally recorded.

[168] The transport agent may request a visual inspection to the goods.

[169] Liability problems tend to be more relevant in those cases on which one vehicle is carried by another, like for example: RO-RO (trucks carried on ships) or piggyback (trucks carried on trains). The point is that the legal framework of each mode of transport foresees different limits of responsibility, which often raises the question of which legal framework to consider.

chains. However, this is an unlawful situation to be treated on the courts and that thus lies outside the scope of this research work.

Summing up, the evidences for supporting or refuting the hypothesis and the conceptual framework (presented in Chapter 3) will be collected along three dimensions of fitness, being: logical fitness, physical fitness and strategic fitness. Upon this decision, the specifications of the model could be drawn as follows:

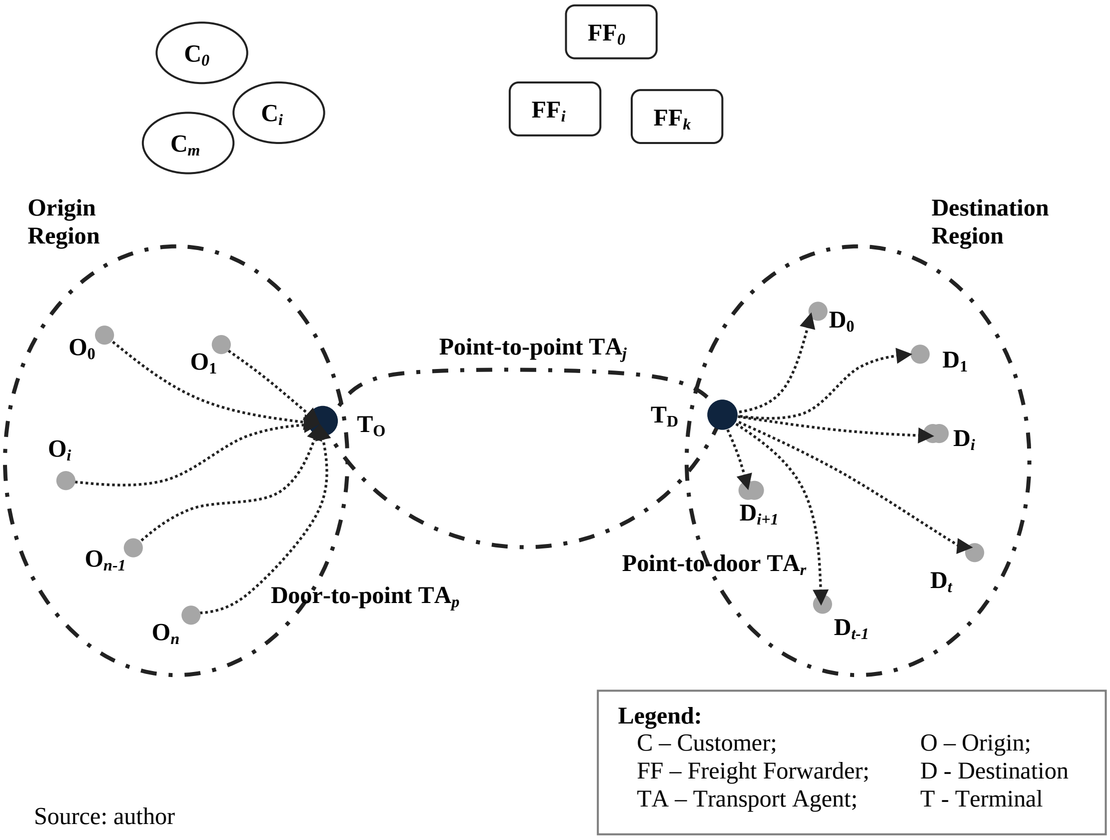
- The model should represent an intermodal freight transport market, with at least one intermodal air transport route. Because the scope of analysis is intermodally based on air transportation.
- The model should simulate both the decision making process and the production of intermodal freight transport services. Because the former occurs when the fitness is taken into consideration; while the latter occurs when the fitness influences the performance of the service.
- The model should consider several transport companies both land based and air. Because, according to the conceptual framework, the level of fitness may evolve with market dynamics, and to recreate the market's dynamic multiple agents are required. Moreover, the level of fitness may influence the performance, thus multiple agents are required to recreate transport chain with potentially different levels of fitness.
- The model should recreate in a way similar to the real world the transport companies' behaviour (if necessary, using real world data). Because, fitness is function of the market dynamics. Additionally, the model should also allow to customise the transport companies' properties, so that dimensions of fitness can be changed.
- The model should consider several freight forwarders. Because freight forwarders compete on the market and influence the market dynamics which, in turn, may influence level of fitness of the agents. Freight forwarders with higher knowledge of the market would be able to better capture the fitness and assemble higher performance transport chains.
- The model should recreate in a way similar to the real world the freight forwarders' decision making process. Because, fitness is taken into consideration during in this moment.

- The model should consider at least one shipper. Because the shipper is responsible for generating demand for freight transport services and choosing the freight forwarder winner.
- The model should recreate in a way similar to the real world the shippers' decision making process.
- The model should allow the individual study of each dimension of fitness, in ceteris paribus conditions; so that, results can be unambiguously assigned.
- The model should have at least one indicator of performance, which should be monitored over time for every transport chain.

5.3 Model architecture

Figure 5.3 presents the conceptual structure of AFETAS's freight transport market. On this market, the Shippers generate the demand for freight transport services. The Freight Forwarders organise and manage their transport services. The freight transport services are provided by multiple Freight Transport Companies. The Freight Transport Companies convey cargo either between origin and terminal (door-to-airport) or terminal and destination (airport-to-door); or between the terminals (airport-to-airport). Each transport company uses one mode of transport.

Competition takes place at two levels: firstly, between freight forwarders when competing for the shippers' transport services; and secondly, between transport agents when competing for the freight forwarders' transport services. Freight forwarders compete based on price, transit time and shipper's perception, while transport agents compete based on price, transit time and freight forwarder's perception. Transport companies are not fully nor equally reliable, therefore failure (either in terms of delay or damage) may occur. Penalties are associated with failure that, ultimately, result in loss of competitiveness, for both transport agent and freight forwarder (that has chosen that transport agent). Additionally, every freight forwarder and transport agent adopts a specific price strategy aiming to leverage their competitive position (which is function of inner properties, external pressures and agreements between them).



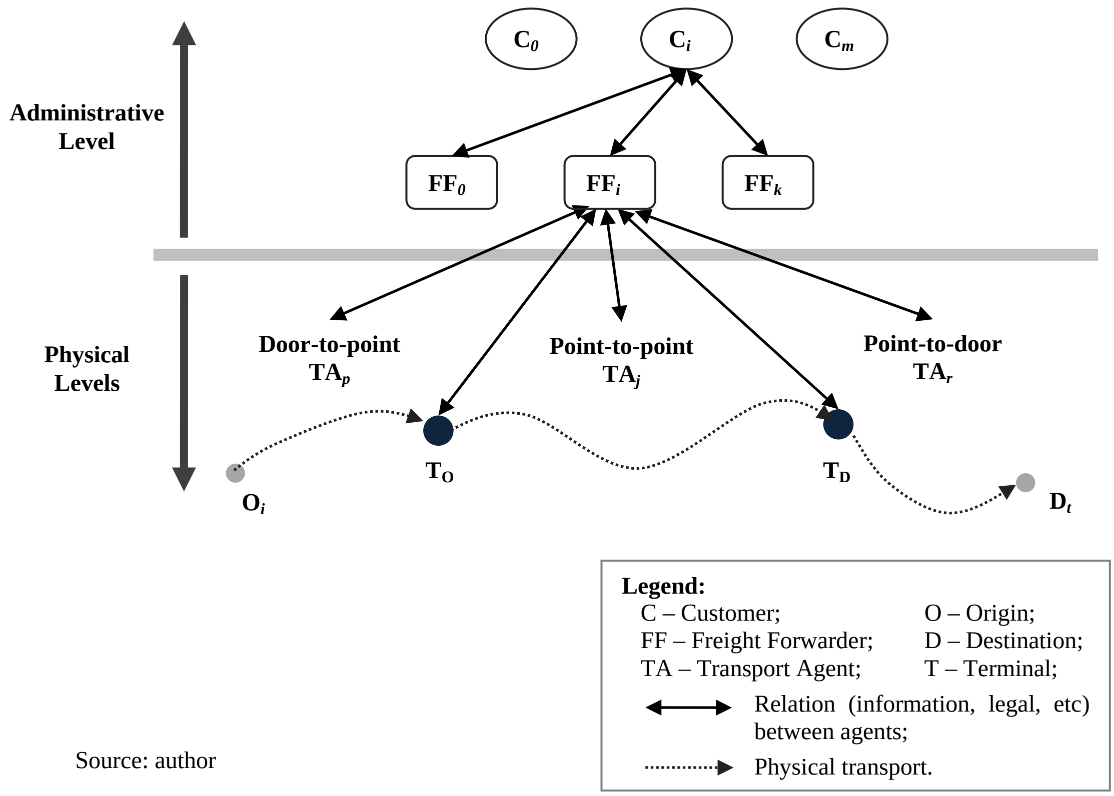
Source: author

Figure 5.3 – AFETAS' virtual freight transport market

In what concerns the organisation of the intermodal freight transport services, AFETAS considers two levels: the administrative level and the physical level (Figure 5.4).

The administrative level embraces both the activities carried out prior to the physical transport (Sub process 1, Figure 2.8) and the activities of management carried out during the physical transport (Activity 9 of Sub process 2, Figure 2.8). It thus embraces all the activities not directly related with the physical transport of the freight, such as: negotiation between shipper and freight forwarders, or communication between freight forwarder and other transport agents. The physical level embraces the activities carried out during the physical transport of the freight (Activities 1 to 5 and 6 to 8 of Sub process 2, Figure 2.8).

Three reasons can be pointed out for the utilisation of this conceptual organisation. Firstly, it mirrors the real world, where there is clear separation between the administrative and physical transport activities. Secondly, this structure introduces transparency into the simulation model, increasing its legibility. Finally, this organisation has already been adopted by other authors[170], such as: Davidsson et al (2008), Bergkvist et al (2005) or Fischer et al (1995), and discussed by the author in international forum (Reis and Macário, 2008).



Source: author

Figure 5.4 – Conceptual market structure of AFETAS

As mentioned at the beginning of the previous chapter, one of the purposes of AFETAS was to support the assessment of the validity of the conceptual framework. Moreover, in Chapter 4 the need to resort to a simulation model was explained as being related with the unfeasibility to find a suitable real world case. Consequently, AFETAS besides incorporating the characteristics of the real world freight transport market, it also embraces the properties of the conceptual framework. For clarity purposes, the author finds relevant to explain, to which extent and how, the conceptual framework is incorporated in AFETAS. Let us first recall some of the properties of the conceptual

[170] Also in the conceptual representation of intermodal transport freight, other authors have considered this division, such as: Jensen (1990) and Woxenius (1998).

framework. From Chapter 3.4 and Figure 3.10, we may identify the following five building blocks, being:

a. *requirements* of the intermodal freight transport service,
b. *modal profiles*,
c. *tiers of friction*,
d. *dimensions of fitness* and
e. *performance* of the intermodal freight transport service.

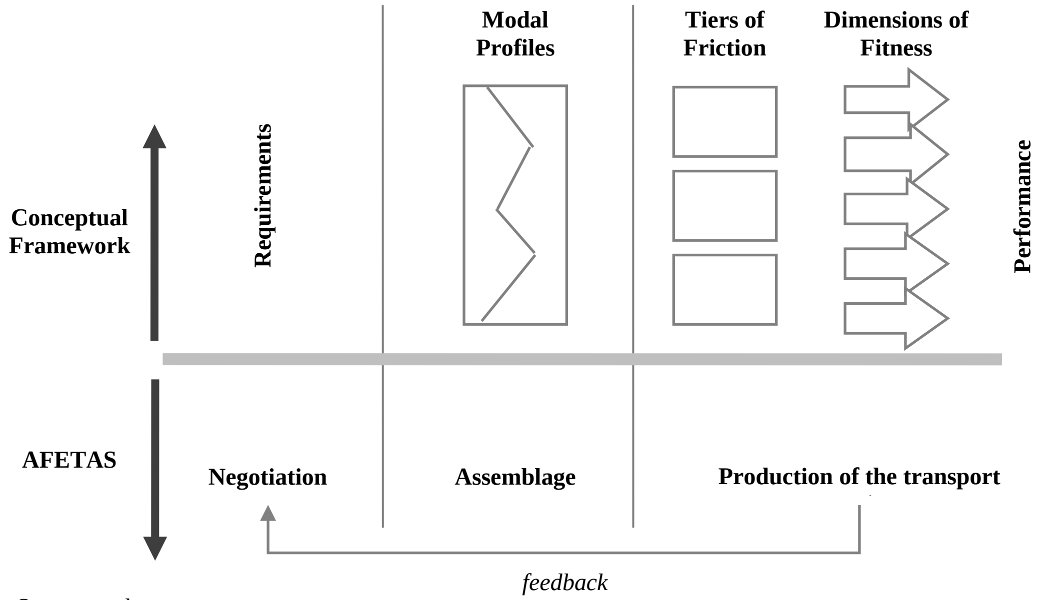
On the other hand, the production of an intermodal freight transport service can be segmented into three moments, being:

i. *negotiation* between the shipper and the freight forwarders (Sub process 1),
ii. *assemblage* of the intermodal freight transport service (Sub process 1)and
iii. *production of the transport service* (Sub process 2).

Figure 5.5 establishes the parallelism between the conceptual framework and the model AFETAS. The upper part of the figure presents the conceptual framework (Figure 3.10); whereas the bottom part presents the three moments in the production of an intermodal freight transport service. The first segment of the conceptual framework (segment *a.*) is incorporated in AFETAS in the negotiation between the shipper and the freight forwarder (segment *i.*). In this period the requirements of the shipper are placed in the market and considered by the freight forwarders in the assemblage of the intermodal freight transport service. The second segment (segment *b.*) is taken into consideration, by the freight forwarder, in the assemblage of the intermodal freight transport service (segment *ii.*). In this stage the freight forwarder will likely choose the agents with higher fitness. Finally, during the production of the intermodal freight transport service (segment *iii.*) friction (segment *c.*) will eventually occur in one or more dimensions (segment *d.*), which will influence the performance (segment *e.*) of the intermodal freight transport service.

The presentation of AFETAS is done in four parts. The fist part describes the engine embedded in AFETAS. An engine simulates a specific process of the real world phenomenon, involving more than one party and encompassing a set of procedures that are complex enough to justify a separated explanation[171]. AFETAS's engine is:

- Decision Making Engine – that simulates the freight forwarder's decision making process leading to the choice of a transport solution.



Source: author

Figure 5.5 – Relation between the Conceptual Framework and AFETAS

The remaining three parts correspond to the description of the three dimensions of an agent based model: environment, agents and interactions. Environment will be described according to the Russell and Norvig (2003, pp 40-42) taxonomy, which is summarised on Table 4.1. The agents' description is done in two steps: attributes and tasks, instead of simply presenting each basic building block (that are: state and transition, Figure 4.7). It should be noted that although every replication of an agent shares the same attributes (and tasks), some of them are randomly generated at the moment of creation, which may result in agents with different behaviours.

The reason for explaining agent's tasks and not their basic building blocks is because the author considers that describing each building block by itself would make difficult to grasp the agent's overall behaviours. Conversely, describing agents' tasks does

[171] The separation of the engines' presentation is for easing the understanding of AFETAS.

provide a better understanding on their behaviours, without hindering the perception of each building block.

The description of interactions will be divided into four streams, each one corresponding to a type of flow that occurs on an intermodal transport chain, being: information, liability, physical or financial. The author believes this division parallels real world making clear its understanding and judgment.

5.3.1 Engines

Engines are complex and autonomous processes that involve two or more agents. They are presented separately for clarity purposes. As said AFETAS has one engine: decision making process.

5.3.1.1 Decision making process

Chapter 2.4 provides a literature review on modal choice factors. The review reveals an abundance of suggestions, and although some of them appear to be more influential, there is neither consensus on the actual modal choice factors nor on their actual relevance. Also in this chapter the author presents his conviction about the mechanisms of the decision making process[172]. The author agrees with D'Este's (1996, pp 10) point of view on modal choice process[173] when he argues that the decision making process is a two-phase process. In a first phase, the decision maker chooses from the market a small set of agents. This phase of decision is meant to reduce the decision making process to a manageable level of complexity, by reducing the amount of possibilities. The choice is based on two main factors, being:

- Familiarity with the agent – there is higher likelihood to choose an agent with whom the decision maker has already worked in the past;
- Past positive experiences – perception of the decision marker towards the agent, which is built upon time and which embraces many of the qualitative factors referenced the literature[174] (such as: reliability, flexibility, safety and frequency).

[172] This view only concerns low commitment decisions (like those taken in a daily basis). Long term commitment and decision making follow a more complex type of process.
[173] D'Este's point of view was explained in Chapter 2.4.
[174] See Chapter 2.4 for a review on this topic.

The second level of decision embraces a more in-depth analysis of the various agents. Eventually, the decision maker may enter into contact with them (requesting information about prices and transit times). And, the final choice falls upon the option that presents a better combination of the decision factors. In summary, the first phase reduces the universe of options to a manageable set of trustful agents and the second phase allows the identification of the best choice.

AFETAS's decision making process was developed to mirror this decision making process. The first phase is conducted through the consideration of a variable so-called Level of Trust (LoT). This variable represents the shipper's trust towards a freight forwarder and the freight forwarder's trust towards transport agent. Trust building (or erosion) is a cumulative process of acquisition of rational and non-rational (subconscious) perceptions about something (or someone) (Kramer, 2009, pp 70), which include both qualitative and non-qualitative attributes.

The second phase of the decision making process is emulated through a Fuzzy Logic Inference Mechanism (FLIM) based on fuzzy sets theory and fuzzy control[175]. FLIM considers two modal choice factors[176] (price and transit time), which can have different impacts in the decision making process (and that are defined through the attributes `Fuzzy weights` in Table 5.1 and Table 5.2).

Fuzzy sets theory and fuzzy control have proved being particularly suitable to handle the subtleties and lack of precision of human language, as well as the prominent qualitative nature and complexity of human decisions; firstly, it allows the direct usage of human language, overcoming the need of a translation into quantitative values; and secondly, it is able to translate into mathematical formulation the qualitative nature or complexity of human language. Such properties have opened the door for the mathematical manipulation and computation of eminently qualitative domains, such as human thinking or reasoning. Over time, fuzzy logic controllers used to emulate human reasoning and decision making processes have been developed (Jang, 1993, pp 665).

---

[175] An introduction to fuzzy logic and fuzzy logic operations is presented in Annex V – An Introduction to Fuzzy Set and Fuzzy logic.
[176] The reasons were presented in Chapter 2.4.

Fuzzy set theory was chosen to incorporate the engine designed to emulate both the shippers and freight forwarder's decision making on the agent based model of this research work for five main reasons. Firstly, the author has, during the research period, conducted a series of interviews with diverse market agents, namely: freight forwarder, road transport agent, air transport agent, and airport handlers. Interviewees have systematically revealed considerable difficulties to provide numerical values or exact premises used on their decision making process. Usually, the answers were given in terms of qualitative intervals, like for example: “very important”, “high quality”, “low price”, “ranging between X and Y”, etc. Fuzzy set theory provides a suitable theoretical and mathematical framework for handling with rigour this kind of situations.

Secondly, as already explained in Chapter 2.4, the author believes that the decision making is a simple and straightforward process, based on few rules and to some extent subjective. Fuzzy logic provided a suitable framework for, firstly, dealing with this nature (in particular, the possibility to allocate different weights to each variable) and, secondly, incorporating the randomness of human subjectivity.

Thirdly, fuzzy set's mathematical concepts are, despite their robustness and soundness, of relative ease of understanding and, consequently, of implementing in computational models. Bearing in mind that an algorithm has had to be developed and implemented in the agent based model, simplicity was a key issue to ensure the validity and to avoid unnecessary noise in the overall model.

Fourthly, Beuthe and his colleagues (Beuthe et al, 2008) compared the outcomes of four different quantitative models of individual decision making[177], on seven attributes[178] and for eight types of freight[179]. The transport modes include road, rail, waterway and multimodal (combination of these) (Beuthe et al, 2008, pp 170). The authors concluded that “there is not much difference between the methods, even though there may be

[177] The methods being: conjoint analysis, multi-criteria analyses, rank-ordered logit models and a neural modelling (Beuthe et al, 2008, pp 157-158).
[178] The variables being: frequency of service per week, door to door transport time, reliability as percent of deliveries at the scheduled time, carriers' flexibility in response to non programmed shipments measured in percentage, loss as percent of commercial value lost from damages, stealing and accidents, and transport cost (Beuthe et al, 2008, pp 157-158).
[179] The types of freight being: steel, textile, electronics, chemical, cement, packing, pharmaceutical and materials (Beuthe et al, 2008, pp 170).

differences in the absolute levels of the weights allocated to each attribute" (Beuthe et al, 2008, pp 176). These results can be taken as an evidence of the lack of knowledge (and thus consensus) on the most suitable technique (or techniques) for modelling decision making processes that still exists.

Fifthly, the application of a behavioural model to the present research would depend upon the availability of either, other models already developed, studies or data in the same domain as this research work. The full development of a specific behavioural model was considered to lie outside the scope of the current research work. Furthermore, the freight forwarders' decision making engine is but one of other building blocks of the overall simulation model, and not the purpose of either the research work or the overall simulation model. Moreover, to the best of the author's efforts no information on behavioural model has been found, focussed on the domain of the current research work: air cargo transport. The vast body of knowledge on behavioural models deals mainly with passenger transport and land based freight transport, which renders their application to air cargo transport not feasible. For these reasons the intention of using behavioural models has been abandoned.

The decision making process engine is divided into two phases:

- Phase 1 - Fuzzy Logic Inference Mechanism (Figure 5.6):
    - *Fuzzification* – conversion of real world variables (normally denominated as crisp variables) into fuzzy input variables based;
    - *Fuzzy inference* – computation of fuzzy output variable (or variables);
- Phase 2 - Identification of the transport solution winner;

Phase 1 - Fuzzy Logic Inference Mechanism[180]

In what concerns the *fuzzification step*, AFETAS considers two fuzzy input variables: price and time. Each of these variables is graded into three levels, being:

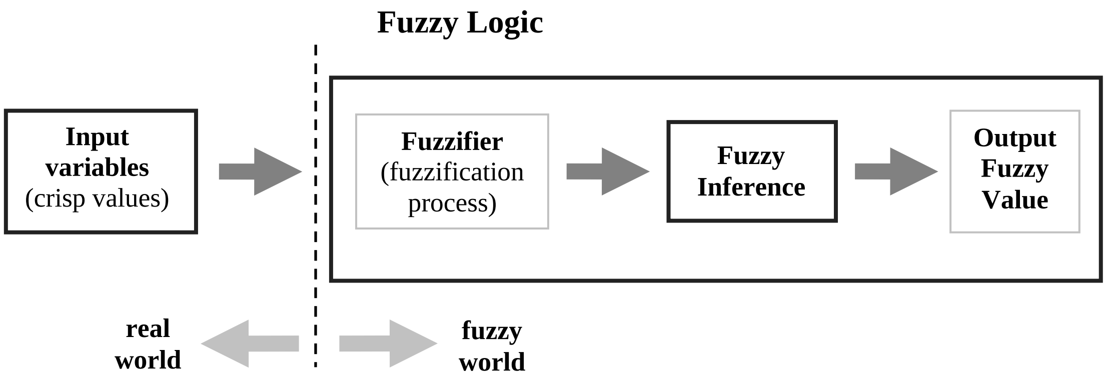
---

[180] There are several techniques for implementing Fuzzy Logic. In this research work the choice of the technique was done based on the appropriateness in relation to real world reasoning process and number of variables and on the easiness of implementation in the agent based model. The interested reader is referred to: Jang (1993) or Nakanishi et al.(1995). More information in Annex V – An Introduction to Fuzzy Set and Fuzzy logic.

$$Price = \{low, medium, high\}$$

$$Time = \{poor, medium, good\}$$

Figure 5.7 sketches the shape of the membership functions for the input variables, the specific valuation depends on the mode of transport they refer (road or air). The output variable ranges between zero (0) and one (1). Zero denotes a bad option; while one denotes maximum values and thus an excellent option.



Source: author

Figure 5.6 – Fuzzy Logic system

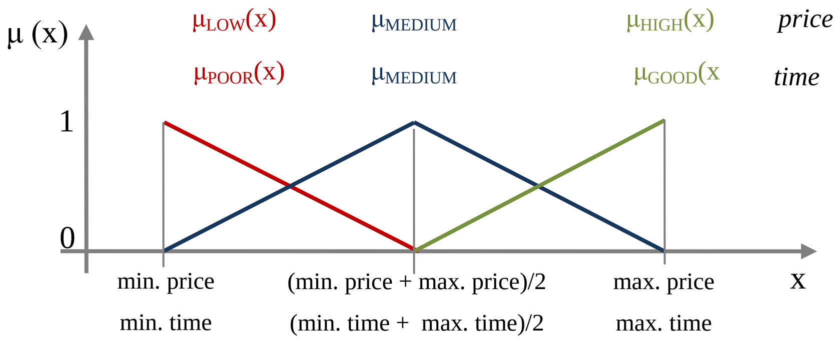
Fuzzy membership functions are defined for every decision making process. The dynamical nature of these functions is justified on the fact that each transport service is unique both in terms of prices and times[181]. Thus for every transport service, transport agents provide a unique pair of time and price values, rendering impossible to define static membership functions that could prove reliable for every possible situation.

On the other hand, in the real world, although freight forwarders (and shippers) are aware of the typical rates and prices for each destination and amount of cargo; in practical terms, they have to decide based on what is actually provided by the transport agents (and not on what they were expecting or would like to have). Certainly, if price is too high or transit time is too long, the freight forwarder (or shippers) may abandon

[181] It is important to recall that each shipper sends from a specific location to a specific destination (that are randomly generated at the start of each run). The same occurs in the real world, since shippers are scattered on the territory.

Moreover, land based transport rates are also function of the length of the transport service, thus, once again, rates are shippers specific.

intention of sending cargo, but this situation is foreseen in AFETAS through the attributes: `Maximum Unitary Price` and `Maximum Transit Time`.



Source: author

Figure 5.7 – Fuzzy membership functions for input variables

The computation of the membership functions for the variable Price is computed as follows:

$$\mu_{Low}(x) = \begin{cases} 1 - \dfrac{x}{P_{Med} - P_{Min}}, x \in [P_{Min}, P_{Med}] \\ 0, x \in [P_{Med}, P_{Max}] \end{cases}$$

$$\mu_{Medium}(x) = \begin{cases} \dfrac{x}{P_{Med} - P_{Min}}, x \in [P_{Min}, P_{Med}] \\ 1 - \dfrac{x}{P_{Max} - P_{Med}}, x \in [P_{Med}, P_{Max}] \end{cases}$$

$$\mu_{High}(x) = \begin{cases} 0, x \in [P_{Min}, P_{Med}] \\ \dfrac{x}{P_{Max} - P_{Med}}, x \in [P_{Med}, P_{Max}] \end{cases}$$

With,

$$P_{Min} = Min\,(P_i), i = 0,1, \ldots n,$$

$$P_{Max} = Max\,(P_i), i = 0,1, \ldots n,$$

$$P_{Med} = 0.5 * (P_{Min} + P_{Max})$$

P being the price of the option;

n being the number of possible options (transport chains, in case of freight forwarder's decision making process, or number of bids, in case of shipper's decision making); process.

The computation of the membership functions for the variable Time is computed as follows:

$$\mu_{Poor}(x) = \begin{cases} 1 - \frac{x}{TT_{Med} - TT_{Min}}, x \in [TT_{Min}, TT_{Med}] \\ 0, x \in [TT_{Med}, TT_{Max}] \end{cases}$$

$$\mu_{Medium}(x) = \begin{cases} \frac{x}{TT_{Med} - TT_{Min}}, x \in [TT_{Min}, TT_{Med}] \\ 1 - \frac{x}{TT_{Max} - TT_{Med}}, x \in [TT_{Med}, TT_{Max}] \end{cases}$$

$$\mu_{Good}(x) = \begin{cases} 0, x \in [TT_{Min}, TT_{Med}] \\ \frac{x}{TT_{Max} - TT_{Med}}, x \in [TT_{Med}, TT_{Max}] \end{cases}$$

With,

$$TT_{Min} = Min\,(TT_i), i = 0,1, \dots n,$$

$$TT_{Max} = Max\,(TT_i), i = 0,1, \dots n,$$

$$TT_{Med} = 0.5 * (TT_{Min} + TT_{Max})$$

TT being the transit time of the option;

n being the number of possible options (transport chains, in case of freight forwarder's decision making process, or number of bids, in case of shipper's decision making); process.

In what concerns the *fuzzy inference step*, the process consists in computing the final output fuzzy value for every option. Thus, for every option *i*, the final output fuzzy value is computed as follows:

$$\mu_i(x) = Weight_{Time} * \mu_{Time} + Weight_{Price} * \mu_{Price}$$

i = 0, 1, …, n

n being the total number of options.

The fuzzy weights represent the behaviour of the shipper (and freight forwarder). They are defined at outset and they remain constant during a simulation.

Phase 2 - Identification of the transport solution winner

The final step of the decision making process consists in determining the actual winner option. This step is conducted outside the fuzzy engine.

AFETAS determines the winner randomly, based on the propensity of each final output fuzzy value. The reason for utilising a random process instead a deterministic one is based on the fact of human judgement not being strictly rational. In case of a deterministic situation, the option with higher output fuzzy value should be the chosen one. However, it is expectable that a human decision maker does not always chooses the highest ranked option Firstly, let us consider a case where more than one option have similar output fuzzy values. In case of a deterministic situation, the choice would always be for the higher, even when the difference is very low. Yet, a human decision-maker could consider then as being practically identical and, therefore, choosing one or another in similar ways. Secondly, for some reason, the decision market may decide for a low valued option (either because she believes on those transport agents, or because she is (in same way) offended with the people working on the high ranked options), instead of the highest ranked option. Certainly, this may occur only sporadically, but it is nevertheless possible to happen.

The procedure built in AFETAS is explained below, and consist in four steps.

Step one consists in determining the propensity of each option, in relation to the set of option. The propensity is determined as follows:

$$Propensity_i = \frac{Final\ \ Output\ \ Fuzzy\ \ Value\ _i}{\sum_{j=0}^{n} Final\ \ Output\ \ Fuzzy\ \ Value\ _j}$$

Step two consists in forming a vector of propensities. Each position is calculated as the sum of the propensities of the previous positions, thus, the first position is equal to the propensity of option 0, the second position is equal to the sum of the propensity of option 0 and option 1, and so on and so forth.

$$List\ of\ Propenities = \{\ Propensity_0, \dots, \sum_{k=0}^{i} Propensity_k, \dots, 1\}$$

Step three consists in drawing a random number, *r*, with uniform distribution, between 0 and 1.

And finally *Step Four* consists in determining the winner option. The winner option is the one that fulfils the following condition:

$$Option\ i\ is\ winner\ if\ \ \sum_{k=0}^{i} Propensity_k\ \leq r$$

This procedure ensures, firstly, the random nature of the decision making process, which is inherent to every human decision. Secondly, it provides similar probability of choice to options with similar output fuzzy values, like for real world. And, thirdly, it provides probability of even options with low output fuzzy values to be chosen, although with low probability, again similar to real world.

5.3.2 Environment

Recalling the taxonomy put forth by Russell and Norvig (2003, pp 40-42) and earlier mentioned (Table 4.1), AFETAS's environment can be classified as follows:

- Partially observable: similarly to real world freight transport market, where transport operators keep most of the information undisclosed to the market (and, consequently, to the other transport agents), AFETAS's agents only have access to information they can capture from the market, such as: number of agents or schedules and routes. Both agent's private information (such as: pricing strategies, reliability levels, or financial performance) and negotiations' details (such as: pricing, volumes or quantities) are private to the agents directly involved.
- Stochastic: AFETAS is inherently random. At the beginning of each run, each agent's internal properties are randomly generated (within a certain interval), consequently an agent's given action seldom produces the same outcome.
- Sequential: the environment subsists throughout the entire lifespan of a simulation run;
- Static: environment's properties only change with intervention of agents (before the first order being placed on the market, there is no change on environment). Moreover, agents' decision making processes are instantaneous (take zero time); therefore, although simultaneous actions may occur, environment's properties do not change during the process, not affecting agents' expectations.
- Discrete: agents' can only assume, at each time, one of a pre-defined set of states. Consequently, the environment has also finite number of states (although, this amount increases with the number of agents).
- Multiagent: there is at least one element of each agent.

AFETAS's environment recreates in identical way the real world's physical properties, namely: time, distance or measure, volume or weight. Additionally, real world objects, such as: vehicles (trucks or aircrafts) or containers, also exhibit similar physical properties: in terms of capacities, speed or others.

In what concerns the geographical-related dimension, AFETAS recreates a market geography where air transport services are offered (Figure 5.3). The market is represented by two separated regions: *Origin Region* and *Destination Region*. Each region has a set of facilities (Origin Region: O_0 to O_n, and Destination Region: D_0 to D_t, $n, t \in N$), and one *Terminal* (Origin Region: T_O, and Destination Region: T_D). Facilities are places of either origin or destination of freight. Terminals correspond to the airport, where cargo is transferred between modes of transport (land and air transport modes). AFETAS considers there is enough cargo flow to support air transport links. Another way to look at these regions is considering them as the airports' hinterlands. This does not mean however that some portions of these regions may not belong to other airports' catchment areas.

Freight transport services occur in one direction from the origin region to the destination region. This represents a simplification in relation to real world air freight markets, but that the author believes does not undermine the process of validation[182].

In what concerns the agent's mobility, there is no actual movement of agents. The transport of freight is simulated using time-based referential: calculated with an average speed and the distance between points, plus a stochastic variable (to incorporate factors causing delays or earlier arrivals)[183].

Time-related dimensional properties of AFETAS are:

- Time is measured in hours;

---

[182] Air freight markets are normally unbalanced (Anderson, 2006, pp 39, Clancy and Hoppin, 2004, pp 179, Zhang and Zhang, 2002)), which results in different pricing strategies in each direction. In particular, market unbalances can be used for cross-subsidisation of directional markets (the most profitable market can subsidy the less profitable).

Also of notice is the fact that some companies may have unfair competitive advantage for any reason (such as: favourable bilateral agreements, exploitation of specific market niches, exploitation of stronger image and traditional relationships). However, these are special situations that lie outside the scope of this research work.

[183] More information will be provided later during agents' description.

- 1 year is considered to have 8736 hours and 52 weeks;
- 1 week has 7 days or 168 hours;
- Time 0 (zero) corresponds to Monday midnight;
- Working week has 5 days or 120 hours, ranging from hour 0 (Monday midnight) to 120 (Saturday midnight).

Distances are measured in kilometres. Object's dimensions, volume and weight are measured in metres, cubic metres and tonnes, respectively.

Freight is considered to have volume, weight and a certain level of fragility. The level of fragility influences the likelihood of damage: the higher isthe level of fragility, the higher will be the probability of damage. Air freight rates are given on basis of Equivalent Weight (EW), which is computed as follows:

$$EW = \max(weight, volume/6).$$

5.3.3 Agents

The following agents have been developed in AFETAS for simulating the freight transport agents:

- Shipper: places the orders on the market;
- Freight Forwarder: assembles and manages the freight transport services on behalf of shippers;
- Freight Transport Companies:
    - Air Transport Company: provides the air transport services between the airports;
    - Land Transport Company: provides the land transport services between the origin and the airport (door-to-terminal) or between the airport and the destination (terminal-to-door).

Additional proto-agents have been considered. These are entities with simple internal structures that perform simple tasks and that do not exhibit all features of an agent.

Instead they embody part of the agent's properties mentioned earlier on this research work[184] (Figure 4.7). These entities are:

- Terminal Handling Company: provides transhipment services, between land and air transport;
- Vehicle (aircraft, truck or multi-modal vehicle): conveys one or more orders between two points.

5.3.3.1 Shippers

Shippers initialisation attributes are presented in the following table (Table 5.1). Shippers perform two main tasks: tendering procedure (Figure 5.8) and payment and indemnities (Figure 5.9).

The tendering procedure is the task whereby the shipper determines the freight forwarder that will manage the transport service. Figure 5.8 presents the structure of this task. The tendering procedure is simulated through an auction process based on "first-price sealed-bid" protocol (Sandholm, 1999, pp 12). This is a one-round auction protocol. Each bidder (freight forwarder) presents one bid without knowing the other's bids. The best bid wins and the auction process ends.

The reasons for choosing this type of auction protocol are the following. Firstly, AFETAS simulates a spot market, where there is no long term contract between shippers and freight transport agents. In the real world, these negotiations tend to be simple and straightforward. The point is that they have to be carried out every time a consignment is to be dispatched. Shippers that periodically dispatch consignments, are not likely willing to consume resources in complex negotiations, if little benefit can be obtained[185] since spot market values are fairly similar[186]. Therefore, shippers contact freight forwarders to get prices and, unless in situation of either high prices or

---

[184] They were designed only for computational reasons, for reducing the complexity and bringing higher visibility to AFETAS.

[185] Higher benefits could be obtained from long term negotiations where freight forwarders and transport agent would be willing to offer special conditions for a minimum amount of transport services. This arrangements lie outside the scope of this research work because they are related with shipper and freight forwarder's relationships.

[186] Air transport agents publish their rates, and other companies are aware of theirs' competitors' prices. And although negotiations could occur, freight forwarders would hardly get significant discounts, since rates have to be first-place competitive enough to attract shippers.

significant price differences, they go for more rounds[187]. Secondly, this particular relationship (shipper and freight forwarder) is not the purpose of this research work and, consequently, this action based negotiation was found adequate to represent real world's procedures.

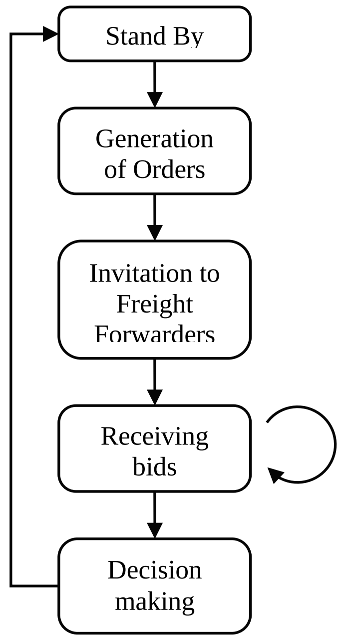
Table 5.1 – Shipper agent's attributes

Attribute	Description
`Fuzzy weights`	Weights for the computation of final fuzzy value (summing weight is equal to one);
`Weight per Shipment`	Interval of generation of orders' weight;
`Volume per Shipment`	Interval of generation of orders' volume;
`Maximum Unitary Price`	Maximum acceptable unitary price;
`Maximum Transit time`	Maximum acceptable transit time;
`Geographic coverage`	Fixed distances of origin to airport (of origin) and airport (of destination) to destination;
`Trust Positive Reward`	Increase on shipper's level of trust([a]) in relation to the freight forwarder for non compliance with initial conditions (delay or damage);
`Trust Negative Reward`	Reduction on shipper's level of trust([a]) in relation to the freight forwarder for non compliance with initial conditions (delay or damage);
φ	Memory effect on the Level of Trust;
`Number of Bids`	Quantity of Freight Forwarders asked for proposing bid;
`Shipments per week`	Maximum number of shipments generated by week, with indication of day of the week.

([a]) Level of Trust will be further explained when describing a shipper's tendering procedure.

Orders are randomly generated accordingly to the agent's initial attribute: `Shipment per week`; and are placed on the market at twelve o'clock (12H00) to be dispatched at eighteen o'clock (18H00) next day. An order consists on the following information: weight (`Weight per Shipment`), volume (`Volume per Shipment`), origin and destination (`Geographic coverage`), pick up time and maximum transit time (`Transit time`).

[187] The situation has however changed with the recent economic downturn. Shippers (and freight forwarders) became more price sensitive and, consequently, more willing to engage in negotiation to get better price conditions. This information was provided by Mr Amilcar Horta.



Source: author

Figure 5.8 – Customer's tendering procedure

The shipper invites a fixed number of freight forwarders for bidding (which is defined by the attribute: `Number of bids`). Real world shippers are typically not experts on transport market issues, being this the reason for hiring a freight forwarder. Certainly, shippers will only engage in negotiations with and eventually entrust their goods to those freight forwarders that they believe (or trust) are in conditions to provide an adequate transport service. Belief (or trust) has a multidimensional nature embracing factors such as: capacity to delivery on time and with no damage, availability to execute unforeseen or unusual demands, willingness to deliver tailored transport services or to give discounts. It is built upon time as freight forwarders give consecutively solid proofs of high and consistent service. Naturally, it can be eroded or destroyed when freight forwarder starts failing in delivering the expected services. Furthermore, the invitation of every freight forwarder on the market would be impracticable and time consuming and, thus, shippers only invite the most trustfully freight forwarders[188].

[188] The author concluded on this after some casual interviews with freight forwarders and from interviews with Mr. Pereira Coutinho and Mr. Mr Amilca Horta.

In AFETAS, the nature of the relationship between a customer and a supplier (shipper and freight forwarder, freight forwarder and transport agent) is simulated by a variable called: Level of Trust (LoT). The LoT of a customer *i* in relation to supplier *j*, for the time *t*, is computed as follows[189]:

$$\mathrm{LoT_{ij}}(\mathrm{t}) = \mathrm{LoT_{ij}}(\mathrm{t}-1) * (1-\varphi) + \mathrm{Reward}$$

The LoT, for time *t*, is function of the past LoT, for *t-1*, plus the amount of Rewards, obtained between time *t* and *t-1*. In AFETAS, LoT is updated every week, at Sunday (interval of time of 168 hours). Reward is given by the amount of successfully accomplished[190] transport services times the parameter `Trust Positive Reward`, plus the amount of non- successfully accomplished transport orders times the parameter `Trust Negative Reward`[191].

The parameter φ simulates the memory effect. The memory effect represents the fading out of the perception (either positive or negative) towards something (or somebody) over time. This mechanism is the result of several factors, namely: the fact of people tending to forget past events over time, or the fact of shipper's employees change and newcomers do not have developed memory.

Shippers will choose the highest freight forwarders in a number equal to the parameter `Number of bids`. Shippers only choose freight forwarders with positive LoT.

The freight forwarders may or may not offer a proposal for transport, depending upon their strategy.

The shipper's decision making process is emulated through the engine - decision making process, based in fuzzy set theories and fuzzy control. The engine considers two decision variables in the modal choice process, being: price and transit time. The rationale for the consideration of these variables is based on the review to the literature about modal choice factors (in Chapter 2.4).

[189] The formulation was inspired on the early work about learning and reinforcement by Roth and Erev (1995).

[190] A transport service is successfully accomplished when cargo is delivered without damage and within the time window initially agreed; otherwise is non-successfully accomplished.

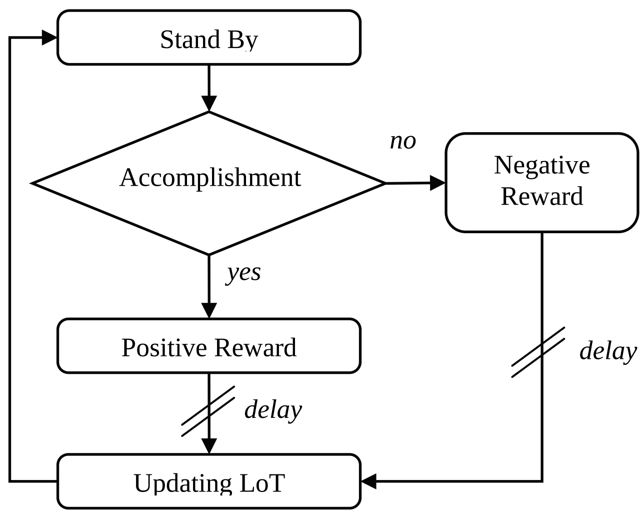
[191] The memory effect has an asymptote for LoT= 0, thus, a supplier with negative LoT would converge to zero (but be always negative). Since, a supplier to be called needs to have a positive value of LoT, an amount of 0.1 is added to any negative LoT, to force passing to positive values.

The *payment and indemnities task* are carried out upon conclusion of every transport service. The structure of the task is represented in Figure 5.9. Details on how AFETAS handles and considers financial flows (related with payments and indemnities) are provided later during explanation of interactions.

One of two situations may occur at the end of a transport service: accomplishment or non-accomplishment of initial demands. In the former case, freight forwarder receives a `Trust Positive Reward`; while in the latter case, the freight forwarder receives a `Trust Negative Reward`. These rewards are memorised to be used afterwards while updating the shipper's LoT.

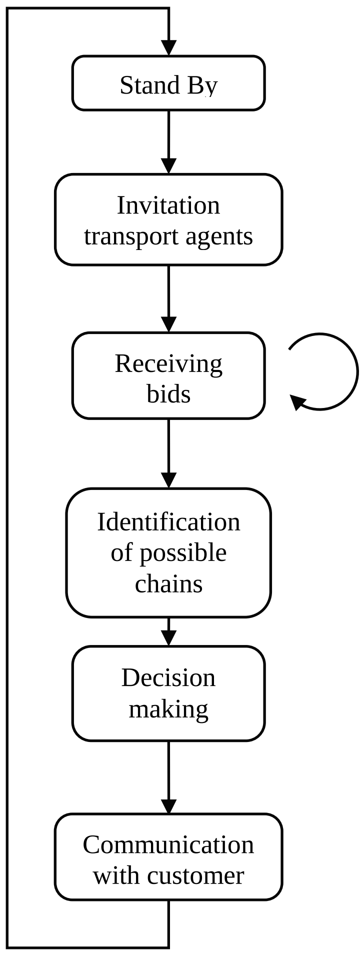
5.3.3.2 Freight Forwarders

Freight forwarder's initialisation attributes are presented in the following table (Table 5.2). Freight Forwarders perform two main tasks: *order processing* (Figure 5.10) and *payment and indemnities task* (Figure 5.9).



Source: author

Figure 5.9 – Customer's payment and indemnity procedure



Source: author

Figure 5.10 – Freight forwarder's order processing

Through the task of *order processing*, the freight forwarder agent builds the transport solution for offering to the shipper. The solution corresponds to an intermodal transport solution with three transport agents: two land legs and one air leg.

Step one, determination of time window for the air leg. In AFETAS both air transport services and land transport service on destination region have fixed schedules[192]. Land transport services at origin region, since do not work on fixed schedules, match their services accordingly to the times of the air leg.

[192] The purpose was to explore in higher detail the influence of fitness, in particular strategic fitness (schedule coordination). Fixed schedules may simulate either rail services and road services (some medium to long distance road services have fixed schedules).

Table 5.2 – Freight Forwarder agent's attributes

Attribute	Description
`Profit Margin`	Initial profit margin applied over transport agent's price, when service is negotiated;
`Profit Margin Variation`	Profit margin variation amount. Whenever freight forwarder decides to change her profit margin, the amount of variation is defined by this variable;
`Interval Profit Margin`	Minimum and Maximum admissible margin profits;
`Fuzzy weights`	Weights for the computation of final fuzzy value (summing weight is equal to one);
`Number of air bids`	Quantity of air transport companies to invite for bidding during the order processing task;
`Number of land origin bids`	Quantity of land transport companies at region of origin to invite for bidding during the order processing task;
`Number of land destination bids`	Quantity of land transport companies at region of destination to invite for bidding during the order processing task;
`Trust Positive Reward`	Increase on shipper's level of trust in relation to the freight forwarder for non compliance with initial conditions (delay or damage);
`Trust Negative Delay Reward`	Reduction on shipper's level of trust in relation to the transport agent for non compliance with initial condition (delay);
`Trust Negative Damage Reward`	Reduction on shipper's level of trust in relation to the freight forwarder for non compliance with initial conditions (damage);
φ	Memory effect on the Level of Trust;
∂	Level of Trust spillage effect.

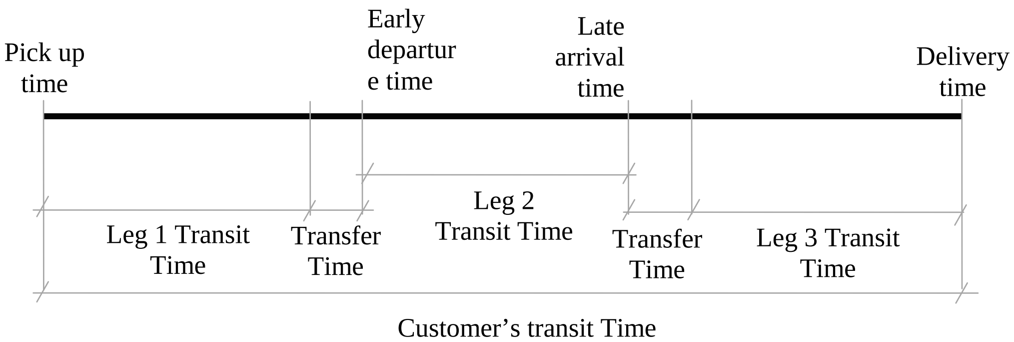
Time windows for air leg and land (destination) leg are computed as follows[193] (Figure 5.11). Air leg early departure time is equal to shipper's pick up time plus expected land based transport time plus expected transfer time at terminal. Land (destination) leg late departure time is equal to shipper's deliver times minus expected land based transport time. Air leg late arrival is equal to land (destination) leg late departure minus expected transfer time at terminal. Expected times are computed with based on average times, which are considered publicly available on the market.

[193] The determination of the time windows consists in a PERT analysis to the process of transport.

Step two, invitation of transport agents. Freight forwarder's invitation process is similar to shipper's. Each Freight Forwarder has a built-in LoT for every transport agent. On the moment of invitation, she invites the most trustful agents (with positive LoT) to the maximum amount defined by the parameters: `Number of air bids`, `Number of land origin bids`, `Number of land destination bids`. It is considered freight forwarder only invites transport agents with positive LoT.

The rationale underlying this process is similar to the one presented above for the shippers' invitation process. In the real world, freight forwarders have preferential relationships with transport agents, which normally stem from either past positive experiences or from market recognition. Certainly, freight forwarders would hardly send cargo on untruthful or unworthy transport agents, as that would imply high risks of non-compliance, with negative consequences on their own image before the customers. Consequence could include a reduction of activity with the shipper and, ultimately, going out of business. Furthermore, it would be unmanageable and costly to ask quotes for every transport agent on the market.

The information conveyed to all transport agents include the goods' volume and weight, in specific for land transport agents, the geographic location, and in specific for air transport agents and land (destination), the time windows. In the opposite direction, the information conveyed to freight forwarder includes the quote (price), transit time and possible schedules (in case of air transport and land based (destination) agents).



Source: author

Figure 5.11 – Intermodal transport service' time intervals

The land based transport agents may decline to offer. If all decline, the freight forwarder invites other transport agents with positive LoT. If there is no more transport agents, the freight forwarder declines the shipper's request. It is assumed the freight forwarder does not take the risk of choosing transport agents with negative LoT, as the quality of the transport solution would be undermined and the likelihood of non-compliance too high.

Freight forwarders' LoT is updated on a weekly basis (every Sunday), following the same mechanism as presented for the shippers. Yet, in this situation, a distinction between delay and damage is made and two different negative reward attributes are considered: `Trust Negative Delay Reward Trust` and `Negative Damage Reward`. The rationale is that a freight forwarder may perceive a delay with a different intensity than a damage .

In the real world, freight forwarders do market intelligence. They are constantly scanning the market for better transport providers for future services or, alternatively, understanding those who underperform in order to avoid them in the future. The author concluded this based on several conversations with freight forwarders and transport agents. Commonly, each freight forwarder was, firstly, able to indicate the shippers and transport companies that her competitors worked with and, secondly, aware of any recent fault (such as: accident, delays, strikes, etc.) or success (such as: reliability flexibility, vehicles acquisitions, etc) of most transport companies. Market intelligence is necessary for agents to remain competitive and to avoid being overruled competitors[194]. In order to simulate, the transport agents' image on the market, a spill over effect was implemented in AFETAS. The change in the LoT of freight forwarder *j* towards transport agent *k* due to a change in the LoT of freight forwarder *i* is given by:

$$\mathrm{LoT}_{jk}(\mathrm{t}) = \partial * \mathrm{Reward}_{ik}(\mathrm{t}) + \mathrm{LoT}_{jk}(\mathrm{t}-1)$$

The factor ∂ is the spillage factor, and represents the impact of a change that is conveyed in the market.

Step three, identification of feasible transport chain solutions. A feasible transport chain is a transport chain whose pick-up and delivery times are within the time windows demanded by the shipper. The pick-up and delivery times are computed by subtracting and adding the land transport times and transfer times to the air leg's schedule,

[194] The same behaviour was not observed with shippers. A reason is the fact of transport not being shippers' core activity, therefore, they were not-likely willing to spend resources on this kind of market intelligence. Likely, they would do market intelligence on their core business.

respectively. Not all possible transport chains are however considered during the decision making process, the worst solutions are immediately discarded. A solution is worse than another if for the same price it has a longer transit time, or if for the same transit time it is more costly[195]. The rationale for this action is due to the non plausibility that a human decision marker would take into consideration solutions that the onset are worst than others. Bearing in mind, that in the real world this process is to be done repeatedly and quickly (Chapter 2.4), most likely the decision maker will use any strategy to reduce the complexity of decision. So, at the end of this process, the freight forwarder has a list of all possible transport chains that fulfils shipper's time (and volume and weight) demands.

Step four, identification of *best* transport solution. The freight forwarder's decision making process is emulated in the same engine as shippers. Moreover, it is assumed that freight forwarders' decision making process is based upon the same attributes and with the same fuzzy weights as the shippers. The consideration of the same attributes by the freight forwarder is based on the need that to assemble the transport chain that best fits into the shipper's demands, the freight forwarder will use the same attributes (price[196] and transit time[197]) and weights. Otherwise, she would end up with a chain that, regardless of its value and performance, would not fit in the shipper's demands. The assumption that the freight forwarder uses the same weights is based on the fact that the shipper presents her demands to the freight forwarder.

Step five, determination of final price. Final price is computed as the sum of the price of each leg plus a profit margin. The initial value of the profit margin is given by the attribute `Profit Margin`. Real world markets are highly competitive with freight forwarders constantly looking for sources of competitive advantage. However freight forwarders have reduced scope for influencing their competitiveness level, since they

---

[195] The author has questioned some freight forwarder's employees about eventual cut off thresholds No explicit values were put forth. Yet, through the analysis of some hypothetical cases the following limits were agreed: in terms of the transit time a maximum difference of four hours and in terms of price a maximum difference of five percent. The time threshold roughly corresponds to a half day work, which is the difference between the cargo to arrive at the beginning of the working day or only in the afternoon. The price thresholds corresponds to a difference of five euro cents per kilogram in a destination with a price of one euro per kilogram, which was considered the difference that begins to make a relevance.

[196] The time variable corresponds to the door to door transport time, equal to the expected delivery time of leg 3 minus expected pick up time of leg 1.

[197] The price variable corresponds to the sum of the price of the three transport legs.

are pure-service providers (at least, in AFETAS); indeed, the only mechanism consists in changing their own profit margins and, thus the final price[198].

In the real world, freight forwarders are constantly adapting their profit margin, in order to offer better prices than competitors and to match shipper's willingness to pay[199]. In order to simulate market's pricing and competition dynamics, AFETAS has implemented a freight forwarder's dynamical profit margin calculator. The mechanism works as follows:

- If previous bid (of that shipper) was lost then profit margin is reduced by the amount defined in the attribute `Profit Margin Variation;`
- If past two bids (of that shipper) were won, then profit margin increased by the amount defined in the attribute `Profit Margin Variation`;
- Otherwise, profit margin does not change.

These simple rules allow for each freight forward adapting to the shippers' willingness to pay, and they are expected to emulate a real world behaviour.

AFETAS considers a maximum and minimum value for the profit margin. In the real world, profit margin moves around certain limits, which are dynamically adjusted by the market conditions. A progressive growth on profit margin will call for new comers or, eventually, force authorities to intervene in the market. Conversely, a continuous reduction of profit margin may signify over-competition and lack of capacity of the agent. The final outcome is typically bankruptcy of one or more agents or, eventually, intervention of authorities. In both cases, natural mechanisms occur to counteract abnormal fluctuations in the market. Although AFETAS simulates a market, in some situation the market dynamics may not be realistic (for example: simulation with a single freight forwarder), and thus artificial boundaries are introduced to prevent agent's profit margin to reach implausible values.

[198] Chapter 2.3 discusses in detail the sources of performance of an intermodal transport chain. One of these sources results from the freight forwarder. Naturally the minimum price is for a profit margin of zero.

[199] The willingness to pay represents the maximum price a shipper is willing to pay for a product of service. The willingness to pay defines, therefore, the upper threshold for the price and the maximum amount a supplier can get. The interested reader on this issue is referred to Breidert (2006).

Step six, communication of the offer. If won then the transport agents are notified, otherwise the freight forwarder waits for a novel request.

The last tasks done by a freight forwarder is the *payment and indemnities* task. This task is identical to the task performed by the shipper presented above, so, no further explanations are necessary to be provided at this moment.

5.3.3.3 Air Transport Company

Air Transport Company's initialisation attributes are presented in the following table (Table 5.3).

AFETAS considers no costs are due per empty flights. The rationale is that combination companies are passenger companies that also provide cargo services and, therefore, flights will occur regardless the existence or not of cargo. Essentially, it is assumed that the air transport companies adopted a strategy of unit business for their cargo division[200]. Furthermore, it is not simple to compute and allocate costs to the freight segment.

The tasks produced by an Air Transport Company are: order processing (Figure 5.12) and physical transport (Figure 5.13).

The order processing task starts with a request from the freight forwarder for presenting a proposal. For the time window indicated by the freight forwarder, the air transport company determines the possible schedules. Secondly, checks if there is available space (weight and volume) to transport freight. In case of availability, market price is obtained by multiplying the `Unitary cost of production` with the freight's equivalent weight and the `Profit Margin`.

The information sent to the freight forwarder includes: price and the identified schedules. If order is won, a physical transport service is scheduled for that date.

AFETAS does not have any revenue management scheme implemented. However, similarly to the case of the freight forwarder agent, a mechanism for determining the

[200] The various strategies of combination companies towards air cargo business were presented in Chapter 1.1.

freight forwarder's willingness to pay is implemented. The rationale and rules of the mechanism are similar to those presented above for the freight forwarder.

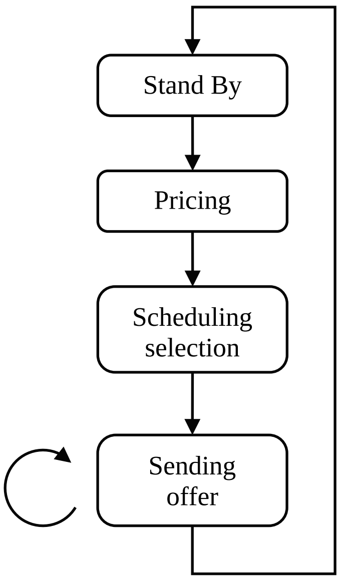
Table 5.3 – Air Transport Company agent's attributes

Attribute	Description
`Transit time`	Transit time between two airports;
`Profit Margin`	Initial profit margin applied over production costs, when service is negotiated on the market;
`Profit Margin Variation`	Profit margin variation amount. Whenever transport agent decides to change her profit margin, the amount of variation is defined by this variable;
`Interval Profit Margin`	Minimum and Maximum admissible margin profits.
`Unitary cost of production`	Cost of transporting one equivalent kilogram;
`Schedule`	Weekly schedule of the flights;
`Reliability damage`	Array of probability of induced damage. It is considered that relevant freight forwarders (in terms of weight transported) receive dedicated treatment and, thus, higher resources are put at their disposal, with a reduction on the probability of damage.
`Reliability delay`	Probability of induced delay. Considered fixed because transport agent's core business is passenger. Thus reliability depends on other factors than cargo business.
`Maximum volume capacity`	Maximum volume of the aircraft;
`Maximum weight capacity`	Maximum weight capacity of the aircraft;

The final task deployed by an air transport company agent is the physical transport of freight between the two airports. On every flight there is a list of booked orders from the various freight forwarders; yet, for diverse reasons (for example: delays) orders may not arrive on time. Therefore, the orders actually loaded may not entirely correspond to the list of booked orders. At the departure time[201] those orders are loaded into the aircraft,

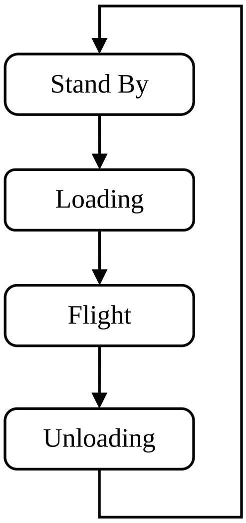
[201] As a matter of fact this is not actual aircraft's departure time, but the flight's closing time, which normally is done 90 to 120 minutes before departure time. During this period freight is loaded onto unit load devices or into containers and transported to the ramp where the aircraft will departure. In AFETAS and for simplicity reasons the air transport company's agent transit time encompasses this period.

and they include booked orders and, eventually, delayed cargo (that missed previous flights and has meanwhile arrived). If aircraft's capacity is not enough for accommodating all the cargo, than the booked orders have priority over delayed cargo. Loading operations are done by the handling agent and simulated through the proto-agent: *terminal*. The flight is simulated by a proto-agent vehicle designated by *aircraft*. Properties of these proto-agents are explained later on this chapter. At the end of the transport, orders are unloaded by the handling operators and made available for land transport.



Source: author

Figure 5.12 – Air transport company agent's order processing



Source: author

Figure 5.13 – Air transport company agent's physical transport

5.3.3.4 Land Based Transport Company

Land Based Transport Company agent's initialisation attributes are presented in the following table (Table 5.4). It performs two main tasks: order processing (Figure 5.14) and physical transport (Figure 5.15). The task order processing is triggered by the receivable of a request from the freight forwarder. The agent starts by determining if there are available resources (in function of the `Refusal order rate`). If so, the transport agents in the destination regions compute the possible schedules in function of the time window provided by the freight forwarder. Transport agents in the origin region do not have fixed scheduled so do not need to perform this task. Finally, in case of availability of resources and schedules (in case of agents in destination region), the final price is computed as:

$$\text{Price} = \text{Profit Margin} * (\text{Unitary fixed price} * \text{Transit time} + \text{Unitary marginal price} * \text{Lenght} * \text{Weight})$$

The profit margin is computed like for freight forwarders and air transport agents. The rationale is also the same as presented for those agents.

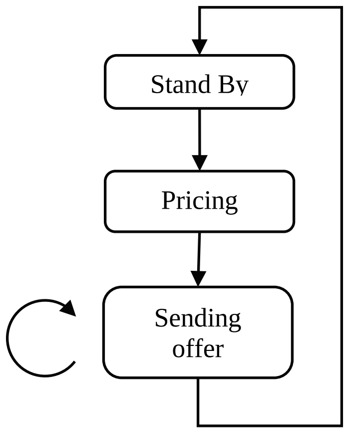
Table 5.4 – Road Transport Company agent's attributes

Attribute	Description
`Unitary fixed price`	Price per hour of transport;
`Unitary marginal price`	Price per kilogram and per kilometre of transport;
`Profit Margin`	Initial profit margin applied over production costs;
`Profit Margin Variation`	Profit margin variation amount. Whenever transport agent decides to change her profit margin, the amount of variation is defined by this variable;
`Interval Profit Margin`	Minimum and Maximum admissible margin profits.
`Reliability damage`	Array of percentage of induced damage. It is considered that relevant freight forwarders (in terms of weight transported) receive dedicated treatment and, thus, higher resources are put at their disposal, with a reduction on the probability of damage.
`Reliability delay`	Array of percentage of induced delay. It is considered that relevant freight forwarders (in terms of weight transported) receive dedicated treatment and, thus, higher resources are put at their disposal, with a reduction on the probability of damage.
`Refusal order rate`	Probability of order that are not accepted. For simplicity reasons, it is assumed road transport companies have infinity capacity (in practical terms: they can go to the market and get as many trucks as they want). Yet, in the real world, for the most diverse reasons, these agents do not positively respond to every request (for example: no available trucks or available trucks too far away). This refusal order is a solution to simulate reality, avoiding the need to simulate a road transport company's fleet management, which lies outside the scope of this research work.
`Schedule` ([a])	Weekly schedule of the transport services;

([a]) Only transport agents in the destination region have fixed scheduling

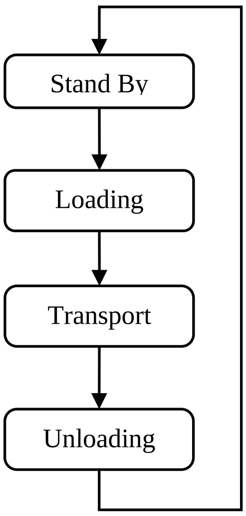
The physical transport of freight comprehends the land transport of freight. In case of the origin region, at the time of booking the transport service is initiated. In case of the destination region, the transport service is initiated accordingly to the transport agent's schedule, and the orders available at the airport are conveyed until destination. Delayed orders are kept at the airport waiting until the next schedule.

Like for air transport company, transport is produced by a proto-agent vehicle: *truck*, which are detailed later on. At the end of the transport service the cargo is delivered and the vehicle agent is terminated.



Source: author

Figure 5.14 – Land based transport company agent's order processing



Source: author

Figure 5.15 – Land based transport company agent's physical transport

5.3.3.5 Proto-agents

The Terminal agent incorporates two real world processes that occur almost in parallel: handling process and customs clearance. The former corresponds to the modal transfer of freight, while the latter corresponds to the legal process necessary for authorising freight to leave the airport. There are two terminal agents each one operating at a terminal. The attributes of this pseudo-agent are presented in the next table (Table 5.5).

Terminal agents do two main tasks: freight's handling services and short period storage. Such tasks are required typically in four moments along an intermodal transport chain: at the airport of origin, for unloading land transport vehicle (and storage freight at the terminal) and for loading aircraft; and at the airport of destination, for unloading aircraft (and storage freight at the terminal) and for loading land transport vehicle. The time to carry out the activities depend on both terminal's productivity and customs clearance time. Since these two processes may to some extent run in parallel, the overall time is not the sum but likely the maximum value.

Table 5.5 – Terminal agent's attributes

Attribute	Description
Reliability damage	Probability of damage induced on cargo during handling process;
Handling transfer time	Required time for processing the handling process.

AFETAS entirely simulates the terminal's tasks. The main actions are:

- Unloading of land transport vehicle upon request and storage of freight at the terminal;
- Loading of aircraft upon request;
- Unloading of aircraft upon request and storage of freight at the terminal;
- Loading of land transport vehicle upon request.

Handling time is considered constant over time, and defined by the attribute: `Handling transfer time`. In the real world, air transport companies impose deadline times for the arrival time of cargo at airport (unless in special conditions[202]). Some reasons may be pointed out: the handling procedures take time and, in case of unexpected peak periods, the handling operator needs to ensure cargo is prepared on time; some customs procedures may require cargo to be physically at the terminal before final clearance; or, the cargo leaves the terminal towards aircraft some time before its departure[203].

In terms of behavioural properties, AFETAS considers that the handling and the storage processes may provoke damage on cargo. The level of reliability is given by the attribute: `Reliability damage`. On every transfer process, a random number is

[202] For example, in case cargo arrive airport already unitised and there is no need for handling procedures.
[203] Not only because there is some distance between the terminal and the aircraft location. For example: at the airport of Lisbon cargo takes 40 minutes to arrive aircraft, while at Brussels that time is around 60 minutes. These values were obtained from an interview with Mr Mário Simonetti.

generated, following a uniformly distributed probability function, to determine whether cargo was damaged or not. If the random number is greater than the reliability level then damage occurs; otherwise, there is no damage.

Any damage provoked by the terminal agent is considered to occur during the air leg. The point is that the handling operator works for the air transport company therefore the liability for any misconduct within the terminal lie with the air transport company. Indeed, the handling operator is invisible for the freight forwarder (or the shipper), which only has a legal bound with the air transport company.

The following proto-agent is the vehicle which is responsible for simulating the physical transport of freight between locations. There are two types of (proto-agents) vehicles in AFETAS: (passenger) aircraft and land transport vehicle (truck). All the properties of the proto-agents vehicles are embedded on the respective transport agent, being inherited during generation process[204]. The following table presents the attributes of the pseudo-agents vehicles.

Vehicles are the only agents that do not endure throughout the lifespan of a simulation run. Instead, they solely exist during the period of transport: they are generated at the moment of starting the transport service, and are terminated at the moment of unloading the cargo. This is the reason for the above mentioned fact of all their properties being inherited from the parent transport agent.

Table 5.6 – Vehicle agent’s attributes

Attribute	**Description**
Reliability damage	Probability of transport services provoking damage on freight;
Reliability delay	Probability of transport services to be delay.

The following behaviours are implemented: delay and damage. A vehicle may suffer a delay in relation to the initial schedule for the most diverse reasons, of which congestion is the most frequent. Delays are simulated in a two-steps approach. First, it is determined whether the service will be delayed or not. A random number between zero

[204] They are presented separately for clarity purposes

(0) and one (1) is generated, following a uniform distribution function, if the random number is greater than the attribute `Reliability delay` then there is delay, otherwise transport service is delivered on schedule. Second, the amount of delay is computed. The amount of delay is randomly generated following a lognormal[205] distribution function with the following properties: mean: -1.5, standard deviation transport time/4 and minimum value of 0. Moreover: a minimum delay of fifteen minutes for land transport and thirty minutes for air transport is considered. Damage is computed following the same rules already described for the terminal agent and utilising the attribute: `Reliability damage`. Recall that reliability delay (Table 5.4) and reliability damage (Table 5.3, Table 5.4) are arrays of values. Each values represents the reliability for a certain type of shipper. Three types of shippers (freight forwarders) are considered: non-relevant if she accounts for less than five percent of transport agent's total volumes; medium-relevant if she accounts for less than twenty percent, and relevant otherwise. The lower bound is the reliability considered for the non-relevant shipper, the middle value the reliability for the medium relevant shipper, and the upper bound the reliability for the relevant shipper.

5.3.4 Interactions

The presentation of AFETAS's interactions will be done independently for each one of these flows. This is for both simplicity and clarity of purposes, as it provides a simpler and direct comparison with real world.

In an intermodal freight transport service there are four main types of flows:

- Physical: corresponding to the transfer of the goods between freight transport agents (unidirectional from origin to destination);
- Informational: corresponding to the exchange of information between freight transport agents;
- Legal: corresponding to a freight transport agent's liability for carrying freight;

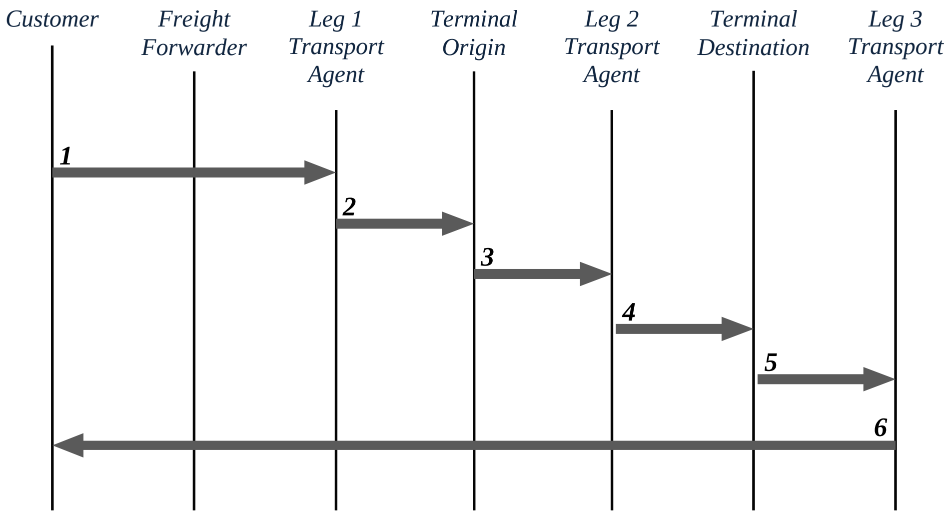
[205] Lognormal function was found the most suitable distribution function, because it does not assume negative values (there is no negative delays) and it is skewed to the right (most delays occurs around a certain value close to the minimum, and long delays tend to be rare).

- Financial: corresponding to the payments (or indemnities) for providing the transport service.

5.3.4.1 Physical

Figure 5.16 presents the physical interactions between transport agents on AFETAS, for an intermodal freight transport service. The physical interactions arise from the transfer of freight between transport agents. The sequence of interactions are:

1. Freight transfer from origin point (shipper) to vehicle of leg 1;
2. Freight transfer from vehicle of leg 1 to terminal of origin;
3. Freight transfer from terminal of origin to vehicle of leg 2 (aircraft);
4. Freight transfer from vehicle of leg 2 (aircraft) to terminal of destination;
5. Freight transfer from terminal destination to vehicle of leg 3;
6. Freight transfer from vehicle of leg 3 to destination point (shipper).



Source: author

Figure 5.16 – Sequence of the physical flow

5.3.4.2 Informational

The production of an intermodal freight transport service requires intensive exchange of information among transport agents. Informational interactions occur in two contexts involving different agents and conveying different contents, being: chain assemblage process (sub process 1 in Figure 2.8) and physical transport process (sub process 2 in Figure 2.8).

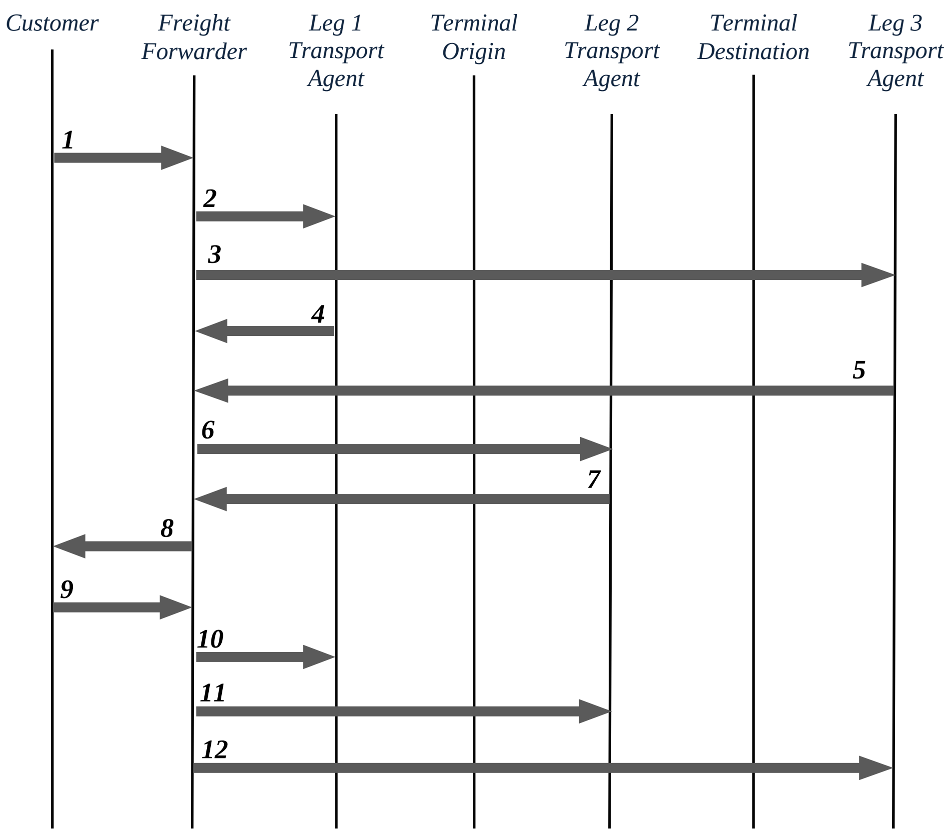
The first event of informational interaction is during assemblage of the freight transport solution. Figure 5.17 presents the sequence of the flow of information during this process. The sequence of interactions are:

1. Shipper agent invites a set of freight forwarders to tender a future transport service;
2. Freight forwarder agent invites a set of land based transport companies (at origin region) to tender transport service;
3. Freight forwarder agent invites a set of land based transport companies (at destination region) to tender transport service;
4. Land based transport companies of origin region present offer;
5. Land based transport companies of destination region present offer;
6. Freight forwarder agent invites a set of air transport company agents to tender transport service;
7. Air transport company agents present offer;
8. Freight forwarder presents its best offer;
9. Shippers notifies every freight forwarder on her decision (win or lose);
10. Freight forwarder winner books land transport company agent winner (origin region);
11. Freight forwarder winner books air transport company agent winner;
12. Freight forwarder winner books land transport company agent winner (destination region).

Figure 5.18 presents the flow of information during the physical transport process.

1. On start of leg 1, land transport company agent generates vehicle and loads information about the transport service;
2. On arrival to terminal of origin, vehicle notifies terminal agent for initiating unloading of freight;
3. Notification of parent agent and consequent termination;
4. On start of leg 2, air transport company agent generates vehicles and loads information about the transport service;
5. Air transport company agent notifies terminal agent for loading cargo on vehicle;

6. On arrival to terminal of destination, vehicle notifies terminal agent for initiating unloading of freight;
7. Notification of parent agent and consequent termination;
8. On start of leg 3, land transport company agent generates vehicle and loads information about the transport service;
9. On arrival to destination, vehicles notifies parent agent and terminates;

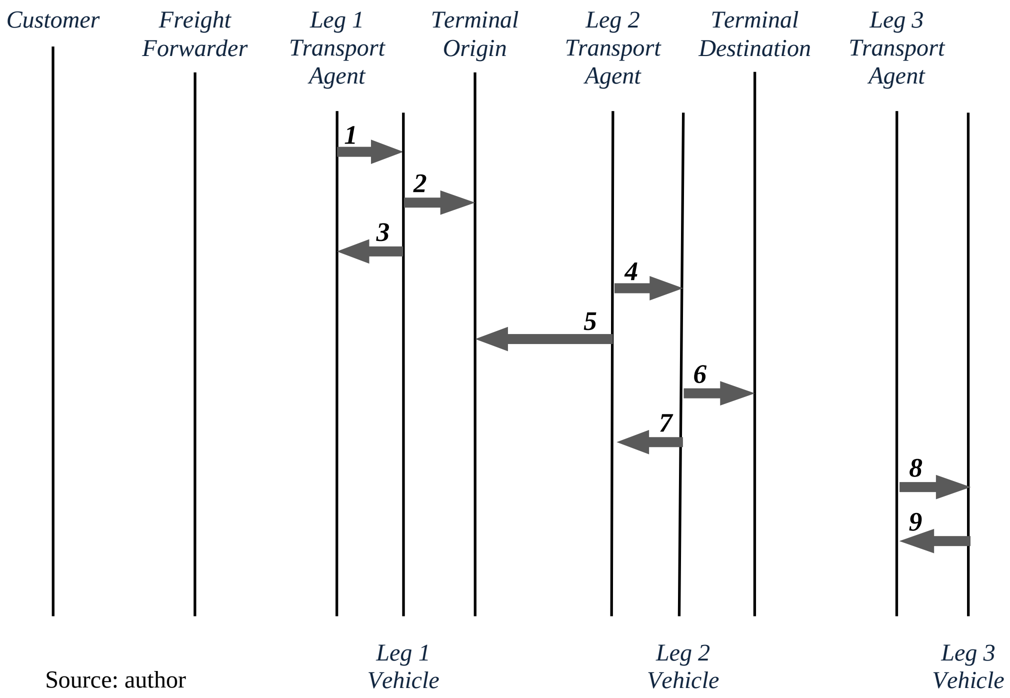


Source: author

Figure 5.17 – Sequence of the information flow – assemblage of transport solution

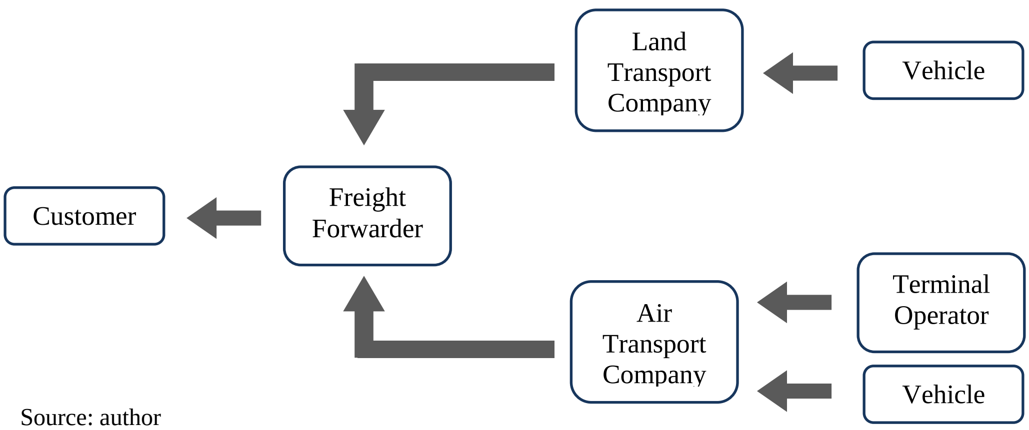
5.3.4.3 Legal

Figure 5.19 presents the hierarchical structure of accountability and liability in AFETAS. Responsibility hierarchy follows a customer - service provider relationship; therefore, every agent is accountable for both own actions and her service providers' actions. As a result, to the shipper the freight forwarder is the sole responsible for any non-compliance in the freight transport service. The freight forwarder in turn considers responsible the transport company agent that provokes the non-compliance. Land transport company agents are liable for their vehicles' operations, while air transport agent is liable for both aircrafts and terminal operator's operations. Air transport company agent bears the responsibility of the terminal operator since this agent works on her behalf.



Source: author

Figure 5.18 – Sequence of the information flow – physical transport process



Source: author

Figure 5.19 – AFETAS's hierarchical structure of liability relationships

In the real world, responsibility claim consists in the payment of an indemnity to the shipper after enquiry, dispute and negotiation. In AFETAS, responsibility claim is taken into consideration by a change in the Level of Trust variable.

AFETAS consider two types of non-compliance sources: delay and damage. A delay occurs when cargo is delivered outside the window time defined by the shipper (after shipper's deadline). A damage occurs when cargo is deliver to shipper damaged. Delay and damage may occur simultaneously.

In the real world, allocation of responsibility depends upon the unequivocal determination of the responsible agent. AFETAS works in the same manner. In what concerns delay, allocation of responsibility is immediate since transit times are known: arrival on terminals and arrival on destination. Therefore, whenever a transport company agents delays, it is automatically recorded[206].

A shipper may claim responsibility from a freight forwarder whenever transit time is longer than the initial demand (delivery is after deadline). The freight forwarder in turn may claim responsibility from (that or) those transport agents that have delayed. Yet, a situation may occur when overall transit time is inferior to shipper's demand (there is no delay), but one or more transport provided have delayed. This may occur on those situations where transit time is inferior to shipper's windows time. Delays on individual legs may be offset by that buffer time. In these situations, the freight forwarder does not claim responsibility to the transport agent (or agents) that have delayed (like in a current procedure in the real world).

In what concerns damage, the principle is the same as adopted in accountability of delay, however, identification of damage is not so straightforward as with delay. AFETAS simulates real world complexity following a set of rules. In case of damage, the shipper may naturally claim responsibility from the freight forwarder, since this is the agent sole responsible for the transport service. Yet, freight forwarder can only claim responsibility from a transport agent if damage is unequivocally determined.

Intermodal transport services are still nowadays a set of individual transport services, with a clear duration: it starts once transport agent accepts cargo for loading and it ends

---

[206] For computational rounding reasons a maximum delay of 1 minute is allowed.

once next transport agent (or shipper, in case leg 3) accepts cargo. Consequently, the acceptance of the freight by the transport agent (or shipper in case leg 3), denotes in legal terms that the freight is in good conditions (there is no damage). Obviously, in case of damage, the transport agent (or shipper, in case leg 3) may refuse to accept freight, or accept but with a remark about the existence of damage. Therefore, at both airports, the freight is conveniently checked for damage (both apparent as well as internal); and, any damage, provoked during transport is detected. If undetected the following transport agent (or shipper in case leg 3) assumes full liability.

5.3.4.4 Financial

Financial interaction corresponds to the monetary transactions between agents. AFETAS does not explicitly consider financial flow. It is therefore assumed that at the end payments or indemnities are duly processed. Payments are due for the compliance of the initial conditions and money flows from the customer towards the transport provider. Indemnities are due for the non-compliance of the initial conditions and money flows in the opposite direction from the transport provider towards the customer.

Financial flow is only considered indirectly, since the existence of an indemnity implies non-compliance and thus negative reward, while the existence of a payment implies compliance and thus positive reward.

5.4 Verification and Validation of ABM models

Verification and validation is an essential phase of the model development process if we want it to be accepted and used. The outcomes of an untested model have no value and, obviously, should not be used. North and Macal (2007, pp 221) put it bluntly by writing that “before appropriate verification and validation, models are toys; after appropriate verification and validation, models are tools”. The key issue lies however on what is meant by *appropriate*, or in other words: how many and what kind of tests are appropriate?

A caveat should be made at this moment, regardless the amount and nature of tests any model is hardly ever verified or validated; at best, we could get confidence on the model’s outcome (North and Macal, 2007, pp 221, Sterman, 2000, pp 846, Carson II, 2002, 52). The reason lies on the fact that models are ill-representations of the reality (Sterman, 2000, pp 846). As such, verification and validation is always a matter of judgement and credibility[207] building.

Although verification and validation are commonly done in parallel, they refer to different concepts (Carson II, 2002, pp 52). Verification refers to the steps, processes or techniques that the modeller deploys to ensure that the model behaves accordingly with the initial specifications and assumptions (North and Macal, 2007, pp 221, Carson II, 2005, pp 21). Validation refers to the steps, processes or techniques that the modeller (and any other interested party) deploys to ensure that the model adequately represents and reproduces the behaviours of the real world phenomenon (North and Macal, 2007, pp 222, Carson II, 2005, pp 21).

Verification and validation of agent based models (or other dynamical methodologies of modelling) raises different challenges than traditional parametric or equation based models, namely the verification and validation of agents' behaviours, interaction mechanisms or the processes and structures that emerge within the model (North and Macal, 2007, pp 222). This is particularly complex as there is currently no satisfactory theory of human behaviour, and often agents do represent human behaviour or activities (North and Macal, 2007, pp 230, Jaeger, 2000, pp 58). Such absence undermines our ability to conveniently verify and validate agent based models. Additionally, agent based model's unexpected results may raise the following doubt: is the result of a model's flaw or a major scientific breakthrough? This is of particular relevance because emergence phenomenon requires tackling the model as a whole (it is irrelevant to look to particular aspects). Yet, often models are too complex for human understanding, rendering that requirement unattainable. These facts emphasise the need of carrying out the verification and validation endeavours more carefully and in depth.

Verification is concerned with the inner part of the model, if it is running well with no mistakes (bugs or other inconsistencies), and if it performs every task as initially specified. The literature is abundant in recommendations and examples of tests for carrying out the verification of models. In this research work, the process of verification

[207] Credibility refers how peers, users or other interested parties consider the model (North and Macal, 2007, pp 227, Carson, 2005, pp 21, Castle and Crooks, 2004, pp 38).

of AFETAS embraced several of those tests that were repeatedly performed throughout the development of the model. The main tests done are presented below:

Stress testing and testing with a wide range of parameters and different random numbers (Carson II, 2005, pp 21, Sterman, 2000, pp 869, Peterson and Eberlein, 1994, pp 162).

Each component of the model and the model itself were tested under extreme or very unlike situations, like for example: zero-percent reliability, zero speed, zero-agents, multiple-simultaneous requests of shippers, or ever growing demand and capacity. In such extreme conditions the behaviour of the model becomes foreseeable and, thus, any errors or flaw are of easier detection (such as: negative transit times).

Thorough review of all model outputs, not just the primary measures of performance, but numerous secondary measures (Carson II, 2005, pp 21). The purpose of these tests is to increase the model's transparency. The variables presented in the discussion of results are only but a few of the total amount of variables collected during the simulations. The other variables also monitored during simulation include (but are not exhaustive[208]):

- Related with the consignment: id of the winner agents, times (such as: pick up and deliver in all legs, and expected and actual times), shippers and agents' payments due, eventual penalties or the values of the fuzzy variables;
- Related with the transport agent, amount of won orders, amount of profits and indemnities, or profit margin for every freight forwarder;
- Related with the freight forwarder: properties of all transport services (such as: transit time, pickup and delivery times, or intermediary fuzzy values), profit margins for each shipper, level of trust for every transport agent.

Debugging the model through automatic procedures (like the software's debugger), this ensures no bug is overlooked (Norh and Macal, 2007, pp 222).

[208] The total list of variables can be seen directly in the AnyLogic model, in Annex VI – Compact Disk.

The author used the Educational version of the AnyLogic software, which does not allow for automatic debugging. The solution passed by implementing a set of conditions (if –then) to detect non-possible situations[209].

Adoption of unit tests[210] while programming way (North and Macal, 2007, pp 224, Castle and Crooks, 2006, pp 35).

AFETAS was built piece by piece and every new feature or improvement was introduced only after being subjected to a complete set of tests. This task was made easy because of the object-oriented nature of JAVA programming, which enables the insertion of new objects (the unit tests) without the need to modify the rest of the software.

However, it should be noted that ensuring the proper working of each unit does not necessarily entails the model is working properly (although, the contrary does, i.e.: a flaw in a sole unit test would inevitably result in the model's failure).

Documentation of the model (Sterman, 2000, pp 855, Peterson and Eberlein, 1994, pp 163).

The process of documentation started in the very inception of the model, it continued throughout its development and it resulted in the current piece of writing[211]. Documentation contains every detail about the model, such as: variables, functions, arguments, assumptions, outputs, or structure. This process ensures the model and results can be understood, replicated, reviewed and extended by others. Replication is of particular interest as it allows others to re-build the model, checking for errors, besides introducing transparency and increasing the utility of the modelling work.

Review by a more senior or other simulation professionals (North and Macal, 2007, pp 222-223, Carson, 2005, pp 21)

---

[209] Every if-then and loop cycles condition were complemented with other if-then conditions to capture absurd situations, in terms of the real world functioning, but possible in terms of computational and mathematical functioning.

[210] A unit test is a portion of either the model (which in case of AFETAS represents real world functions), such as: decision making engine, communication protocols, allocation resources, or loading vehicles; or the software, such as: function, method, module, or class.

[211] A full working version of AFETAS is available in Annex VI – Compact Disk with AFETAS Model.

Often, modellers undergo myopia[212], reducing their ability to detect bugs and other inconsistencies and a first-time observer is aware of details and aspects that the modeller would never think about. In the development of AFETAS, the author often exchanged thoughts and doubts with other doctoral fellows, professors and real practitioners[213], which were very helpful in eliminating some flaws and conceptual errors. Additionally, an early version of AFETAS was employed in the GLS case study and publically presented at a conference (Reis and Macário, 2008), and the current version of AFETAS was also publically presented in conferences (Reis and Macário, 2009a, 2009b), which allowed the author to receive useful comments and suggestions for improvement from other professionals and researchers.

After concluding the verification, the model was subjected to validation. The process of validation is meant to ensure that the model adequately represents the real world and that its results are meaningful. There are diverse techniques for validation, the one adopted in this research work was largely based in the proposal of North and Macal (2007, pp 227) and involves several features, being:

- *Requirements Validation*: the model should to answer to clear requirements and questions about the real world.

  AFETAS's specifications were described in detail in Chapter 5.2. Amongst others, AFETAS is required to simulate a real world freight transport model where intermodal air transport is feasible. Moreover, AFETAS is required to serve as a tool in the assessment of the validity of the conceptual framework.

- *Data Validation*: the data in the model should be valid.

  As is explained during the presentation of AFETAS, to the maximum possible extent, all the data used was from the real world. The data was obtained from either literature references, statistics sources or interviews.

- *Face Validation*: the assumptions of the model should be valid.

---

[212] Myopia refers to the phenomenon whereby the errors and flaws on an object became invisible by those who are continuously looking or experimenting it (Levitt, 1960).

[213] In particular the author is deeply grateful to Prof. Hilde Meersman; Mr. Deepak Baindur and Mr. Miguel Martínez, both doctoral students at the Instituto Superior Técnico; and Mr. Amilcar Horta for their comments and suggestion in the development of the model.

Likewise data, every assumption was either based on literature references or discussed with real world practitioners (or other academicians).

- *Process Validation*: agents and interactions' structure and steps in the model have to be clear, meaningful and correspond to real world process.

  The structure of AFETAS replicates the process of production of an intermodal freight transport service. Furthermore the structure was developed upon a previous model developed within the context of GLS case study, other literature references and real world experience gathered during the training periods.

- *Agent Validation*: agents' behaviours, relationships or interactions have to correspond to real world actions.

  The construction of AFETAS was based on the author's perception about real world operations and literature references. The purpose was always to recreate in virtual environment a real world freight transport market. Thus, inclusion and adoption of real world action was always the most important aspect.

- *Theory Validation*: model's theories (either about agents or process) have to be valid and used correctly.

  The behaviour of the agents and their interactions, and the properties of the environment were, to maximum possible extent based on sound theoretical formulations, like for example: memory effect (based on Roth and Erev, 1995) or the decision making engine (based on Zadeh, 1965).

  All theories were documented.

Other steps of validation included: the GLS case study, interviews with practitioners and the abovementioned publications and public presentations of the research work. The GLS case study also served as validation of AFETAS (besides the abovementioned verification) by allowing comparing the outcomes of the model with the real world behaviour. The process of validation included various calibrations and adjustments.

Additionally, multiple interviews[214] with both real world practitioners and academicians were conducted in the process of development, verification and validation of AFETAS. Unfortunately, most of the times these interviews (in particular with practitioners) served as an indirect way to validate the model. The main problem was that AFETAS simulates a fictitious market. Practitioners revealed major difficulties in grasping the full details of and, more importantly, to understand the purpose of the model. Consequently, they scarcely provided insightful feedbacks about its results. To overcome this difficulty, the author questioned about details (such as: demand patterns and volumes, number of shippers, freight forwarders or transport agents, transit or transhipment times, modal choice process, etc.) and not directly about the model.

Finally, the publications and public presentation (Reis and Macário, 2009a, 2009b, 2008) also served to for the author validating the model, since he has had to discuss the mode's details and outcomes with other academicians and practitioners. In this process insightful comments were received.

Concluding, since every step of the method proposed by North and Macal has been fulfilled; based on the results of the GLS case study, based on the interviews, and based on the feedbacks from publications and presentations; the author believes that the validation process was correctly conducted and, consequently, the model can be considered validated.

In complement to the description, in the following chapter during the presentation of the simulations and whenever relevant, further details of the validation process will be presented.

5.5 Experiments

This chapter presents and discusses the Experiments[215] undertaken with AFETAS to test the hypothesis and to assess the validity of the conceptual framework.

---

[214] The list of interviews is available in Annex III – The List of Interviews.

[215] An Experiment corresponds to a simulation of AFETAS with a specific configuration of its variables.

The hypothesis of this research work was presented in Chapter 1.4 and it claims that the integration of combination companies in intermodal freight transport services can enhance their competitiveness in the air cargo market.

The conceptual framework, developed in Chapter 3, explains the mechanisms of integration in the intermodal transport.

5.5.1 Design of the Experiments

The utilisation of AFETAS, for purposes of testing the hypothesis and of assessing the validity of the conceptual framework, required the customisation of the following set of features:

- Variable of competitiveness;
- Type of shippers;
- Type of markets;
- Type and amount of Experiments;
- Price variation;
- Time of simulation and number or runs;
- Properties of agents and proto-agents.

5.5.1.1 Variable of competitiveness

In order to test the hypotheses, the (change in the) competitiveness of the combination companies had to be assessed. The variable chosen to measure the competitiveness was the market share of an intermodal freight transport service. An intermodal freight transport service’s market share is defined as the ratio between the total quantity of freight transported and the total quantity of freight transported in the market.

The reason for this choice is that the market share of an intermodal freight transport service reflects its competitiveness in the market. Thus, a variation of an intermodal freight transport service's market share denotes a variation in its competitiveness. In practical terms, an increase in an intermodal freight transport service's competitiveness should result in an increase of its market share; whereas the opposite is expected to occur in case of a reduction of her competitiveness[216].

5.5.1.2 Type of shippers

Bearing in mind that the conceptual framework considers that the shipper's requirements influence the level of fitness, three types were considered, being:

- Time sensitive shipper – emulates shippers that give higher importance to time than price. The Price Fuzzy Weight was set to 0.25 and the Time Fuzzy Weight was set to 0.75 (Table 5.1);
- Neutral shipper – emulates shippers that give similar importance to price and to time. The Price Fuzzy Weight was set to 0.50 and the Time Fuzzy Weight was set to 0.50 (Table 5.1);
- Price sensitive shipper – emulates shippers that give higher importance to price than time. The Price Fuzzy Weight is of 0.75 and the Time Fuzzy Weight is of 0.25 (Table 5.1).

The choice of the type of shippers was done aiming to ensure the widest coverage of situations. The time sensitive shipper corresponds to the traditional shipper of air transport services that considers transit time as the key factor on modal choice. Conversely, the price sensitive shipper corresponds to the non-traditional shippers. The inclusion of this type of shipper in the Experiments was because price seems nowadays to play a growing role on the decision making process. The neutral shipper' behaviour lies in the middle of the other two types of shippers and it embraces all shippers that value both time and price, in similar fashion.

5.5.1.3 Type of markets

Accordingly to the conceptual framework, the level of fitness between dual systems influences the performance of the intermodal freight transport service. It is then fair to assume that at the outset a freight forwarder does not know which transport agents fit better. Only, by a matter of change, trial-and-error or looking to what others are doing,

---

[216] This also required no change in the competitiveness of the other intermodal transport services. Because if the others improved above the given intermodal transport service, then its competitiveness would reduce. Yet, as it is explained later in this chapter, the properties of the other agents remained unchanged and, therefore, their competitiveness remains constant.

the freight forwarder will in due course became aware of them. Consequently, the amount of transport agents in the market (and, thus, the amount of combinations of intermodal freight transport services) may influence the freight forwarder’s awareness process. After all, in a small market a freight forwarder will work with all possible transport services combinations sooner than in a larger market.

In order to remove a possible bias due to the amount of transport agents in the market, three types of markets were taken into consideration (Table 5.7). In Market Type 1 and Market Type 2, every transport agent, with positive a Level of Trust, is invited and all possible combinations are taken into consideration during the modal choice process; while in the Market Type 3, only the agents with a positive Level of Trust and up to a maximum of four (on each leg) are invited (number in brackets, last row Table 5.7).

Table 5.7 – Quantity of transport agents and shippers

Market Type	Transport Agents				Shippers
	Land Base Origin Leg	Air Leg	Land Base Destination Leg	Freight Forwarders	
1	1	2	1	1	1
2	2	4	5	3	10
3	20 (4)	10 (4)	20 (4)	5	12

Interviews with market agents were inconclusive on the amount of transport companies that each freight forwarder contacts during modal choice process. The factors influencing include: the freight forwarder’s own fleet, the type of destination (for example, infrequent destinations normally leads to a higher number of contacts), the amount of transport agents available, or specific demands (for example: large or dangerous goods may reduce the possibility of transport agents).

In the process of validation, a set of tests were produced using different amount of transport agents and shippers. It was concluded that to avoid the chaotic behaviour of the model the ratio of consignments per chain and per year should be above ten[217] (right column in Table 5.8).

[217] Indeed lower values could be used, however, this would imply running the series for a longer time in order to eliminate initial oscillations on the results.

Table 5.8 – Key attributes of the markets

Market Type	Number of Intermodal Transport Services	Number of Consignments per chain per year
1	2	26
2	40	13
3	4000 (64)	0.16 (10)

Additional tests were conducted to assess the influence of the number of freight forwarders on the behaviour of the model. Freight forwarders influence the market dynamics, firstly, by driving the transport agents' profit margin and, ultimately, the market prices; and, secondly, by the cross influence on others' Level of Trust owing to the spill over effects. Yet, experiments revealed that in Market Type 1 and Market Type 2 the influence was of limited scope. The main reason being that every transport agent, with positive level of trust, is invited and all possible combinations are taken into consideration during modal choice process. It seems that in such situations freight forwarders' awareness process occurs regardless of the others' influence. In Market Type 3, only a portion of transport agents is contacted, and thus freight forwarders' cross influence is higher.

The reasons for the choice of these three types are as follows. The Market Type 1 represents the smallest possible existent market, with only two options of intermodal freight transport services (interviews with market agents were inconclusive on the amount of transport companies that each freight forwarder contacts during modal choice process. The factors influencing include: the freight forwarder's own fleet, the type of destination (for example, infrequent destinations normally leads to a higher number of contacts), the amount of transport agents available, or specific demands (for example: large or dangerous goods may reduce the possibility of transport agents).

In the process of validation, a set of tests were produced using different amount of transport agents and shippers. It was concluded that to avoid the chaotic behaviour of the model the ratio of consignments per chain and per year should be above ten (left column in Table 5.8). Indeed, such type of market hardly occurs in the real world. The interests of this type of market are two-fold, one, for validation purposes, since the behaviour of such small market is better predictable and understandable than a larger market; two, for theory validation purposes, since if fitness actually plays a role in the market, its influence should be visible regardless the size of the market.

Markets Type 2 represents a typical market. More transport agents are considered in the destination leg than in the origin leg, in order to reduce the computational running time (without affect the model's results). Origin land based transport agents have non-fixed schedules and, thus, play a minor role on the study of the strategic fitness. The number of shippers was defined to reach a value of ten consignments per chain and per year; while the freight forwarder number was the minimum required to enable the existence of the abovementioned market dynamics, because regardless their minor influence, such influence may exist and it should not be ignored.

Market Type 3 represents a larger market with multiple transport agents and only a portion is considered each time. This is the market type closer to the real world, because it considers the larger amount of agents and because only a small portion of the transport agent is evaluated in the each decision making process. The amount of freight forwarders is the maximum amount that did not compromise the computational running time.

5.5.1.4 Type and amount of Experiments

The test of the hypothesis and the validation of the framework also required the ability to change the level of fitness of the dual systems, in particular, to change it along each dimension. It also implied the ability to link the changes in the level of fitness with the eventual change in the performance of the intermodal transport service. Bearing in mind that the integration influences but one - friction gap - of the three sources of performance[218], this requirement implied in practical terms the isolation the various sources of performance.

The solution devised to fulfil these requirements consisted in measuring the change in the level of performance of the intermodal freight transport service due to a change in *one* dimension of fitness of the various dual systems and freight forwarder. This solution implied the consideration of two cases corresponding to different configurations of AFETAS (and thus Experiments):

[218] Recall from Chapter 2.3 the sources of the performance in an intermodal freight transport service

- A Base Case to serve as benchmark for measuring the default level of performance;
- A Fitness Case where only one dimension of fitness was changed.

The only difference between the Base Case and the Fitness Case was the change in *one* dimension of fitness, thus any eventual change in the level of performance could be ascribed with confidence to that dimension of fitness.

The dimensions of fitness that were considered in the tests are presented in the Chapter 5.2, being: physical, logical and strategic. Since in each Fitness Case only one dimension is assessed, then four cases - Experiments - had to be considered, being:

- Base Case;
- Physical Fitness Case;
- Logical Fitness Case;
- Strategic Fitness Case.

The next table summarises (Table 5.9) the various cases considered, in a total of 60, for the design of the experiments.

In the Base Case no dimension of fitness was evaluated. Its presence is meant for enabling the ceteris paribus situation, since all other cases are variants of this one. In other words, the results of the base case are the benchmark against which the (eventual) influence of the variation in the level of fitness was assessed. In the Base Case, all of the agents and proto-agents were considered to be identical (apart from the properties that are randomly generated). In the cases of Physical Fitness, Logical Fitness and Strategic Fitness only *one* single dimension of fitness is analysed each time. In each case, the properties of a set of transport agents will be changed (at outset) to force them to have lower friction. The remaining transport agents (and every market related-variable) remained with the properties defined in the Base Case.

The description of the changes in the production of an intermodal freight transport service owing to a change in a given level of fitness and the explanation of how it was simulated in AFETAS are done later in this chapter during the presentation of the results.

Table 5.9 – Experiments for theory validation

Factor	Properties
Nature of shippers	Time sensitive; Neutral; Price sensitive.
Amount of transport agents and shippers	Market Type 1: 1 -2 - 1 - 1 - 1; Market Type 2: 3 -4 - 5 - 3- 10; Market Type 3: 20(4) -10(4) - 20(4) - 5- 20;
Dimensions of fitness	Physical Fitness; Logical Fitness; Strategic Fitness.

The purposes of the Experiments were, as mentioned at the beginning of this chapter, to, firstly, test the hypothesis and, secondly, validate the conceptual framework. Such difference led to the consideration of two Situations in each Experiment of fitness: Situation 1 and Situation 2. In Situation 1, the Experiment only differs in relation to the Base Case in one aspect, which is a change in the level of fitness. In Situation 2, besides the change in the level of fitness (similar to Situation 1), the (eventual extra) costs of such change are also considered through price variations. Situation 1 was meant to assess the validity of the conceptual framework, while Situation 2 was meant to test the hypothesis.

5.5.1.5 Price variation

Another issue taken into consideration was the eventual costs associated with a change in the level of fitness. The point is that a change in the level of fitness may require the transport agents to carry out some sort of modifications (like for example: to invest in equipments, to adapt the processes or to hire different services), which may raise the problem of changes in the costs of production. Although such extra costs will have to be recovered, each transport agent will proceed in a different way, depending on her own strategy. A possible solution may be the incorporation of those costs (entirely or partially) in the price. Such situation results in an increase of the price which may offset the eventual benefits accruing from the change in the level of fitness and, thus, integration.

If the increase of performance accruing from a change in a given dimension of fitness surpasses the negative effects of the increase in price, than the competitiveness of an intermodal transport should increase, which should be reflected in an increase of its market share. Therefore, an increase of the market share due to an improvement of the integration evidences that it could contribute to the increase the competitiveness of the intermodal freight transport service and, consequently, of the combination company. And it makes an evidence in favour of the hypothesis.

In this research, the valuation of the eventual changes in the price due to the change in the level of fitness was done through an analysis of the production process and the factors of production. However, it must be emphasised that in the real world the freight forwarder perceives only changes in prices and quality of service, without having any knowledge or control over the associated costs. Indeed, the transport operator may well chose to increase the quality of a given service at the expense of any other activity (i.e. cross subsidisation). The specific values are presented later in this chapter during the presentation of the results.

5.5.1.6 Time of simulation and number of runs

A time span of six years was defined for the simulation runs of each experiment. Additionally, the first year was ignored for purposes of analysis, thus the results refer to the last five years of simulation.

The results of the market shares tended to exhibit a high oscillation throughout the first year. By the end of this year, the level of oscillation reduced. Over the course of year two, the values of the market share tended to stabilise, giving origin to a given trend (although oscillation was still visible). By the end of the year four, the trends tended to converge towards a horizontal asymptote, and the oscillations were minimal. The trends did not stabilised on a fixed value owing to the inherent randomness of the market.

Every experiment was run 50 times (in every case market type). The choice for repetitions was related with the need to obtain confidence in the results of the model. The point is that drawing conclusions upon one (or few runs) would be inconclusive (and could lead to erroneous conclusions), since it would not be possible to know if the results were the outcome of the influence of the fitness or of the random effects. By running the model a large amount of times, it was possible to distinguish the influence of the fitness from the randomness[219]. The results will be presented showing for every variable two statistical values: average and standard deviation.

5.5.1.7 Properties of agents and proto-agents

The Table 5.10 up to Table 5.14 present the data used to simulate every agent and proto-agent in AFETAS, namely: shipper, freight forwarder, air transport company, road transport company and terminal agent.

Shipper (Table 5.10)

In what concerns the shippers, it is considered that they place one weekly consignment on the market, on a random day from Monday to Friday. The consignment is placed at 18H00M, to be ready for transport next day at 12H00M.

The intervals for weight and volume were defined to simulate the typical values (weight and size) of general freight. The general air cargo is the traditional air cargo of air transport companies. In the real world, there is a wide variation between shippers, yet the author believes these intervals represent typical values.

The maximum unitary price and transit times were defined as cut off values for non-meaningful proposals. They represent the maximum typical values.

The intervals of geographic coverage at origin and destination were set to represent typical values. The interval of distances at origin is different that the interval of destination to introduce variability in the model.

The difference in absolute values between the positive and negative trusts is justified on the fact that errors (non-compliance) are perceived differently than non-errors (compliance). The production of transport services without errors is what the shipper expected at outset, thus, a transport service without problems is how it should be. Conversely, when there is an error (either delay or damage), shippers are likely to incur in losses and the reward (in absolute value) is certainly higher than the former case. Indeed, the attribution of a positive reward greater than zero was more a way to

[219] Indeed, the variation of the results may indicate if the experiment is stable around a static or dynamic equilibrium or, by the very opposite, if it is chaotic with every run showing very different results.

simulate trust building than as a reward for the correct accomplishment of the transport service.

Table 5.10 – Shipper agent's data

Attribute	**Value**
Weight per Shipment (kg)	[500, 1500]
Volume per Shipment (dm3)	[3000, 9000]
Maximum Unitary Price (€)	3
Maximum Transit time (h)	48
Geographic coverage (km)	Origin: [25,100] Destination: [300, 500]
Trust Positive Reward	1
Trust Negative Reward	-3
Φ	0.2
Shipments per week	1

In what concerns the value of the variable φ, responsible for the behaviour of the memory effect, a value of .2 and .125 was defined for the shippers and freight forwarders, respectively. The latter value renders a longer memory effect than the former. The rationale is that the freight forwarders, with a deeper knowledge on the transport market, may not be so receptive to excuses than shippers. The determination of the parameter φ was done based on a sensitivity analysis. In practical terms, this parameter influences the amount of time that an agent is not called as the sequence of a non compliance. An higher value would lead to the exclusion of an agent, whereas a lower value would render this parameter useless. From the real world market, the author was unable to obtain values for the time of exclusion. The interviewees invariantly answered that would depend on multiple factors such as: magnitude of the fault, historic relation between agents, repetitiveness, etc. In this sense, the author opted for choosing a value with an average influence (that is, around the middle between no effect and practical exclusion of the transport agent).

Freight Forwarder (Table 5.11)

Profit related values were the most difficult data to obtain since invariantly this was considered a confidential matter. The values were set upon some informal interviews with transport companies that often commented on allegedly large profit margins of the freight forwarders, around the upper half of the interval considered. Later interviews with freight forwarders were inconclusive, although they did not refute these values. The initial profit margin is the middle value of the interval profit margin, and the profit margin variation was defined in such a way that sudden oscillations on market prices are avoided.

Table 5.11 - Freight Forwarder agent's data

Attribute	Value
Profit Margin (%)	15
Profit Margin Variation (%)	0.1
Interval Profit Margin (%)	[10, 20]
Trust Positive Reward	1
Trust Negative Delay Reward	-2
Trust Negative Damage Reward	-3
Φ	0.125
∂	0.05

The rationale for the values of trust rewards is identical to the shipper values. The difference between delay and damage was established on the assumption that damage is typically worst than delay, because damage implies the loss of the goods, while delay implies a temporal gap before goods could be used[220].

[220] This assumption can be disputed on the ground that there are occasions where the opportunity cost is very high, and delay could be as costly as damage. Yet, the author believes that often this is not the case.

Air Transport Companies (Table 5.12)

In relation to the duration of the flight, an intercontinental flight was considered because the costs referred precisely to an intercontinental flight[221].

The data for the interval of profit margin was obtained, firstly, from Doganis (2006, pp 4) that found that airlines members of the International Air Transport Association (IATA) scarcely have profits above seven percent per year and, secondly, from the fact that cargo is priced often based on marginal costs[222]. The interval represents a balance between these figures. This interval was meanwhile verified with transport company agents and again the interviews were inconclusive, although the upper limit was considered too optimistic. The interval was kept, because during model validation the maximum limit was only attained in the situations with two air transport companies and in circumstances of high demand. Often the margin profit stabilised in the inferior half of the interval (denoting competition between companies or low demand).

The unitary cost of production assumed for the air transport companies is in fact not the cost of production. To the best of his efforts, the author was unable to find production costs for the air transport companies. Instead, the author was able to obtain access to information about the procedures for the calculation of price in the Air France – KLM Cargo division, for the passenger flight between Amsterdam and Hong Kong[223]. The procedures consider the direct costs of production (namely: variable fuel costs, trucking cost[224] and interline costs[225]) and indirect costs of production. The indirect costs appear undifferentiated but include, amongst others, the costs of production. The minimum price offered to the shipper should cover both direct and indirect costs. The value considered in AFETAS include the amount of 0.152€/kg concerning the surcharge of variable fuel costs plus the amount of 0.40€/kg concerning the indirect costs. Although this amount does not explicitly refer to the costs of production, it nevertheless reflects

[221] Additionally, the majority of the freight in combination companies is conveyed on intercontinental flights.

[222] In particular in those combination companies that adopt the strategy of unit business. See Chapter 1.1 for further details on this strategy.

[223] The author wished to express is gratitude to Mr Amilcar Horta for this information.

[224] Trucking costs refer to road transport from airport of Oporto to airport of Amsterdam..

[225] Interline costs refer to the costs of transhipment at Amsterdam Airport.

the minimum amount of costs that necessarily have to be covered. Therefore, it can be considered as a minimum threshold for prices.

In conversations, transport companies agents answered favourably when asked if a value of 0.55€/kg from Europe towards Far East was meaningful. They acknowledged that it is a somewhat low value but plausible in face of the current downturn economic cycle.

The remaining values on Table 5.12 are the typical ones for a Boeing 747, which is the type of aircraft used by the Air France-KLM between Amsterdam and Hong Kong.

Table 5.12 – Air Transport Company agent's data

Attribute	**Value**
Transit time (h)	10
Profit Margin (%)	10
Profit Margin Variation (%)	0.1
Interval Profit Margin (%)	[5, 15]
Unitary cost of production (€/kg)	0.552
Schedule	1 daily flight at 24H00M
Reliability damage (%)	[0.93, 0.98]
Reliability delay (%)	0.90
Maximum volume capacity (kg)	12000
Maximum weight capacity (dm^3)	76000

Road Transport Company (Table 5.13)

The unitary fixed and marginal prices were obtained from the study carried out by the Portuguese national association of road transport operators concerning the costs of production of transport (ANTRAM, 2008). The refusal order rate was based on sensitivity tests. The objective was to reach an acceptable amount of refusals (too many refusals might preclude the possibility of assembling chains, while a too low value would render this value useless). The one percent value was considered an adequate value. The remaining values have already been explained for the other agents.

Terminal Agent (Table 5.14)

Finally, in the proto-agent terminal’ data was based on an interview with an experienced ground handler agent Mr. Mário Simonette.

Table 5.13 – Road Transport Company agent’s data

Attribute	Value
Unitary fixed price (€/hour)	15.64
Unitary marginal price (€/km/kg)	0.139×10^{-4}
Profit Margin	[10, 20]
Profit Margin Variation (%)	0.1
Profit Margin Variation (%)	15
Reliability damage (%)	[0.90, 0.98]
Reliability delay (%)	[0.93, 0.98]
Refusal order rate (%)	1
Speed (km/h)	50 (origin) or 60 (destination)
Schedule ([a])	1 daily service at 20H00M

([a]) Only transport agents in the destination region have fixed scheduling

Table 5.14 – Terminal agent’s data

Attribute	Value
Reliability damage (%)	0.95
Handling transfer time (hours)	Exportation: 6 Importation: 4

5.5.2 Results

5.5.2.1 Base Case

The purpose of the Base Case experiment was to enable the analysis ceteris paribus of the dimensions of fitness. It served as referential to the other experiments, since every agent and proto-agent in AFETAS was loaded with identical data (Table 5.10 to Table 5.14). That is, every transport agent shared the same properties.

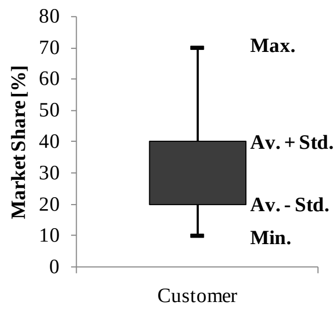
The following graphs (Figure 5.23 to Figure 5.25) and the Table 5.15 present the results obtained for the various types of markets. In the graphs, the horizontal axis presents the three types of shippers (Table 5.9). The vertical axis represents the market share of each type of transport chain or transport chains.

Recalling that each experiment was run multiple times and that AFETAS has a random nature, some variability between the results was thus expected. In order to better represent this variability, several statistical variables are presented. The statistical variables are: average, standard deviation, maximum and minimum. Both the table and the graphs[226] exhibit these four variables. In addition, the table presents the information of the total market share of the type of chains[227]. The results are as expected since they show a market share similar to the theoretical market share, that is: 50% for each of the two combinations in Market Type 1, 2.5% for each of the forty combinations in Market Type 2 and 0.025% for each of the 4000 combination in Market Type 3. As detailed before, all agents and proto-agents were identical. Consequently, the chains they formed also exhibited similar properties (and similar behaviour), and they should be valued in similar way by the freight forwarders, rendering similar probabilities of being chosen. Although variations in the Level of Trust could eventually affect the choice that effect should be dissolved in the long term dynamics of the market

The coefficient of variation of the results is computed in Table 5.16. The results evidence the random nature of the market. Randomness exists in the many situations of

---

[226] The graph should be interpreted as follows: **Max**. stands for the maximum value recorded on the series of results; **Min.** stands for the minimum value recorded on the series of results; **Av.** stands for the average value recorded on the series of results; and **Std.** stands for the standard deviation of the series of results. All values refer to the intermodal transport chains' market share.



[227] The total market share is obtained by multiplying the average market share times the number of chains.

Table 5.15 – Results of Base Case

Chain	Type of Shipper	Market Type 1					Market Type 2					Market type 3				
		TMS	Av.	Std.D.	Max.	Min.	TMS	Av.	Std.D.	Max.	Min.	TMS	Av.	Std.D	Max.	Min .
Fitness Chain	T. Sensitive	100.0	50.0	5.870	66.19	33.81	100.0	2.50	0.961	6.531	0.0471	100.0	0.0252	0.0660	1.050	0.0
	Neutral	100.0	50.0	5.578	62.65	37.35	100.0	2.50	0.989	6.454	0.0	100.0	0.0253	0.0658	0.8328	0.0
	P. Sensitive	100.0	50.0	5.870	66.19	33.81	100.0	2.50	0.951	6.482	0.0	100.0	0.0252	0.0661	0.9238	0.0

Legend: TMS - Total Market Share (TMS = Av. * number of intermodal freight transport services), Av. - Average, Std.D. - Standard Deviation, Max. - Maximum, Min - Minimum, T. - Time, P. - Price. All values in percentage.

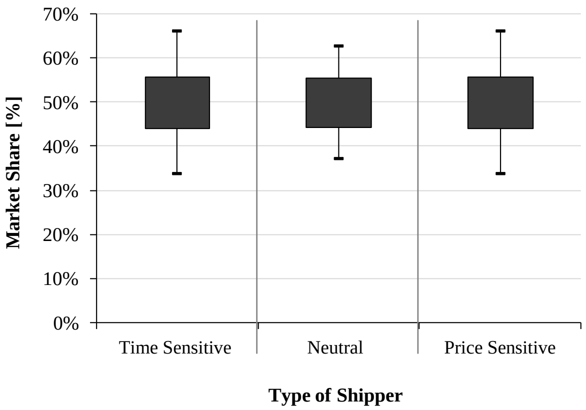


Figure 5.20 - Market share of the chains in Market Type 1

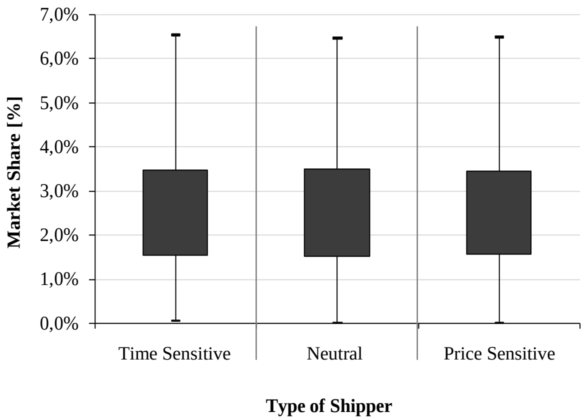


Figure 5.21 - Market share of the chains in Market Type 2

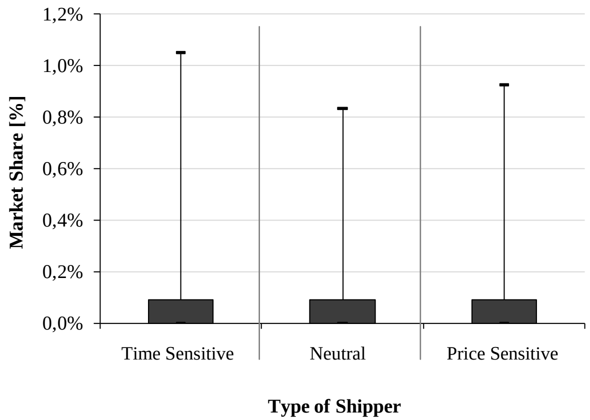


Figure 5.22 - Market share of the chains in Market Type 3

the model, such as: freight forwarder's modal choice or transport agents' delays. If the market was fully deterministic the coefficient would be zero.

The coefficient is similar among the types of shipper, within each Market Type, due to the fact that every chain is similar and, thus, equally valuable regardless of the type. The differences of the coefficient between the Market Types are explained by the growing number of possible combinations (two in Market Type 1, forty in Market Type 2 and 4000 in Market Type 3), which increases the likelihood of the variation of the market share between combinations. The leap in the coefficient from Market Type 2 to Market Type 3 is explained by the fact that in this market only a small fraction of the combinations is scanned (64 out of 4000 on each decision process).Thus the variations in the market shares are expected to be much higher in this market than in the other two (where all the combinations are scanned and, thus, they have a higher probability of being chosen).

In summary, the Base Case will provide a reference for the assessment of the eventual influence of each dimension of fitness in the performance of the intermodal freight transport services. Additionally, it has also been used as validation tool of the simulation model AFETAS, since in the Base Case the market's behaviour is predictable.

Table 5.16 – Dispersion of the results

Type of Shipper	**Market Type**		
	1	**2**	**3**
Time Sensitive	0.117	0.384	2.62
Neutral	0.111	0.396	2.60
Price Sensitive	0.117	0.380	2.62

5.5.2.2 Physical Fitness Case

Modifications in the production brought by the change in the fitness

The physical dimension of fitness is related with the nature of the movement of the goods along an intermodal transport chain. In Chapter 3.3, three factors affecting the fitness were identified, being the: type of containerisation, type of handling equipment and modes of transport. Thus, to bring about a change in the level of fitness, one or more of these factors are required to change. In this research work the following changes in each factor were assumed:

- Changes in the type of containerisation - introduction of an interoperable type of container[228]. The container is transferred between modes of transport along the transport chain. That is, the goods are loaded into (or onto) the container at origin and unloaded at destination;
- No changes in the type of the handling equipment - the reason is that most of the handling equipment (such as: reach stackers, forklifts, etc) is suitable to handle most types (if not all) of containers;
- No changes in the modes of transport - a change in the mode of transport is not feasible to occur in the simulated market. It would make no sense to change leg 1 or leg 3 from land based transport to air transport, or to change the leg 2 from air transport to land based transport.

In this experiment the dual systems' profile is compound of a single variable, which is the *physical interoperability*.

The benefits accruing from the introduction of interoperable containers can now be identified:

- Reduction in the airport transhipment times because the object of transhipment is the container (and not the goods that follow inside).
- Reduction in the handling operator's level of damage because cargo is protected all the journey within containers and it is not subjected to any handling procedures at airports.

Changes in the process of producing an intermodal freight transport service are likely to occur due to a change in the physical fitness. These are now analysed. Recalling the process of production of an intermodal freight transport service in Chapter 2.2, we may conclude that the introduction of a new container will not likely influence the sub

[228] The containers specially developed for the air transport (albeit being used by other modes) are called as Unit Load Devices (ULD). ULDs can be either closed, resembling to a box, or opened, resembling to a pallet. Moreover, the different sizes of aircrafts led to the development of different types of ULDs.

In this research, it is assumed the utilisation of ULDs The traditional containers (used in sea or road transport) are scarcely used in air transport, precisely because they are quite heavy and have a squared shape, that reduce the amount of liquid weight and volume for carrying the goods.

process 1, since in this sub process there is no movement of the goods. Moving now to sub process 2, Activity 1 and Activity 8 (Figure 2.8) are likely to suffer no changes since the efforts to load a truck are similar to those to load a container. Indeed, a container could ease the loading or unloading process because it can be placed next to the goods. Activity 2 and Activity 7 (Figure 2.8) are also likely to suffer no changes since the transport is done in the same way whether the cargo follows loaded in a container or loaded in the truck. Conversely, Activity 4 (Figure 2.8) is likely to be eliminated or significantly reduced, because the container is due to be transferred to the aircraft as soon as possible. Likewise, Activity 3 and Activity 6 (Figure 2.8) are likely to be simplified since these activities now correspond to the transhipment of the container from the road vehicle towards the aircraft (and vice-versa)[229].

These changes may also bring changes in the costs of the process which must be taken into consideration. Firstly, the physical fitness may imply a change in the technology, due to the introduction of interoperable containers. Since the air is the most costly mode of transport, it is fair to assume that the new containers should minimise the cost impact on this mode. Thus, we may assume that the new containers are Unit Load Devices (ULDs[230]). The utilisation of the ULDs in the land based transport legs can result in an increase of the turnaround time, which may generate the need for further containers and, thus, to add costs to the intermodal freight transport service. A factor to have into consideration is the ownership or rental of the containers. Starting with the analysis for the case of ownership, Bertsch (2009) put forth the following values per container:

- Price: 1000€;
- Maintenance: 300€/year
- Other costs[231]: 50€/year
- Life time: 3 years.

[229] Eventually an additional transport may be required between the road vehicle (near to the terminal) and the aircraft (parked within the airport), but these transport would be necessary anyway.
[230] See Footnote 228 for further information about ULDs.
[231] Other costs include overheads, communications, etc.

In order to compute a possible upper bound for the extra costs, let us assume the worst possible situation:

- Containers are only used in this intermodal service.
- Each container is used in 104 trips per year which corresponds to two trips per week. Recalling that each customer places one service per week, we may assume one trip in each direction per week
- A full year with the minimum demand of 500 kilograms per trip. This generates a total amount of 52 tonnes per year.

The extra cost can then be computed in a total of 1.3 €cents. per kilogram[232]. This extra amount represents an increase of 2.3% in the cost of the air transport. This extra cost is added to the cost of air transport because the combination company owns the ULDs. In case of rented containers, Bertsch (2009) refers that a cost reduction up to 15% may be achieved. Since the renting represents a better situation, it was not considered in the Experiment.

In what concerns the operations at the airports, albeit the introduction of an interoperable container is likely to introduce changes in the handling processes, it is not clear if that would add costs or, by the opposite, it would generate economies[233]. The potential economies could be generated from:

- Reduction of the space used in the terminal, since the need for loading and unloading activities and storage are reduced;
- Compression of the handling processing time, since the object of movement is the container and not a set of boxes, and since mechanical or automatic handling equipment (such as: forklifts, reach stackers or robots) with high rates of performance can be used;
- Gains in the productivity due to the two previous factors;
- Reduction in the labour force due an increase in the level of mechanisation of the handling system.

---

[232] Extra cost= (1000/3 + 300 + 50) / 52000

[233] The full identification of the implications in the handling operations lies outside the scope of this research work. The purpose here is to discuss the most relevant changes and, with it, to evidence the difficulty of a rigorous computation of the costs or gains.

The extra costs may result from the likely concentration of the arrival of containers in small time windows. After all, the arrival of the containers should be as close as possible to the departure of the flight. The handling company would have to move a large amount of containers in a short period of time. This could lead the handling company to investment in new handling equipment, changing and streamlining its processes, providing additional training periods or hiring out services.

Other factors that influence the gains or losses of the handling company are: the annual handling volumes and the relevancy of the interoperable service. The annual volumes influence the handling agent's level of mechanisation. The higher is the volume, the higher is likely to be the level of mechanisation. The replacement of goods in boxes per containers in a highly mechanised handling system is likely to generate further economic benefits. In what concerns the influence of the relevancy of the interoperable service, the point here is that the behaviour and willingness of the ground handling company to adjust their processes will depend on the relevancy of the combination company and of her interoperable service. The higher is the relevancy of the interoperable service, the higher will be the ground handler's willingness to adjust the processes, which will determine the amount of costs or economies.

An interview with a ground handler was inconclusive on the likely change in the costs because of the multiple situations of influence of the abovementioned factors. In any case, when asked if in the worst case scenario a twenty five percent increase in the handling costs would be plausible, the answer was not negative[234]. Let us assume this as a maximum value for the increase of the handling costs.

The cost of the air transport service indicated in Table 5.12 includes, as mentioned, the handling services. This value accounts for a total of 6€cents per kilogram. An increase of twenty five percent in this value would result in a increase of 1.5€cents per kilogram in the cost of the air transport service.

In what concerns the land based transport agents, an increase in the price is foreseen due to extra weight of the interoperable container (in addition to the goods). In order to

[234] Interview with Mr. Mario Simonette. Values for the airport of Lisbon.

compute a possible upper bound for the extra costs, let us again assume the worst possible situation. The typical tare weight of a ULDs is around 100 kilograms, which represents an extra weight of twenty percent in case of a demand of 500 kilograms. The formula for computing the road based prices has two terms: one related with the fixed component of the cost, which is dependent of the transport time, and another related with the variable component of the cost, which is dependent of the length and the weight. Thus the extra weight affects the second term.

The most non-favourable situation occurs for the maximum possible distance (when the extra weight is carried for the longest distance). From Table 5.10 and Table 5.13, we have a maximum distance of 100 kilometres, for the origin region, and 500 kilometres, for the destination region, this implies an extra cost of 13.9€cents. per service, in the origin region, and 69.5€cents. per service, in the destination region[235]. In relative terms, these increases imply, considering the minimum demand, and increase in 0.23%, for the origin region, and 0.25% for the destination region[236].

In summary, three sources of extra costs were found due to an increase in the physical fitness. The sources are:

---

[235] The Cost is given by the following expression:

Cost = 15.64 * Transit Time + 0.139E-4 * Distance * (Weight + 20000).

The cost difference (ΔCost) between the base case and the fitness situation, for a same distance, is given by:

ΔCost= 0.138E-4 * Distance * ΔWeight.

Considering the ΔWeight equal to the tare weight of the container, then in the:

Origin Region:

ΔCost= 0.139E-4 * 100 * 100 = 0.139€

Destination Region:

ΔCost= 0.139E-4 * 500 * 100 = 0.695€

[236] Assuming now the minimum demand we have:

Origin Region (distance= 100 kilometres):

Base Case Situation (weight = 500kg): Price= 15.64 * 100/50 + 0.139E-4 * 100 * (20000 + 500) = 59.775€

Fitness Situation (weight = 500kg + 100kg): Price= 15.64 * 100/50 + 0.139E-4 * 100 * (20000 + 600) = 59.914€

Destination Region (distance= 500 kilometres):

Base Case Situation (weight = 500kg): Price= 15.64 * 500/60 + 0.139E-4 * 500 * (20000 + 500) = 272.808€

Fitness Situation (weight = 500kg + 100kg): Price= 15.64 * 500/60 + 0.139E-4 * 500 * (20000 + 600) = 273.503€

- Utilisation of interoperable containers: maximum increase of 1.3€cents. per kilogram in the air transport service. The sources for information on this cost variation were: Bertsch (2009) and author's own calculations;
- Change in the handling processes: maximum increase of 1.5€cents per kilogram in the cost of the air transport service. The sources for information on this cost variation were: experts judgment (ground handler[237] and unit business manager of a combination company[238]) and author's own calculations;
- Extra weight of the container in the road services: maximum increase of 13.9€cents. per service, in the origin region, and 69.5€cents per service in the destination region. The sources for information on this costs were: author's own calculations;

Thus, the maximum expectable increase in the air transport service is of 2.8€cents. per kilogram in the air transport service, that corresponds to an increase around: 5.1%.

The following table (Table 5.17) presents the variation in the cost of production for some possible services and for the base case and the fitness case. The cases correspond to extreme situations, in terms of maximum and minimum weight and distances in the origin and destination regions. Thus, the table provides the range for the expected variation of the costs of production in the freight transport market simulated with AFETAS. The minimum increase in costs owing to the fitness case is of 2.4% whereas the maximum increase is of 4.2%.

Finally, it should be noted that the market relations are done based in prices and not in costs. This is specially so in short term negotiations and spot markets. Moreover, the (changes in) prices do not necessarily reflect the (changes in the) costs of production, but they are the consequence of market dynamics and the agent's strategic movements. Therefore, the changes in the costs may not immediately or directly be translated in changes of prices. In fact cross subsidisation of one service can occur, although in the long term every agent must ensure her economic and financial balance otherwise risks of bankruptcy will accrue.

[237] Mr. Mário Simonette.
[238] Mr Amilcar Theias.

Table 5.17 - Maximum variation in the cost of production of intermodal freight transport services

Distances between airports and		**Weight 500 kg**		**Weight 1000 kg**		**Weight 1500 kg**	
Origin	Destination	Base Case	Fitness Case	Base Case	Fitness Case	Base Case	Fitness Case
100 km	500 km	608.3 €	623.1€	888.5€	917.3€	1168.6€	1211.5€
		ΔCost= 2.4%		ΔCost= 3.2%		ΔCost= 3.7%	
25 km	300 km	454.5€	468.9 €	732.7€	761.2€	1011.0€	1053.4€
		ΔCost= 3.2%		ΔCost= 3.9%		ΔCost= 4.2%	

Modifications in AFETAS

The modifications in AFETAS to simulate the abovementioned changes are now justified. The following types of market were defined:

- Market Type 1:
  - One (1) agent in each leg, forming 1 intermodal freight transport service, was flagged as being interoperable;
  - The remaining agents (1 air transport agents), forming 1 intermodal freight transport service, was flagged as not being interoperable.
- Market Type 2:
  - One (1) agent in each leg, forming 1 intermodal freight transport service, was flagged as being interoperable;
  - The remaining agents, forming 39 intermodal freight transport services, were flagged as not being interoperable.
- Market Type 3:
  - 8 agents in each leg, forming 32 intermodal freight transport services, were flagged as being interoperable[239];
  - The remaining agents, forming 3968 intermodal freight transport services, were flagged as not being interoperable[240].

[239] It should be noted that each chain has a different flag. For example: a chain with agents id 2, 3 and 5 is flagged with the value 1; while chain with agents if 6, 9, 12 is flagged with the value 2. If freight forwarding is analysing chain with agent id 2, 3 and 12, there is no physical interoperability (since they have different flags).

In addition, every agent in the model was loaded with the data on Table 5.10 to Table 5.13. The proto-agent terminal was loaded with the data on Table 5.14, but aware for the transport agents flagged as interoperable.

The dual system with higher level of physical fitness were considered to exhibit the following two properties, both properties were checked in interviews with experts: ground handler[241] and unit business manager of a combination company[242]:

- The transfer time, at the airports, is considered to be a minimum possible amount of time, in a total of 3 hours that corresponds to the minimum necessary time to carry out with the transhipment operations and customs procedures.
- The level of reliability of the transfer process, at the airport, is considered to improve due to the fact of the goods not being directly handled. The level of non-reliability[243] of the dual systems with higher level of fitness is considered to be 50% of the other dual systems.

Finally, in what concerns the Situations, they were defined as follows:

- Situation 1: No increase in the price. In this situation the increase in the level of physical fitness is considered to not change the transport agents' costs[244].
- Situation 2: Increase in the price, equal to the above discussed costs, for the transport agents with higher level of physical fitness[245].

---

[240] The reason for choosing more than one intermodal freight transport service was to increase the possibility of, at least, one interoperable transport services being chosen by the freight forwarder. In Market Type 3, only 64 out of 4000 (or 1 out of 62.5) transport chains are randomly chosen (at the start of simulation) and afterwards following the rules already explained. If only a single chain was interoperable, the possibility of being chosen (and thus detected) by the freight forwarder was very small. Some experiments ran during the validation of model showed no significant results accrued from fitness in case of a single intermodal transport.

[241] Mr. Mário Simonette.

[242] Mr Amilcar Theias.

[243] Level of Non-Reliability = 1 - Level of Reliability

[244] This Situation can also represent Situation 2, since an increase in the level of physical fitness does not necessarily introduces costs (and, indeed, it may result in economies). Thus, Situation 2 corresponds to Situation 1 in this case.

[245] The increase in the price is only considered, by the freight forwarder, if all agents are flagged. This means that, in what concerns the flagged transport agents, the freight agents considers two prices. The lowest price (no costs owing to physical fitness) if any of the other agents in the chain are not flagged, the higher price (costs owing to physical fitness) if all the others are flagged.

Results

The results are now presented and discussed. The results obtained for Situation 1 are presented in the Table 5.18 and sketched in Figure 5.23 to Figure 5.25; while the results obtained for Situation 2 are presented in the Table 5.19 and in Figure 5.26 to Figure 5.28. The graphs and tables contain the same information as in the Base Case, in order to improve the readability of the results. Moreover, the results of the chains with higher level of fitness and the other chains are sketched side by side to allow a better comparison. For each pair of results, corresponding to a specific type of shipper, the chains with higher level of fitness are presented on the left, while the other chains are presented on the right.

A first conclusion to draw is the visible divergence of the results in relation to the results of the Base Case, in both Situations, which makes the evidence of the influence that fitness has in the performance of the transport agents.

Starting the analysis with Situation 1, the chains with higher level of fitness were able to invariantly obtain higher market shares vis-à-vis the others. The advantage of chains with higher level of fitness is more perceptible in both Market Type 1 and Market Type 2, than in Market Type 3. A possible reason is the fact that in the former the freight forwarder evaluated all the possible chains. Thus, the advantages of those chains with higher level of fitness could be easily grasped and exploited. Conversely, in Market Type 3 not all chains are scanned on each modal choice process and, thus, the freight forwarder may either take longer to or never become aware of the chains with higher level of fitness[246].

Also visible is the variation of the market share in function of the type of customer. The results show that the higher is the relevance of the time in the decision making process, the higher is the difference in the results of the market shares. Such results were to some extent expected since the physical fitness has a direct impact in the transit time.

---

[246] Indeed, this market presents some characteristics of a chaotic system. One of the properties of this type of systems is their behaviour to be highly sensitive to the initially conditions (that is, small variations at the beginning may result in significant diverge of behaviour) (Wilding, 1998, pp 43). This is the case in this market, since the freight forwarder randomly picks ups at the start of each run 64 chains out of a universe of 4000 possible chains.

Table 5.18 – Results of Situation 1 of Physical Fitness Case

Chain	**Type of Shipper**	**Market Type 1**					**Market Type 2**					**Market type 3**				
		TMS	Av.	Std.D.	Max.	Min.	TMS	Av.	Std.D.	Max.	Min.	TMS	Av.	Std.D	Max.	Min.
Fitness Chain	T. Sensitive	55,0	55,0	5,0	66,0	44,9	5,37	5,37	0,77	9,68	3,69	2,02	0,0630	0,216	11,4	0,00
	Neutral	53,3	53,3	5,5	66,7	39,5	4,49	4,49	0,93	8,61	2,70	1,78	0,0557	0,257	8,48	0,00
	P. Sensitive	52,3	52,3	5,8	67,1	39,5	4,11	4,11	0,75	7,89	2,66	1,65	0,0514	0,225	7,19	0,00
Other Market Chain	T. Sensitive	45,0	45,0	5,0	55,1	34,0	94,6	2,43	0,369	3,83	1,27	98,0	0,0247	0,0577	1,627	0,00
	Neutral	46,7	46,7	5,5	60,5	33,3	95,5	2,45	0,370	3,70	1,13	98,2	0,0248	0,0550	0,986	0,00
	P. Sensitive	47,7	47,7	5,8	60,5	32,9	95,9	2,46	0,352	3,40	1,22	98,4	0,0248	0,0594	1,02	0,00

Legend: TMS - Total Market Share, Av. - Average, Std.D. - Standard Deviation, Max. - Maximum, Min - Minimum, T. - Time, P. - Price. All values in percentage.

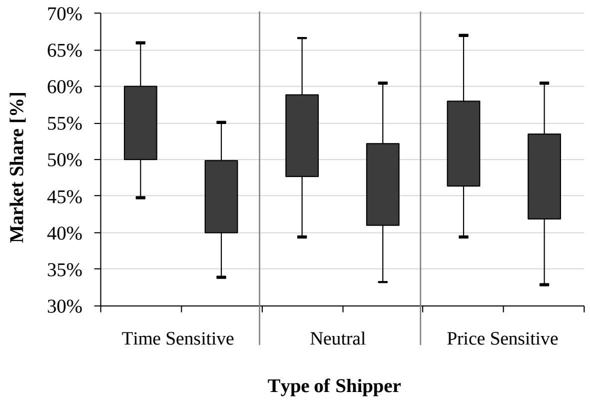


Figure 5.23 - Market shares of Market Type 1 of Situation 1 of Physical Fitness Case

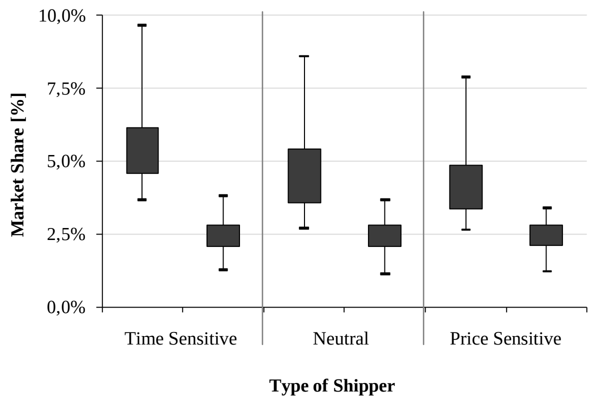


Figure 5.24 - Market shares of Market Type 2 of Situation 1 of Physical Fitness Case

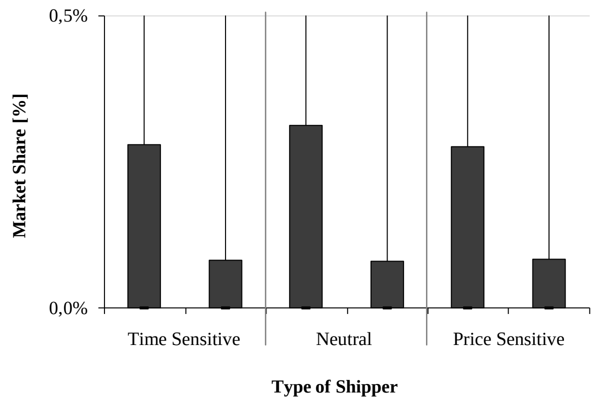


Figure 5.25 - Market shares of Market Type 3 of Situation 1 of Physical Fitness Case

Table 5.19 – Results of Situation 2 of Physical Fitness Case

Chain	Type of Shipper	Market Type 1					Market Type 2					Market type 3				
		TMS	Av.	Std.D.	Max.	Min.	TMS	Av.	Std.D.	Max.	Min.	TMS	Av.	Std.D	Max.	Min.
Fitness Chain	T. Sensitive	52,6	52,6	5,0	65,7	45,3	5,15	5,15	0,733	7,48	4,07	1,862	0,0582	0,279	14,9	0,00
	Neutral	51,8	51,8	5,4	63,3	35,6	3,15	3,15	0,355	4,15	2,42	1,45	0,0454	0,125	4,49	0,00
	P. Sensitive	49,3	49,3	5,7	63,7	35,1	1,61	1,61	0,239	2,11	1,03	0,728	0,0228	0,107	5,89	0,00
Other Market Chain	T. Sensitive	47,4	47,4	5,0	54,7	34,3	94,8	2,43	0,335	4,04	94,8	98,1	0,0247	0,0697	0,931	0,00
	Neutral	48,2	48,2	5,4	64,4	36,7	96,9	2,48	0,361	5,07	96,9	98,5	0,0248	0,0677	0,622	0,00
	P. Sensitive	50,7	50,7	5,7	64,9	36,3	98,4	2,52	0,378	4,97	98,4	99,3	0,0250	0,0704	1,03	0,00

Legend: TMS - Total Market Share, Av. - Average, Std.D. - Standard Deviation, Max. - Maximum, Min - Minimum, T. - Time, P. - Price. All values in percentage.

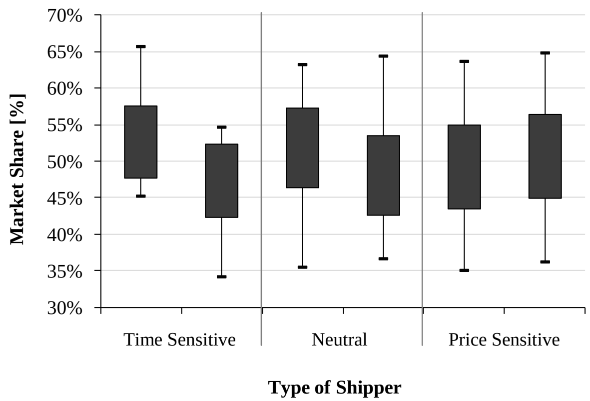


Figure 5.26 - Market shares of Market Type 1 of Situation 2 of Physical Fitness Case

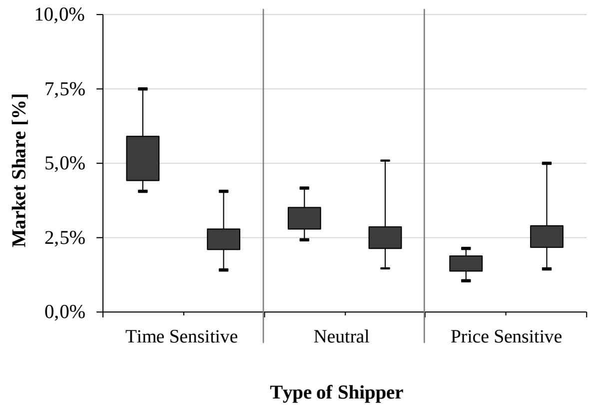


Figure 5.27 - Market shares of Market Type 2 of Situation 2 of Physical Fitness Case

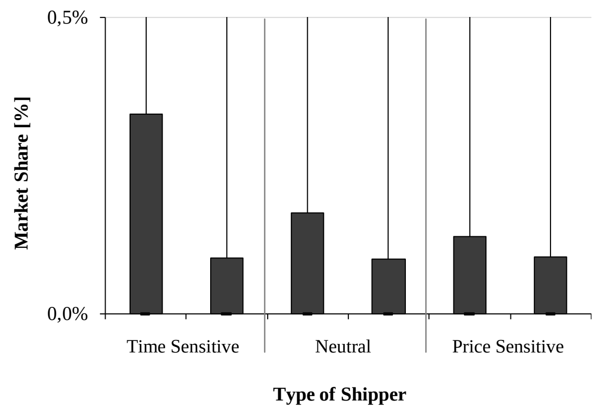


Figure 5.28 - Market shares of Market Type 3 of Situation 2 of Physical Fitness Case

At last, in what concerns the assessment of the conceptual framework, the results provide an evidence about its validity. Situation 1 differs in relation to the Base Case situation in a single property, which is the change in the level of physical fitness. The differences in the market shares of the chains with higher level of fitness vis-à-vis the others can in this way be ascribed to that difference in the level of fitness. Therefore, the differences in the market shares evidence that the level of fitness influences the performance of the intermodal freight transport service.

Moving now to the analysis of Situation 2. In this situation besides the change in the level of fitness, there is also a change in the prices (which is considered to be similar to the change in the costs due to the change in the level of physical fitness). The results differ from the Situation 1. Again there are differences in the market shares of the chains with higher level of fitness vis-à-vis the others. Conversely to Situation 1, the chains with higher level of fitness do not always have higher market shares.

In the Market Type 1, the chains with higher level of fitness were able to get a visible[247] higher market shares for the time sensitive shippers. In the case of the neutral shippers, these chains were still able to obtain advantage; whereas in case of the price sensitive shipper the chains with lower level of fitness were able to record higher market shares. In the Market Type 2 the results were similar. The chains with higher level of fitness were able to get a visible higher market shares in both time sensitive and neutral shippers, whereas they also recorded lower market shares in case of price sensitive customers. Finally, in Market Type 3, the chains with higher level of fitness recorded higher market shares in both time sensitive and neutral shippers, and lower market shares in the last type of shippers. The inferior market shares of the chains with higher level of fitness in the price sensitive shippers versus the other shippers was to some extent expected, because in this Situation, the costs of integration are incorporated in their price.

[247] Visible denoting that the average minus the standard deviation of the market shares of the chains with higher level of fitness is higher than the sum of the average plus the standard deviation of the other chains. In these cases the advantage is likely ascribable to the fitness and not some random effects.

In what concerns the assessment of the hypothesis of this research work, the results do not entirely corroborate the hypothesis. This research work was grounded on the assumption that the integration could be a strategy for the combination companies to improve their positioning in the market. Albeit in time sensitive and neutral shippers the results evidence this assumption, the same does not occur for the case of the price sensitive shippers. Although we may argue that the typical shipper of air transport values time over price and, as such, the results may evidence the benefits of integration. The fact is that price is increasingly relevant and the results cannot be ignored.

In summary, the results evidence that benefits may accrue from an improvement in the level of physical dimension of fitness. As such, they provide an evidence about the validity of the conceptual framework. The advantages of the chains with higher market share are stronger in the Market Type 1 and Market Type 2 than in Market Type 3. Also, the results evidence that an improvement in the integration does not always result in an improvement in the market positioning of the agent. In the time sensitive and neutral shippers evidences in favour of integration were collected in every market type, while no evidences were collected in case of the price sensitive, again, in all market types.

5.5.2.3 Logical Fitness Case

Modifications in the production brought by the change in the fitness

The logical dimension of fitness is related with the exchange of information between the transport agents during the production of the intermodal freight transport service. Two channels of communication were identified for the exchange of information: a physical channel, when the information is transferred by paper (or other physical support) and a virtual channel, when the information is transferred resorting to some electronic device (such as: telephone, fax or internet). The sources of friction occur when there are problems in the communication channel, leading to difficulties in the communication or, even rendering it non possible.

In this research work the eventual influence of the logical fitness was analysed along the virtual channel. The improvement in the level of fitness is done by considering the implementation of a compatible communication system in the various transport agents that would enable the exchange of information between them.

In this Experiment the profile of the dual systems is made of a single variable, which is the logical interoperability. This is the variable that varies between the pairs of dual systems.

Recalling from Chapter 3.1 the tiers of friction, we have that the logical friction belongs to the second tier. This means that the logical friction does not induce by itself non-compliances in the production of the transport service but, instead, it makes their identification or solving difficult to achieve. That is, if every transport agent performs well (i.e.: no delays or no damage), then, in no way, the logical friction could occur. Therefore, the benefits of a higher level of logical fitness (that is, compatible communication system) can only be enjoyed in case of a delay in the transport services. In such a situation, the freight forwarder becomes aware and she may intervene to eliminate or to minimise the problem, which can be accomplished in different ways:

- If the delay occurs in leg 1:
    - To request an express transhipment[248] at the airport - if the delay is inferior to the gains of time;
    - To book another flight - if the gains of time with an express transfer is not enough[249].
- If the delay occurs in leg 2:
    - To request an express transhipment - if the delay is inferior to the gains of time;
    - To book another land based transport service - if the gains of time with an express transfer is not enough.
- If the delay occurs in leg 3, than there is nothing that could be done, unless to warn the shipper for a late arrival.

---

[248] An express transhipment is offered in certain airports and it basically consists in providing a transhipment service in a shorter time than the standard transhipment. The express transhipment time depends upon the airport, but it can be inferior as much as 50% of the standard transhipment. The express transhipment is considered a premium service and, thus, more expensive than the standard transhipment.

[249] To book another flight implies extra costs that have to be compared with the costs incurred with the delay. The costs incurred with the delay may include the penalty to be paid to the shipper and the cost associated with a reduction of the image in the market.

No changes in the process of producing an intermodal freight transport service are expected to occur due to a change in the logical fitness. Recalling the process from Chapter 2.2, we may conclude that the sub process 1 (Figure 2.8) is not affected by a change in the logical fitness. In what concerns sub process 2, some changes are expected to occur in Activity 9 (Figure 2.8), due to the eventual need to take actions in face of a delay. The exchange of message can be either automatic, if sent by a computer, or manual, if sent by an employee. In the former situation, the exchange of message is carried out in parallel with the production of the transport service and it does not affect it in any way. In the latter situation, there is the need for an employee to send a message. But in overall no changes are expected to occur in the process.

An improvement in the level of the logical fitness is likely to introduce costs in the production of the intermodal freight transport service. The costs include, for example: the cost of the equipment for exchanging the information (such as the cost of acquisition or rental, the cost of maintenance or upgrading, or the cost of training), costs of communication, or the costs of the employees (when working with the equipment). Nowadays, there is a vast array of technological solutions, ranging from a simple manual mobile communication system up to fully automated systems that continuously trace the location of the goods (often resorting to a global positioning by satellite). Therefore, the actual costs will ultimately depend on the type of system.

In this research work, a solution of a semi-automatic communication system based on barcode labels was found adequate. This is a relatively simple system, widely used in the industry and relatively economic.

The functioning of the system is now briefly described. During Activity 1 (Figure 2.8), a barcode label is printed for every individual unit of transport (such as: box, pallet or container). After tagging each one, an employee with portable barcode reader reads all the tags. This information is loaded into a management software and it is sent, using any communication system (typically, over internet, although, wireless communications could also be used), to the freight forwarder's management software. Here the software performs a set of verifications to ensure the compliance of the transport service.

During Activity 3 (Figure 2.8), an employee with (another) portable barcode reader reads the various labels. This information is loaded into a management software and it is sent, using any communication system, to the freight forwarder's management software. Here, again, the software performs a set of verifications to ensure that compliance of the transport service. The same operation is repeated in Activities 6 and 8 (Figure 2.8).

In case of any delay in leg 1 or 3, the vehicle driver is requested to sent a (text) message to the freight forwarder's management system. In case of delay in leg 2, the combination company is required to perform the same task. The freight forwarder's management system in face of a non-compliance warns an employee that manually attempts to recovery it.

For the computation of the costs due to the improvement of the logical fitness let us consider the equipment, quantities and unitary costs presented in Table 5.20.

In addition, there is the costs of communication[250] which can be computed in 10€cents. per each message sent, the costs of employees[251] which can be computed in a total of 7.5€ per hour.

In order to compute an overall cost, let us assume the following conditions:

- The shipper expedites an average of 500 kilograms[252] per shipment. The cargo is loaded in boxes of 15 kilograms, in a total of 34 boxes per shipment;
- An employee takes about 10 seconds to print a label and tag a box, 5 seconds to read each label, and 15 minutes per shipment to process and to send the information to the freight forwarder;
- The life time of the equipment is 5 years;
- The freight forwarder works 5 days per week and manages an average of 25 shipments per day;
- Vehicles in leg 1 and leg 3 process an average of 2 transport services per day.

[250] Information provided by Mr. Lopes Bastos.
[251] Information obtained with informal conversations during the author's training at airport of Oporto.
[252] This corresponds to the worst case with minimum demand.

Table 5.20 - Equipment, quantity and unitary cost for a barcode communication system

Equipment	Quantity	Unitary Cost
Barcode printer ([a])	1 (carried in the vehicle of leg 1)	500€/printer
Labels ([a])	1 per each unit of transport	0.10€/label
Portable barcode reader ([a])	2 (carried in the vehicles in leg 1 and 2)	300€/reader
Management Software ([b])	1 server at the freight forwarder and 1 shipper per each transport agent	5000€/acquisition/ server 450€/acquisition/ shipper 15000€ of acquisition for the annual operation and maintenance([b,c])

([a]) Source: BarcodesInc (http://www.barcodesinc.com, 11th June 2010)

([b]) Source: Infos (http: www.infos.pt, 11th June 2010)

([c]) Includes the cost of one employee plus 10% of the cost of acquisition for maintenance.

It is now possible to compute the maximum expectable costs of each label and per service, being:

- $Cost_{Barcode\ printer}$ = 0.58€cents./label[253]
- $Cost_{Portable\ barcode\ reader}$= 1.04€cents./label[254]
- $Cost_{Management\ Software}$= 3.27€/service[255]
- $Cost_{Employee}$= 1.88€/service + 0.0313€/label[256]

Thus, the extra costs due to an improvement in the level of fitness can be computed in:

- Cost= 5.15€/service + 0.475€/label

Considering an average of 34 boxes per shipment the extra cost is around 6.77€/service.

[253] Number of Labels per year = 52weeks per year *(2 services per day * 5 days per week * (500kg per shipment / 15 kg per box) = 17333 labels per year

$Cost_{Barcode\ printer}$= 500€/(5years * 17333) = 0.0058€/label

[254] $Cost_{Portable\ barcode\ reader}$= 3units * 300€ / (5 * 17333) = 0.0104€/label

[255] Number of services per year= 25 services per day * 5 days per week * 52 weeks per year = 6500

$Cost_{Management\ Software}$ = (20000€ + (3units * 450€ + 5000€)/5years) /6500= 3.27€/service

[256] $Cost_{Employee}$= 7.5€ per hour * 15minute per services/60minutes per hour = 1.88€/service

$Cost_{Employee}$= 7.5€ per hour * (10seconds to print and tag per label + 5seconds to read per label)/3600seconds per hour = 0.031€/label

Finally, there would be the need to consider to extra costs that the freight forwarder would incur to mitigate or solve a situation of delay. In this situation two costs would be considered. The extra costs by requesting an express transhipment or the extra costs corresponding to the hiring of another transport service. In what concerns the former case, the cost of the express transhipment can be up to thirty percent of a standard transhipment[257]; while, in what concerns the latter case, the price of the new service would depend upon the market conditions.

Modifications in AFETAS

The modifications in AFETAS to simulate the abovementioned changes are now presented. The following types of market were defined:

- Market Type 1:
  - 1 agent in each leg, forming 1 intermodal freight transport service, was flagged as having a compatible communication system;
  - The remaining agents (1 air transport agents), forming 1 intermodal freight transport service, was flagged as not having.
- Market Type 2:
  - 1 agent in each leg, forming 1 intermodal freight transport service, was flagged as having a compatible communication system;
  - The remaining agents, forming 39 intermodal freight transport services, were flagged as not having.
- Market Type 3:
  - 8 agents in each leg, forming 32 intermodal freight transport services, were flagged as having a compatible communication system[258];
  - The remaining agents, forming 3968 intermodal freight transport services, were flagged as not having[259].

[257] Information kindly provided by Mr. Amicar Theias.
[258] The identification of the various chains is similar to the case of the physical fitness. More information in Footnote 239.
[259] The reason for choosing more than one intermodal freight transport service was the same as presented in the case of the physical fitness, More information in Footnote 240.

In addition, every agent in the model was loaded with data the in Table 5.10 to Table 5.13. The proto-agent terminal was loaded with the data in Table 5.14, but knowledgeable about the transport agents flagged as interoperable.

The simulation of the higher level of logical fitness was done by considering that the freight forwarder, upon receiving the information about a delay, in leg 1 or leg 2, was able to either request an express transhipment service or hire another transport service, and thus to solve it. In practical terms, this means that a delay in leg 1 or leg 2 (but not in leg 3) in a chain with higher level of logical fitness does not result in a delay of the transport service. The simulation of an eventual increase of the costs was done by adding the above calculated costs to the price of a chain with higher level of logical fitness. The costs are 5.15€ plus 0.475€ time the number of boxes.

The economies[260] earned by the freight forwarder with the resolution of the delay are not directly considered in the decision making process; instead they are incorporated in the Level of Trust of the agents and, thus, they are implicitly considered in the next service[261].

The two Situations were again considered as follows:

- Situation 1: No increase in the price of the services with higher level of logical fitness;
- Situation 2: Increase in the price, equal to the above discussed costs, for the transport agents flagged as being interoperable. The increase in the price is only considered, by the freight forwarder, if all agents are flagged[262].

---

[260] Economies are obtained from the difference of the indemnity that the freight forwarder would have to pay to the shipper minus the extra costs of requesting the express transhipment service or hiring another transport service.

[261] The improvement in the Level of Trust is considered half of the improvement of a transport service without delay.

[262] This means that, in what concerns the flagged transport agents, the freight agents considers two prices. The lowest price (no costs owing to logical fitness) if any of the other agents in the chain are not flagged, the higher price (costs owing to logical fitness) if all the others are flagged.

Results

The results are now presented and discussed. The results obtained for Situation 1 are presented in the Table 5.21 and sketched in Figure 5.29 to Figure 5.31; while the results obtained for Situation 2 are presented in the Table 5.22 and sketched in to Figure 5.32 to Figure 5.34. The results are presented following a similar structure as the results of the Physical Fitness and Base Case.

In Situation 1, in both Market Type 1 and Market Type 2, the chains with higher fitness obtained a visible advantage in all types of shippers In what concerns the Market Type 3, the results also reveal a higher market share of the chains with higher fitness vis-à-vis the others, in all types of shippers, although less notable than in the other two types of market.

A possible explanation for these results is related with the nature of the logical fitness. This dimension of fitness reveals itself only in situations of non-compliance. Since the transport agents have high levels of reliability (all above ninety percent), we may conclude that the cases of non-compliance are rather few. As such, the opportunities to benefit from this dimension of fitness are also few.

Other conclusion to be drawn from the results is the apparent no influence of the type of shipper in the market share, since, all types of market, the values of the market shares are similar in all types of shippers. The reason is linked with the shipper's modal choice variables (the transit time and the price). This dimension of fitness has no direct influence in these variables, as such, the valuation of the various combinations is similar for the various types of shippers. Instead, this dimension of fitness influences the agents' memory (through the Level of Trust). The Level of Trust determines the choice of the transport agents in the freight forwarder's modal assemblage process.

At last, in what concerns the assessment of the conceptual framework, the results make an evidence about its validity. Like for the Physical Fitness experiment, the Experiment only differed in relation to the Base Case experiment in single aspect, which was the change in the level of logical fitness. The differences in the market shares can thus be ascribed to that difference in the level of fitness. In all types of market, the validity of the framework is assessed since the chains with higher fitness recorded a higher market share than the others.

Table 5.21 – Results of Situation 1 of Logical Fitness Case

Chain	Type of Shipper	Market Type 1					Market Type 2					Market type 3				
		TMS	Av.	Std.D.	Max.	Min.	TMS	Av.	Std.D.	Max.	Min.	TMS	Av.	Std.D	Max.	Min.
Fitness Chain	T. Sensitive	57,2	57,2	3,48	70,3	50,2	3,43	3,43	0,532	4,49	2,01	1,07	0,0334	0,0844	0,536	0,00
	Neutral	56,7	56,7	3,59	65,0	47,9	3,32	3,32	0,484	4,22	2,31	1,02	0,0317	0,0764	0,542	0,00
	P. Sensitive	56,9	56,9	3,25	66,8	48,2	3,38	3,38	0,534	4,57	2,11	1,10	0,0344	0,0836	0,693	0,00
Other Market Chain	T. Sensitive	42,8	42,8	3,48	49,8	29,7	96,6	2,48	0,587	5,09	0,797	98,9	0,0249	0,0606	0,588	0,00
	Neutral	43,3	43,3	3,59	52,1	35,0	96,7	2,48	0,575	4,85	1,27	98,9	0,0249	0,0603	0,554	0,00
	P. Sensitive	43,1	43,1	3,25	51,8	33,2	96,6	2,48	0,594	6,02	0,767	98,9	0,0249	0,0606	0,674	0,00

Legend: TMS - Total Market Share, Av. - Average, Std.D. - Standard Deviation, Max. - Maximum, Min - Minimum, T. - Time, P. - Price. All values in percentage.

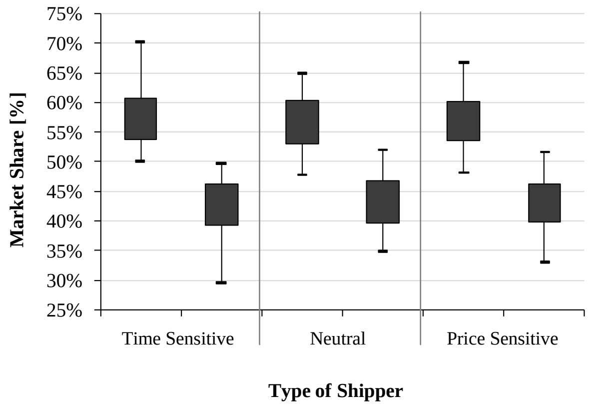


Figure 5.29 - Market shares of Market Type 1 of Situation 1 of Logical Fitness Case

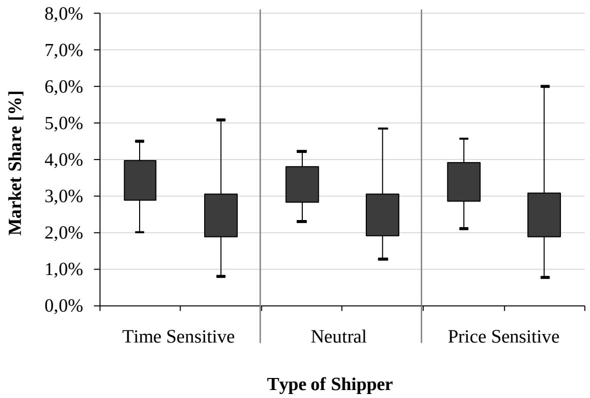


Figure 5.30 - Market shares of Market Type 2 of Situation 1 of Logical Fitness Case

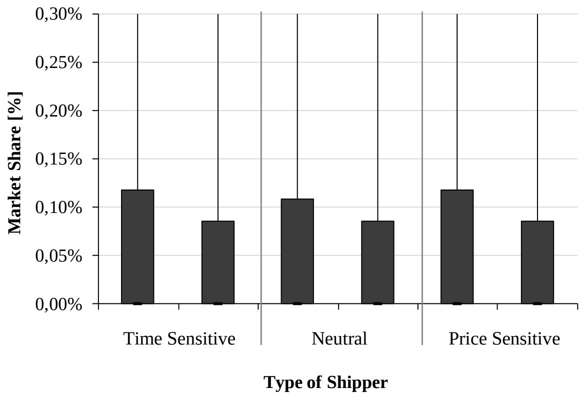


Figure 5.31 - Market shares of Market Type 3 of Situation 1 of Logical Fitness Case

Table 5.22 – Results of Situation 2 of Logical Fitness Case

Chain	**Type of Shipper**	**Market Type 1**					**Market Type 2**					**Market type 3**				
		TMS	Av.	Std.D.	Max.	Min.	TMS	Av.	Std.D.	Max.	Min.	TMS	Av.	Std.D	Max.	Min.
Fitness Chain	T. Sensitive	53,4	53,4	3,1	61,9	47,6	2,54	2,54	0,398	4,01	1,80	0,546	0,0170	0,00706	0,0553	0,00
	Neutral	51,6	51,6	4,0	63,2	42,6	2,48	2,48	0,412	3,31	1,68	0,501	0,0157	0,00879	0,0524	0,00
	P. Sensitive	48,6	48,6	3,8	58,5	40,5	2,45	2,45	0,398	4,01	1,80	0,457	0,0143	0,00655	0,0712	0,00
Other Market Chain	T. Sensitive	46,6	46,6	3,1	52,4	38,1	97,5	2,50	0,475	4,87	1,37	99,5	0,02506	0,0607	0,645	0,00
	Neutral	48,4	48,4	4,0	57,4	36,8	97,6	2,50	0,456	4,52	1,32	99,5	0,02508	0,0617	0,521	0,00
	P. Sensitive	51,4	51,4	3,8	59,5	41,5	97,5	2,50	0,475	4,87	1,37	99,5	0,02509	0,0607	0,552	0,00

Legend: TMS - Total Market Share, Av. - Average, Std.D. - Standard Deviation, Max. - Maximum, Min - Minimum, T. - Time, P. - Price. All values in percentage.

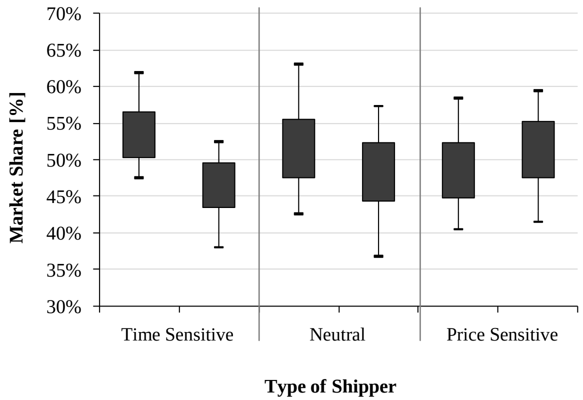


Figure 5.32 - Market shares of Market Type 1 of Situation 2 of Logical Fitness Case

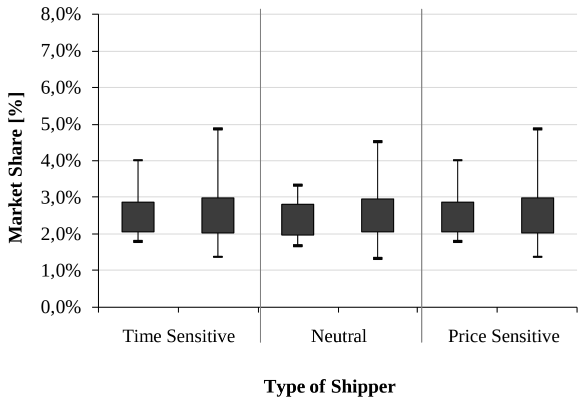


Figure 5.33 - Market shares of Market Type 2 of Situation 2 of Logical Fitness Case

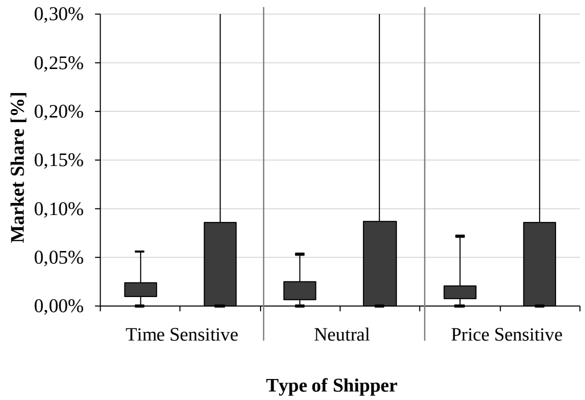


Figure 5.34 - Market shares of Market Type 3 of Situation 2 of Logical Fitness Case

In Situation 2, the chains with higher level of fitness were able to record a visible advantage in case of time sensitive shippers and an advantage in case of neutral shippers in the Market Type 1. In the remaining shippers and market types, the chains with higher level of fitness recorded either a similar or a lower market share.

In some of the Experiments the differences between the chains with higher level of fitness and the others are small, which may raise the question if the advantage could be generated by random factors instead of the higher level of fitness. The author believes not since the higher level of fitness should have contributed for the results like it did in Market Type 1. A reason for this outcome is related with intrinsic behaviour of the market in AFETAS. The freight forwarder's modal choice process is based on time and price, after a selection of the agents with higher Level of Trust. In markets with several agents (as in the case of Market Type 2 and Market Type 3), both agents flagged as having communication system as well as agents flagged with no communication are likely to be selected. The latter with lower prices will tend to be highly evaluated than the former. In any case, no definitive conclusions can be drawn

In what concerns the assessment of the hypothesis of this research work, again the results do not entirely corroborate the hypothesis. Evidences about the benefits of integration in the improvement of companies' market positioning were obtained in the time sensitive shippers in Market Type 1. In Market Type 2, the time sensitive shippers were also able to obtain some advantage. In the remaining cases, the results did not evidence benefits of integration. Although we may argue that the typical shipper of air transport values time over price and, as such, the results may evidence the benefits of integration. The fact is that price is increasingly relevant and the results cannot be ignored.

In summary, the results evidence that benefits may accrue from an improvement in the level of logical dimension of fitness. As such, they provide evidence about the validity of the conceptual framework. The advantages of the chains with higher market share are stronger in the Market Type 1 and Market Type 2 than in Market Type 3. Also, the results partially evidence that an improvement in the integration may result in an improvement in the market positioning of the agent. The evidences were collected in the time sensitive and neutral shipper, in Market Type 1, and in the time sensitive, in Market Type 2.

5.5.2.4 Strategic Fitness Case: schedule coordination

Modifications in the production brought by a change in the fitness

The last experiment to be carried out concerned the strategic fitness case. As explained in Chapter 3.3 this dimension of fitness refers to the nature of the relationships between the dual systems. This dimension embraces several factors and properties, such as: trust amongst agents, alignment of strategies, cultural proximity or similarity of processes. Although being eminently intangible, it may nonetheless influence the production of intermodal freight transport chains. Amongst the various possibilities, the coordination of the transport agents' schedules was the factor chosen to assess the eventual influence of the strategic fitness in the performance of intermodal freight transport services. The reason lays in the direct impact of this factor in the production of the transport service, which should ease assess the assessment of the influence of the fitness.

In this experiment the profile of the dual systems is made of a single variable, which is the *schedule*.

No changes are expected to occur in the process of producing an intermodal freight transport service owing to a change in the transport agents' schedule. The sub process 1 is not influenced by this change, and the freight forwarder will make use of the transport agents' schedules regardless any type of coordination or alignment. In what concerns the sub process 2, again, no changes are expected to occur as the production of each activity does not depend on the eventual coordination of the schedules between the transport agents.

The analysis of the costs due to an improvement in the level of strategic fitness would naturally depend on the changes that the transport agents would be required to introduce. Firstly, the change of the schedule on a given route would impact to a more or a less extent the agent's network of transport. The point is that the agent works with a finite set of resources (such as: vehicles, drivers, etc.). A change of schedule on a give route would most likely lead to a reallocation of the resources on the others. Secondly, in the case of air transport, the combination companies typically define their networks in function of the passenger business. Thus, a change in a schedule owing to the cargo business would also have to be compatible with the passenger's market. Thirdly, in both air transport and rail transport, a change of a schedule is dependent upon the availability of slots[263]. Yet, slots may either not be available in certain schedules or be more expensive, which may hinder the attempt of rescheduling.

We may thus conclude that the improvement in this type of strategic fitness impact cost factors that lay outside the production of the intermodal freight transport service. For such reason the assessment of the eventual costs, as it was done in the previous experiments, is not feasible in this Experiment.

Modifications in AFETAS

The modifications in AFETAS to simulate the abovementioned changes are now presented. The improvement in the level of strategic fitness was done through the coordinating of schedules of some combination companies (in leg 2) and some land based transport agents at destination (in leg 3). No changes were introduced in the land based transport agents at origin because they work based on non-fixed schedules.

The markets in AFETAS were defined as follows:

- Market Type 1 and Market Type 2:
    - One (1) air transport agent and 1 destination land based transport agent were set to have coordinated schedules. The air transport agent was defined with a daily schedule at 02H00M and the land based transport agent was defined with a daily schedule at 18H00M.
- Market Type 3:
    - Two (2) air transport agents and 2 destination land based transport agents were set to have coordinated schedules. The air transport agent was

[263] In case of air transport, availability of slots at the airport. In case of rail transport, availability of slots at the railways tracks.

defined with a daily schedule at 2H00M and the land based transport agent was defined with a daily schedule at 18H00M.

In case of Market Type 1 there is 1 coordinated chain in a total of 2 chains, in Market Type 2 there is 2 coordinated chains in a total of 40 chains, and in Market Type 3 there is 80 coordinated chain in a total of 4000 chains[264]. The changes in the transport agents' schedule were introduced in the variable `Schedule` (Table 5.12 and Table 5.13). In addition, every agent in the model was loaded with data the on Table 5.10 to Table 5.14.

The two Situations were defined as follows:

- Situation 1: Improvement in the level of strategic fitness with no increase in the price. In this situation the increase in the level of logical fitness is considered to not change the transport agents' costs.
- Situation 2: Improvement in the level of strategic fitness with an incremental increase in the price. To overcome the practical unfeasibility of assessing the costs, two cases with different increments in the price were considered. The purpose is to understand the amount of increase that exhausts the benefits accruing from the improvement in the level of fitness. This will support the transport agents in understand the upper bound for an increase in the price.
  The increments in the price were: 5% and 15%.

Results

The results are now presented and discussed. The results obtained for Situation 1 are presented in the Table 5.23 and sketched from Figure 5.35 to Figure 5.37. In what concerns Situation 2, the presentation of the results are somewhat different from the other experiments. The results for the price increase of five percent is presented in Table 5.24 and sketched from Figure 5.35 to Figure 5.37 and the results for the price increase of fifteen percent is presented in Table 5.26 and sketched from Figure 5.38 to Figure 5.40.

---

[264] Market Type 2: 2 origin land based agents * 1 air agent * 1 destination land based agent= 2 chains;
Market Type 2: 20 origin land based agents * 2 air agent * 2 destination land based agent= 80 chains.
Footnote 240 explains the reasons for chosing more than one agent in Market Type 3.

Starting the analysis with Situation 1, a first conclusion to draw is the visible divergence of the results in relation to the results of the Base Case, which evidences the influence of the level of fitness in the performance of the transport agents.

The chains with higher level of fitness were able to obtain higher market shares in every market type. In both Market Type 1 and Market Type 2, there is a visible advantage, while in Market Type 3 the advantage is somewhat reduced. A possible reason, similar to the one presented in the Physical Fitness, is the freight forwarder to evaluate all the possible chains in the first two market types; while she only evaluates a small fraction on the modal choice process in Market Type 3. As such, the advantages of those chains with higher level of fitness can be easily grasped and exploited in Market Type 1 or Market Type 2 than in Market Type 3.

Also visible is the variation of the market share in function of the type of customer. The results show that the higher is the relevance of the time in the decision making process, the higher is the difference in the results of the market shares. Again, the same reason presented for the Physical Fitness can be used in the dimension of fitness. The point is that the coordination of schedules has a direct impact in the transit time, which is one of the factors of the modal choice process. Thus, differences amongst the type of shippers were to some extent expected.

In what concerns the interest of the results for the evaluation of the conceptual framework, the results provide evidence about its validity. Situation 1 differs in relation to the Base Case situation in single aspect, which is the change in the level of strategic fitness. The differences in the market shares of the chains with higher level of fitness vis-à-vis the others can in this way be ascribed to that difference in the level of fitness.

Therefore, the differences in the market shares evidence that the strategic fitness (factor: schedule coordination) influences the performance of the intermodal freight transport service.

Table 5.23 – Results of Situation 1 of Strategic Fitness Case

Chain	Type of Shipper	Market Type 1					Market Type 2					Market type 3				
		TMS	Av.	Std.D.	Max.	Min.	TMS	Av.	Std.D.	Max.	Min.	TMS	Av.	Std.D	Max.	Min.
Fitness Chain	T. Sensitive	59,7	59,7	1,69	70,2	50,9	10,7	5,34	0,375	6,26	4,34	5,11	0,0639	0,2741	2,387	0,00
	Neutral	55,5	55,5	1,76	64,8	51,3	10,2	5,08	0,507	6,58	4,27	3,40	0,0426	0,0748	0,710	0,00
	P. Sensitive	53,4	53,4	1,39	61,8	46,7	9,56	4,78	0,337	5,57	3,97	2,84	0,0355	0,1572	1,971	0,00
Other Market Chain	T. Sensitive	40,3	40,3	1,69	49,1	28,1	89,3	2,35	1,52	5,22	0,810	94,9	0,0242	0,125	1,793	0,00
	Neutral	44,5	44,5	1,76	50,7	35,2	89,8	2,36	1,60	4,71	0,835	96,6	0,0246	0,132	2,059	0,00
	P. Sensitive	46,6	46,6	1,39	50,3	38,2	90,4	2,38	1,30	4,13	1,08	97,2	0,0248	0,126	1,742	0,00

Legend: TMS - Total Market Share, Av. - Average, Std.D. - Standard Deviation, Max. - Maximum, Min - Minimum, T. - Time, P. - Price. All values in percentage.

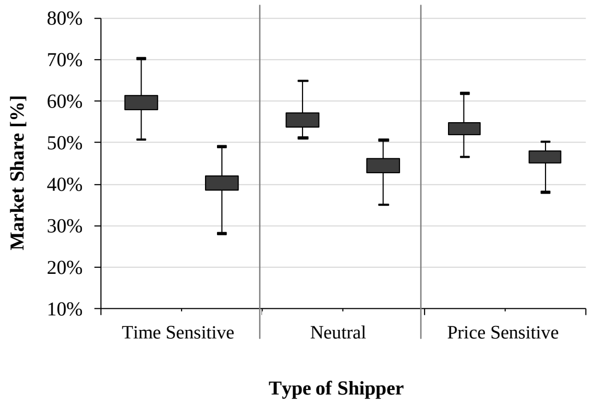


Figure 5.35 - Market shares of Market Type 1 of Situation 1 of Strategic Fitness Case

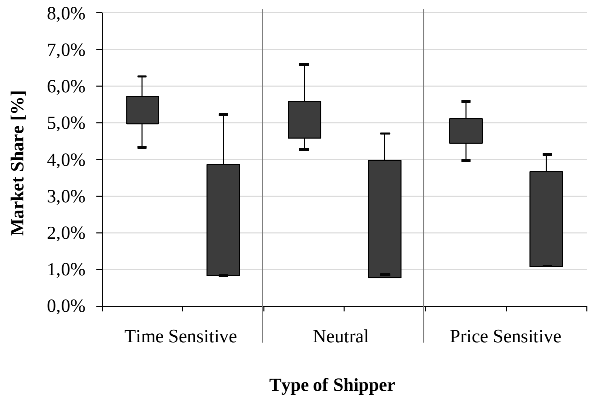


Figure 5.36 - Market shares of Market Type 2 of Situation 1 of Strategic Fitness Case

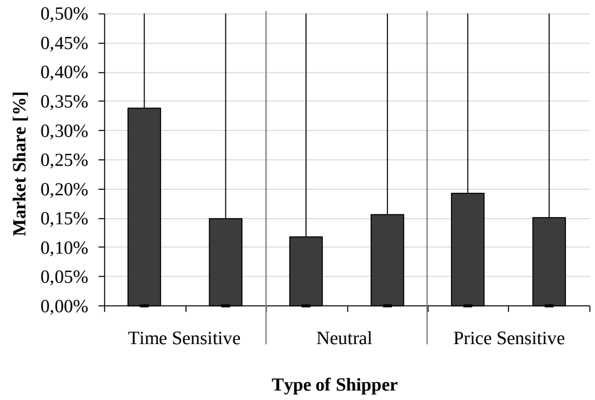


Figure 5.37 - Market shares of Market Type 3 of Situation 1 of Strategic Fitness Case

Table 5.24 – Results of Situation 2 of Strategic Fitness Case (increase in price of 5%)

Chain	Type of Shipper	Market Type 1					Market Type 2					Market type 3				
		TMS	Av.	Std.D.	Max.	Min.	TMS	Av.	Std.D.	Max.	Min.	TMS	Av.	Std.D	Max.	Min.
Fitness Chain	T. Sensitive	55,8	55,8	2,07	65,7	50,9	9,02	4,51	0,344	5,30	3,48	3,27	0,0409	0,313	2,49	0,00
	Neutral	52,7	52,7	2,36	61,0	47,4	7,66	3,83	0,275	4,47	2,96	2,85	0,0356	0,256	1,95	0,00
	P. Sensitive	51,0	51,0	2,09	57,9	45,9	4,97	2,49	0,240	3,44	2,08	1,99	0,0249	0,114	1,40	0,00
Other Market Chain	T. Sensitive	44,2	44,2	2,07	51,1	37,4	91,0	2,39	1,16	5,05	1,05	96,7	0,0247	0,124	1,98	0,00
	Neutral	47,3	47,3	2,36	55,9	38,3	92,3	2,43	0,763	4,68	1,22	97,1	0,0248	0,127	1,87	0,00
	P. Sensitive	49,0	49,0	2,09	60,6	40,3	95,0	2,50	0,316	3,48	1,59	98,0	0,0250	0,129	2,24	0,00

Legend: TMS - Total Market Share, Av. - Average, Std.D. - Standard Deviation, Max. - Maximum, Min - Minimum, T. - Time. All values in percentage.

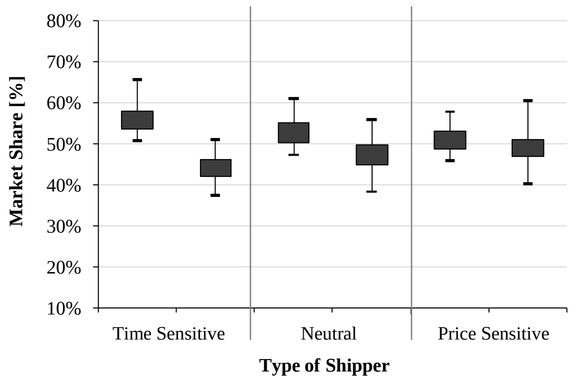


Figure 5.38 - Market shares of MT 1 of Situation 2 of Strategic Fitness Case (increase in price of 5%)

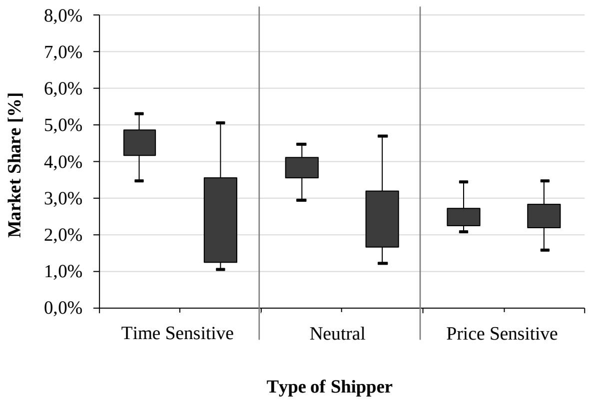


Figure 5.39 - Market shares of MT 2 of Situation 2 of Strategic Fitness Case (increase in price of 5%)

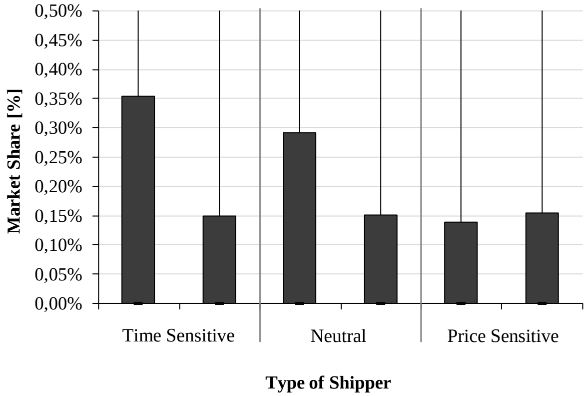


Figure 5.40 - Market shares of MT 3 of Situation 2 of Strategic Fitness Case (increase in price of 5%)

Table 5.25 – Results of Situation 2 of Strategic Fitness Case (increase in price of 15%)

Chain	**Type of Shipper**	**Market Type 1**					**Market Type 2**					**Market type 3**				
		TMS	Av.	Std.D.	Max.	Min.	TMS	Av.	Std.D.	Max.	Min.	TMS	Av.	Std.D	Max.	Min.
Fitness Chain	T. Sensitive	48,8	48,8	2,09	53,7	42,3	4,97	2,48	0,327	3,67	1,54	1,98	0,0247	0,3609	2,204	0,00
	Neutral	45,4	45,4	2,32	51,2	40,6	4,56	2,28	0,251	2,86	1,69	1,65	0,0206	0,1945	1,406	0,00
	P. Sensitive	42,2	42,2	2,18	47,4	38,3	4,18	2,09	0,225	2,74	1,58	1,04	0,0130	0,0588	0,611	0,00
Other Market Chain	T. Sensitive	51,2	51,2	2,09	62,1	41,2	95,0	2,50	0,89	3,81	1,20	98,0	0,0250	0,129	2,346	0,00
	Neutral	54,6	54,6	2,32	64,3	44,9	95,4	2,51	0,65	3,53	1,34	98,4	0,0251	0,128	1,761	0,00
	P. Sensitive	57,8	57,8	2,18	64,1	52,6	95,8	2,52	0,50	3,47	1,69	99,0	0,0252	0,129	1,533	0,00

Legend: TMS - Total Market Share, Av. - Average, Std.D. - Standard Deviation, Max. - Maximum, Min - Minimum, T. - Time. All values in percentage.

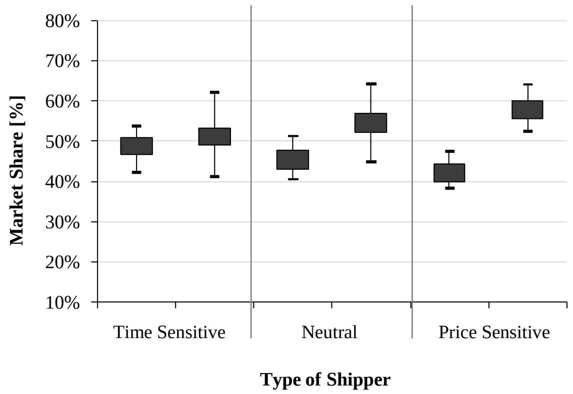


Figure 5.41 - Market shares of MT 1 of Situation 2 of Strategic Fitness Case (increase in price of 15%)

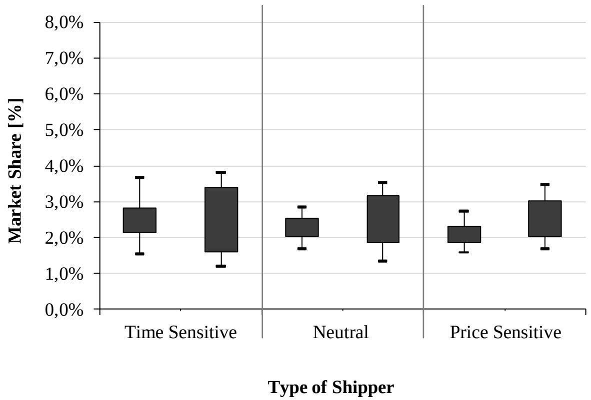


Figure 5.42 - Market shares of MT 2 of Situation 2 of Strategic Fitness Case (increase in price of 15%)

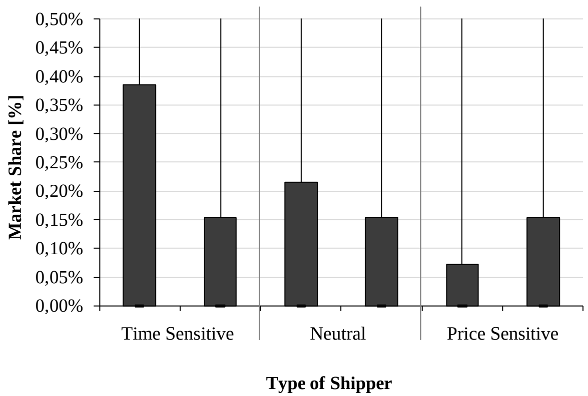


Figure 5.43 - Market shares of MT 3 of Situation 2 of Strategic Fitness Case (increase in price of 15%)

Moving now to the analysis of Situation 2. In this situation besides the change in the level of fitness, there is also a change in the prices. As justified above, in face of the practical unfeasibility of assessing the extra costs of an improvement in the level of fitness, two cases of price increase were considered. A first conclusion is that an increase in the price renders a reduction in the market share of the chains with higher level of fitness.

For the minimum increase in price (five percent), in every market type, the chains with higher level of fitness recorded higher market shares than the others and in Market Type 1 and Market Type 2 they achieved a visible advantage. The same did not occur in the case of the maximum increase of price (fifteen increase). In this case, the chains with higher level of fitness were able to obtain a visible advantage in the time sensitive shipper, in all the market types. In what concerns the neutral and price sensitive shipper, these chains recorded similar or lower level of market share than the other chains. The reasons for the variations of the results between market types and type of shippers is similar to the reasons presented for the Situation 1.

In what concerns the assessment of the hypothesis of this research work, the results reveal a decrease in the benefits of integration with an increase in the price of the services, which corresponds to an increase in the costs of integration. The pace of exhaustion varies from market type to market type and among type of shippers. Yet, there are limits to the integration. So, if the costs of integration are below the threshold of exhaustion then the transport agents may benefit with integration, otherwise they will likely lose competitiveness and integration will not be advantageous.

In summary, the results evidence that benefits accrue from an improvement in the level of strategic dimension of fitness. As such, they provide evidence about the validity of the conceptual framework and about the hypothesis. The advantages of the chains with higher market share are stronger in the Market Type 1 and Market Type 2 than in Market Type 3. Also, the results evidence that an improvement in the integration does not always result in an improvement in the market positioning of the agent, but that it depends on increase of the costs due to an increase in the level of fitness.

5.5.3 Final Discussion

This chapter summarises the results and elaborates the main conclusions of the Simulation Assessment. The Simulation Assessment was developed to test the hypothesis[265] and to validate the conceptual framework (presented in Chapter 3).

In the Simulation Assessment, a virtual freight transport market was tested in different conditions. A set of four Experiments was considered, being:

- Experiment 0 - Base Case - no dimension of fitness was considered. Its purpose was to allow the ceteris paribus condition.
- Experiment 1 - Physical Case - physical dimension of fitness was tested;
- Experiment 2 - Logical Case - logical dimension of fitness was tested;
- Experiment 3 - Strategic Case - strategic dimension of fitness was tested. This dimension was simulated through the coordination of the transport agents' schedules.

In every Experiment two different Situations were taken into consideration. In Situation 1, the Experiment had a single change in relation to the Base Case, which was a change in the level of fitness (in a given dimension). Therefore, any eventual difference in the performance of the intermodal transport chains is certainly caused by that change in the level of fitness. The results were used to test the hypothesis. In Situation 2, the Experiment , besides the change in the level of fitness, the eventual extra costs owing to the change were also taken into consideration through an identical increase in the price of the transport service. The results can therefore be used to evaluate the benefits of integration for the combination companies and, thus, to test the hypothesis.

Starting with the analysis of the results for Situation 1, Table 5.26 summarises for every experiment, market type and type of shipper the attainment or not of an evidence supporting the conceptual framework. The legend is:

[265] The hypothesis claims that the integration of combination companies in intermodal freight transport services can enhance their competitiveness in the air cargo market.

- *Yes V* - denotes that the outcomes exhibited a visible[266] advantage of the chains high higher level of fitness vis-à-vis the other chains. The results provide evidence in favour of the conceptual framework.
- *Yes* - denotes that the outcomes exhibited an advantage of the chains high higher level of fitness vis-à-vis the other chains. The results provide partial evidence in favour of the conceptual framework, since the advantage could be caused by the random effects and not by the fitness.
- *No* - denotes that the outcomes exhibited a disadvantage of the chains high higher level of fitness vis-à-vis the other chains. The results do not provide evidence in favour of the conceptual framework[267].

In every dimension of fitness, evidences (Yes V and Yes) supporting the conceptual framework were always collected. The author may thus conclude that the conceptual framework can be valid and that it may adequately represent the mechanisms of integration in intermodal freight transport services.

Table 5.26 - Evidences collected with the Experiments, in Situation 1

Experiment	**Market Type**	**Type of Shipper**		
		Time Sensitive	**Neutral**	**Price Sensitive**
Physical	MT 1	Yes V	Yes	Yes
	MT 2	Yes V	Yes V	Yes V
	MT 3	Yes	Yes	Yes
Logical	MT 1	Yes V	Yes V	Yes V
	MT 2	Yes	Yes	Yes
	MT 3	Yes	Yes	Yes
Strategic (schedule coordination)	MT 1	Yes V	Yes V	Yes V
	MT 2	Yes V	Yes V	Yes V
	MT 3	Yes	Yes	Yes

[266] Visible denoting that the average minus the standard deviation of the market shares of the chains with higher level of fitness is higher than the sum of the average plus the standard deviation of the other chains. In these cases the advantage is likely ascribable to the fitness and not some random effects.

[267] Although we could argue that a disadvantage could also be caused by the random effects (that surpassed the eventual benefits of the fitness), this situation was not considered.

Moving now to the results obtained in Situation 2, Table 5.27 provides the same information[268] as Table 5.26, except for the Strategic Case. In this case, the legend is as follows:

- *Yes* - denotes that evidences in favour of the hypothesis were collected for every increase of price,
- Numeric value - corresponds to the increase of the price on which the benefits of integration were exhausted.

Table 5.27 - Evidences collected with the Experiments, in Situation 2

Experiment	Market Type	Type of Shipper		
		Time Sensitive	Neutral	Price Sensitive
Physical	MT 1	Yes	Yes	No
	MT 2	Yes V	Yes	No
	MT 3	Yes	Yes	No
Logical	MT 1	Yes V	Yes	No
	MT 2	Yes	No	No
	MT 3	No	No	No
Strategic (schedule coordination)	MT 1	15%	15%	15%
	MT 2	15%	15%	5%
	MT 3	15%	15%	5%

Again, in every Case evidences supporting the hypothesis were collected. Yet, in a substantial amount of the Experiments no evidences were collected, which denotes that the benefits of integration are quite dependent on the increase in the prices. In the Physical Fitness Experiment, only in the price sensitive shipper, it was not possible to found evidences in favour of the hypothesis. The Logical Fitness Experiment was the Experiment with less evidences. Indeed, only in Market Type 1 for the time sensitive and neutral shippers and in Market Type 2 for the time sensitive shipper evidences in favour of the hypothesis were collected. Finally, in the Strategic Fitness Experiment,

[268] Now the evidences refer to the Situation 2.

only in Market Type 2 and Market Typ3 for the price sensitive shipper the benefits accruing from integration were exhausted for the minimum increase in prices; while in all the others the benefits were exhausted for the increase of fifteen percent, which denotes that benefits may be accrued. Also, substantial variations between the shippers are visible, which denotes the influence of the requirements in the influence of the level of fitness.

The main conclusion is that integration can improve the market positioning of the combination companies. Yet, the eventual increase in the prices may curb the benefits of integration. The limits of integration depend on the dimension of fitness and on the type of shipper. Therefore, the departure hypothesis of this research work can be considered as only partially validated.

6 CONCLUSIONS

The final chapter of this dissertation brings together the main conclusions, achievements and limitations of the research work. Also, a list of topics for future research is elaborate at the end.

Let us first start with a brief summary of the research work. The domain of research was the air cargo market. The author argued that for several reasons the combination companies are nowadays in a difficult positioning in this market. Additionally, several challenges were found to hinder their attempts of improvement. This research work was precisely motivated by the difficult positioning of the combination companies in the air cargo market.

The air cargo business in the combination companies, despite being a secondary business, may nevertheless be influential in their survival, and this was explained in detail in Chapter 1.1. Based on this observation, the overall research objective was to contribute to the competitiveness of the combination companies in the air cargo market.

From the analysis to the current dynamics of the freight transport market, the author considered that *intermodality* can be a strategic option for combination companies to foster their current positioning in the market. The combination companies may deploy the strategy of intermodality in two ways: as participant in the intermodal freight transport service (single role: transport agent) or as freight forwarder of the intermodal freight transport services in which they may participate (dual role: freight forwarder and transport agent). The hypothesis was then phrased to support this proposal as follows: integration in intermodal freight transport service can enhance the competitiveness of the combination companies in the air cargo market.

To apply this strategy, an understanding of the *mechanisms of integration* is of paramount relevance, since the performance of the intermodal transport services is determined by the nature of the integration between the transport agents[269]. Moreover, such understanding will contribute to the combination company to deploy in the most adequate way her own capabilities or, alternatively, to help her in better improving them. This reasoning led to the elaboration of the operational objective that was the development of a conceptual framework about the mechanisms of integration of intermodal freight transport services.

In summary, intermodality was the strategy proposed to help the combination companies enhancing their positioning in the market. The conceptual framework was developed as an instrument to support the combination companies to deploy that strategy.

With the research work fully defined, the research has focussed, in Chapter 2 and in Chapter 3, in the development of the conceptual framework. The framework was grounded on the early works of Nadler and Tushman (1980) about the concept of fitness in organisational context. Two major assumptions about the properties of intermodal transport were central in its development, being:

- The assumption that a process analysis could provide an accurate tool for depicting and researching an intermodal freight transport service (Chapter 2.2);
- The assumption that intermodal freight transport service presents the properties of a complex system and therefore could be analysed using systems thinking and systems dynamics approach (Chapter 3).

The conceptual framework represents the mechanisms of integration through the concept of fitness (Figure 3.10 in Chapter 3.4). It is made of five building blocks:

1. Shipper's requirements;
2. Modal Profiles;

[269] Recall from Chapter 2.3 that the integration determines one of the three sources of performance in an intermodal transport service.

3. Tiers of Friction;
4. Dimensions of Fitness;
5. Performance of the Intermodal Transport Service.

The basic concept of the framework is the fitness that represents the increment of performance accruing from the integration of a set of dual systems[270]. Five dimensions of fitness were identified, being: physical fitness, logical fitness, liability fitness, financial fitness and strategic fitness.

The final part of the research work (developed in Chapter 4 and Chapter 5) was dedicated to test the hypothesis and to validate the conceptual framework. These were done with the simulation model named AFETAS. AFETAS simulates a freight transport market in which intermodal air cargo services can occur. The need to resort to a simulation model lain in the impossibility to use a real world case. Agent Based Modelling (ABM) was the modelling technique deployed in this research work.

Finally, the simulation assessment was carried out in Chapter 5.5. A set of four experiments was considered, being:

- Experiment 0: Base Case - no dimension of fitness was considered. Its purpose was to allow the ceteris paribus condition.
- Experiment 1: Physical Case - improvement in the level of physical fitness through the introduction of an interoperable container;
- Experiment 2: Logical Case - improvement in the level of logical fitness through the implementation of a compatible communication system.
- Experiment 3 - Strategic Case - improvement in the level of strategic fitness through the coordination of the transport agents' schedules.

In every Experiment two different Situations were taken into consideration. In Situation 1, the Experiment differed in relation to the Base Case in the level of fitness (in the given dimension); while in Situation 2, the Experiment, also considered the eventual extra costs accruing from the change in the level of fitness. The purpose of Situation 1 was to validate the conceptual framework, and the purpose of Situation 2 was to test the

[270] Dual system is a set compound by the transport agent and the mode of transport. If the same transport agent operates more than one mode of transport, than she forms several dual systems (one for each different mode of transport).

hypothesis. The results of the simulation assessment were presented and discussed in Chapter 5.5 and can be summarised as follows:

- The integration can improve the market positioning of the combination companies. Yet, an eventual increase of the prices would curb its benefits.
- The conceptual framework seems to be valid and, thus, it may adequately represents the mechanisms of integration in intermodal freight transport services.

From these results and bearing in mind that the purposes of the simulation assessment were to test the hypothesis and to validate the conceptual framework. The main conclusions to be drawn from this research can be written as follows.

The hypothesis was not entirely validated. Evidences supporting that integration may enhance the competitiveness of the combination companies were indeed collected. Yet, an improvement of the integration may raise the costs of production that may result in the increase of the prices of the transport services. The benefits of integration are then limited by the eventual increase in the prices and they can be exhausted if the prices go above a certain threshold[271].

The conceptual framework was validated, since the results corroborate the laws of interaction of the conceptual framework[272], in particular they evidenced that:

- The dimensions of the fitness influenced the performance of the intermodal freight transport services;
- The variables of the modal profiles influenced the performance;
- The level of fitness influenced the performance, since variations in the fitness resulted in changes of the performance in the intermodal freight transport services;
- The requirements of the shippers influenced the relevance of the variables of the modal profile, since different results were obtained for the different shippers;
- The latency of the logical fitness was visible (although further tests should be done).

[271] This threshold depends on the specific market conditions and it has to be computed in each situation.
[272] The laws of interaction of the conceptual framework are presented in Chapter 3.4.

Recalling the motivation and overall objective of this research work and taken into consideration the research work and the results, the main conclusions of this dissertation can be written as follows:

- Integration is a feasible strategy for combination companies. However, in order to be successful the costs of integration should be duly taken into consideration.
- The conceptual framework may be an adequate support tool, to support the combination companies in achieving a better integration.

The main contributions to the body of research, in the domain of freight transport, added by this research work can be summarised as follows:

- Understanding of the sources of performance in an intermodal freight transport service;
- Development of a novel conceptual framework representing the mechanisms of fitness;
- Understanding of the mechanisms of influence of fitness in the performance of an intermodal freight transport service;
- Contributing to the literature concerning the problems related with the organisation and management of intermodal freight transport services;
- Development of a novel micro-simulation model concerning freight transport market;
- Contribution to the experience of the application of agent based modelling technique in the domain of transports.
- New perspective for the study of the problems affecting combination companies in the cargo market and the production of intermodal freight transport services.

Notwithstanding the efforts to develop a sound research work, it presents some limitations that should be taken into consideration:

- The tests were done based on a simulation model (AFETAS), which is a simplification of the real world.
- The simulation assessment was but a single test and many others are required to improve confidence in the conceptual framework. In what concerns the

hypothesis, the Simulation was enough to evidence some of its limitations. In what concerns the conceptual framework the evidences were favourable. But this should not be interpreted as the validation of the conceptual framework. Further more tests are required until the conceptual framework could be considered duly valid.

The research developed in this research work identified other avenues of research and raised new questions for future research:

- Integration was the strategy defended in this research work for helping combination companies in the air cargo market. Yet, others could be followed, such as: increase of frequencies, exploitation of market niches, vertical integration with freight forwarders, etc. Every one of this possibilities is a new stream of research to explore;
- This work researched one of the three sources of performance. Further research in the other two sources are necessary to build a complete framework about the mechanisms determining the performance in an intermodal freight transport service;

- The results evidence the existence of a relationship between market size and influence of fitness. Future research should clarify if this evidence holds and, if so, to clarify the underlying mechanisms.
- The study of the actual influence of each dimension of fitness lied outside the scope of this research work. Future research work should be conducted along each dimensions to quantity the impact.
- Strategic fitness was assessed through a specific type: schedule coordination, others types should be investigated, such as: joint acquisition of equipment, streamlining processes and procedures, etc.
- Fitness is likewise influence by agents' strategies. Future work should consider different types of agents' strategies, which could be analysed through game theory (AFETAS could be upgraded to incorporate game theory engine).

- Assessment of the validation is still in an early stage, more testing involving the other dimensions of fitness are required to build trust;
- Assessment of the validation was carried out in three of the five dimensions of fitness. Further assessments in other transport markets, where the remaining dimensions are relevant, are required to enrich the validation process.

- AFETAS considers a single directional freight transport. Bearing in mind that market unbalances are common in air freight markets, such limitation may introduce some bias in the analysis of fitness (Footnote 182). Further development of AFETAS to consider freight transport in both directions is of interest and should be followed.
- AFETAS's decision making engine is based in fuzzy logic. Future research should also investigate other alternative models;

7 BIBLIOGRAPHY

- Ackoff, R. (1962) “Scientific Method: Optimizing Applied Research Decisions“, John Willey and Sons, Oxford
- Ackoff, R. (1994) “Systems thinking and thinking systems” , Systems Dynamics Review, Vol 2, Issues 2-3, pp 175-188
- Adler, J.; Satapathy, G.; Manikonda, V.; Bowles, B.; Blue, V. (2005) “A multi-agent approach to cooperative traffic management and route guidance”, Transportation Research Part B: Methodological, Volume 39, Issue 4, May 2005, pp 297-318
- Air Transport World (several years) “World airline report”, published July
- Allaz, C. (2004) “The history of air cargo and airmail from the 18th century”, Christopher Foyle Publishing, London (United Kingdom), ISBN: 1902579828
- Álvarez, I., Marin, R., Fonfria, A. (2009) “The role of networking in the competitiveness of firms”, Technological Forecasting and Social Change, Vol. 76, Issue 3, pp 410-421
- Ambastha, A., Momaya, K (2004) “Competitiveness of Firms: Review of Theory, Frameworks, and Models”, Singapore Management Review, Vol 26, Issue 1, pp 45-61
- Anderson, C. (2006) “Imbalance a costly business”, Orient Aviation, November 2006, pp 39, Link: http://www.mergeglobal.com/articles/2006-11-20_OAMag_Imbalance.pdf (2nd May 2009).
- ANTRAM (2008) “Anuário 2008 - Custos de Producção de Transportes”, Link: http://www.antram.pt/list.aspx?idc=2689 (12th August 2009).
- Ariew, A., Lewontin, R. (2004) "The Confusions of Fitness", The British Journal for the Philosophy of Science, Vol 55, Issue 2, pp 347-363
- Asariotis, R. (1999) “The need for an integrated intermodal transport liability Regime”, Transport Quarterly, Vol 53, Issue 2, pp 45-55
- Ashford, N.; Stanton, M.; Moore, C. (1997) “Airport operations”, McGraw Hill , New York (Unites States), ISBN: 0070030774

- Axelrod, R. (1997) “The Complexity of Cooperation: Agent-Based Models of Competition and Collaboration”, Princeton University Press, Princeton (United States), ISBN: 0691015678
- Axtell, R. (2000) “Why agents? On the varied motivations for agent computing in the social sciences”, CSED Working Paper 17, Brooking Institution
- Azevedo, A.; Alves, J. (2002) “Gestão por Processos - da Estratégia à Melhoria Contínua das Organizações: o potencial da ISSO 9001:2000”, IberoGestão (internal report), Vila Nova de Gaia (Portugal).
- Baindur, D. (2010) “Exploring the conditions for success of the “Motorways of the Sea” concept”, Doctoral Research work, Instituto Superior Técnico, Technical University of Lisbon, Portugal
- Ballis, A., Golias, J. (2004) "Towards an improvement of a combined transport chain performance", European Journal of Operational Research, Vol 152, pp 420–436
- Bergkvist, M.; Davidsson, P.; Persson, J.; Ramstedt, L. (2005) “A hybrid micro-simulator for determining the effects of governmental control policies on transport chains”, in “LNAI 3415 - Multi agent based simulation 2004”, Ed. Paul Davidsson. Brian Logan and Keiki Takadama, ISBN: 9783540252627, pp 236-247
- Bergqvist, R., Tornberg, J. (2008) " Evaluating Locations for Intermodal Transport Terminals", Transportation Planning and Technology, Vol. 31, Issue 4, pp 465-485
- Bertsch, L. (2009) " Managing through Financial Crisis - Outsourcing ULD Supply & Management", The World Air Cargo Even, Bangkok
- Beuthe, M.; Bouffioux, C.; Krier, C.; Mouchart, M. (2008) “A comparison of conjoint, multi-criteria, conditional logit and neural network analyses for rank-ordered preference data”, in “Recent developments in transport modelling: lessons for the freight sector”, ed. Moshe Ben-Akiva, Hilde Meersman and Eddy Van de Voorde, Emerald Group Publishing Limited, Howard Houe (United Kingdom), ISBN: 978-0080451190, pp158-178
- Black, J. (1976) “Methods and issues in social research”, John Wiley & Sons, Inc., ISBN: 0-471-07705-4
- Black, I., Seaton, R., Ricci, A., Enei, R. (2003) “RECORDIT – final report: actions to promote intermodal transport”, Commission of the European Communities, 5th RTD Framework Programme
- Blauwens, G.; Da Baere, P.; Van de Voorde, E. (2007) “Transport economics”, Uitgeverij De Boeck, Antwerp (Belgium), ISBN: 9045516381
- Blauwens, G.; Vandaele, N.; Van de Voorde, E.; Vernimmen, B.; Witlox, F. (2006) “Towards a Modal Shift in Freight Transport? A Business Logistics Analysis of Some Policy Measures”, Transport Reviews, Vol. 26 Issue 2, pp 239-251, DOI: 10.1080/01441640500335565
- Blum, J.; Eskandarian, A. (2002) “Enhancing intelligent agent collaboration for flow optimization of railroad traffic”, Transportation Research Part A: Policy and Practice, Vol 36, Issue 10, pp 919-930
- Böcker, J.; Lind, J.; Zirkler, B. (2003) “Using multi-agent approach to optimise the train coupling and sharing system”, European Journal of Operational Research, Vol 131, Issue 2, pp 242-252

- Boeing (2008) “World air cargo forecast 2008-2009”, Boeing Commercial Airplanes, Seatle (United States), Link: www.boeing.com/commercial/cargo (4th September 2009)
- Boeing (2008a) “World air cargo forecast 2008-2009: Power Point Slides”, Boeing Commercial Airplanes, Seatle (United States)
- Bonabeau, E. (2002) “Agent-based modelling: methods and techniques for simulating human systems”, PNAS, Vol 99, Issue 3, pp 7280-7287,
- Bontekoning, Y.; Macharis, C.; Jan T. (2004) “Is a new applied transportation research field emerging?—A review of intermodal rail–truck freight transport literature”, Transportation Research Part A, Vol 38, pp 1-34
- Bowen, J.; Leinbach, T. (2004) “Market concentration in the air freight forward industry”, Tijdschrift voor economische en sociale geografie, Vol 95, Issue 2, pp 174-188
- Bowers, D.; Franklin, J.; Pecorella, P. (1975) “Matching problems, precursors, and interventions in OD: a systemic approach”, The Journal of Applied The Journal of Applied, Vol 11, pp 391-409, DOI: 10.1177/002188637501100402
- Bradshaw, J. (1997) “An introduction to software agents”, in “Software Agents”, Ed Jeffrey Bradshaw, American Association for Artificial Intelligence, Menlo Park (United States), ISBN: 0262522349, pp 3-46
- Brantingham, J. (2003) “A Neutral Model of Stone Raw Material Procurement”, American Antiquity, Vol 68, Issu 3, pp 487-509
- Breidert, C. (2006) “Estimation of willingness-to-pay: theory, measurement, application”, DUV, Wiesbaden (Germany), ISBN: 978-3835003996
- Bryman, A. (1988) “Quantity and Quality in Social Research”, Routledge, New York, ISBN: 0043120393
- Bryman, A. (2004) “Social research methods”, Oxford University Press, Oxford (Great Britain), ISBN: 0199264465
- Button, K. (1996) “Liberalising European Aviation: Is There an Empty Core Problem?Liberalising European Aviation: Is There an Empty Core Problem?”, Journal of Transport Economics and Policy, Vol 30, Issue 3, pp 275-291
- Button, K. (2002) “Towards an efficient European air transport system”, Association of European Airlines, November 2002
- Button, K. (2003) “Does the theory of the ‘core’ explain why airlines fail to cover their long-run costs of capital?”, Journal of Air Transport Management, Vol 9, pp 5-14
- Button, K. (2010) "Transport economics", Edward Elgar Pub, ISBN: 978-1840641912
- Button, K.; Stough, R. (2000) “Air transport networks – theory and policy implications”, Edward Elgar Publishing Limited, Glos (United Kindgom), ISBN: 184064429X
- Caris, A., Macharis, C., Janssens, G. (2008) " Planning Problems in Intermodal
- Freight Transport: Accomplishments and Prospects", Transportation Planning and Technology, Vol 31, Issue 3, pp. 277-302

- Carley, K. (2002) “Simulating society: the tension between transparency and veridicality”, Proceedings of Agents 2002, Chicago, IL
- Carlzon, J. (2006) “A hora H”, Lua de Papel, Oporto (Portugal), ISBN: 972-4146189
- Carrilho, M. (1994) “A filosofia das ciências - de Bacon a Feyerabend”, Editorial Presença, Lisbon, ISBN: 9722317555
- Carson II, J. (2002) “Model Verification and validation”, in “Proceedings of the 2002 Winter Simulation Conference”, ed. E. Yücesan, C.-H. Chen, J. Snowdon, J. Charnes, pp 52-58, DOI: 10.1109/WSC.2002.1172868
- Carson II, J. (2005) “Introduction to modelling and simulation”, in “Proceedings of the 2005 Winter Simulation Conference”, ed. M. Huhl, N. Steiger, F. Armstrong, J. Joines, , pp 16-23
- Castle, C.; Crooks, A. (2006) “Principles and concepts of agent based modelling for developing geospatial simulations”, University College of London, Working paper series – paper 110, ISSN: 14671298
- Chan, D. (2000) “The development of airline industry from 1978 to 1998”, Journal of Management Development, Vol 19, Issue 6, pp 489-514
- Chan, Y.; Regan, E.; Pan, W. (1986) “Inferring an origin-destination matrix directly from network-flow sampling”, Transportation Planning and Technology, Vol. 11, pp 27-46
- Chan, Y-C.; Williams, G. (2009) “An ongoing process – a review of the open skies agreements between the European Union and the United State”, Transport Reviews, Vol. 29, Issue 1, pp 115-127
- Chen, B.; Cheng, H.; Palen, J. (2009) “Integrating mobile agent technology with multi-agent systems for distributed traffic detection and management systems”, Transportation Research: Part C, Feb2009, Vol. 17 Issue 1, p1-10, 10p; DOI: 10.1016/j.trc.2008.04.003
- Clancy, B.; Hoppin, D. (2000) “Post crisis management”, Air cargo World
- Clancy, B.; Hoppin, D. (2002) “Dawn of recovery?”, Air cargo World, May 2002
- Clancy, B.; Hoppin, D. (2004) “After the storm”, Air cargo World, May 2004
- Clancy, B.; Hoppin, D.; Moses, J.; Westphal, J. (2008) “End of an era?”, American Shipper, August 2008, pp 33-47
- Clippinger III, J. (1999) “The Biology of Business: Decoding the Natural Laws of Enterprise”, Jossey-Bass, ISBN: 078794324X
- CO-ACT (2002) Deliverable 1- Reference Framework. “CO-ACT - Creating Viable Concepts for Combined Air/Rail cargo Transport“, Project funded by the European Community under 5th Framework Programme, Project Co-ordinator AAS. Unfinished.
- CO-ACT (2003a) Deliverable 4- Solutions for Compatibility and Interconnection. “CO-ACT - Creating Viable Concepts for Combined Air/Rail cargo Transport “Project funded by the European Community under 5th Framework Programme. Project Co-ordinator AAS
- CO-ACT (2003b) Deliverable 3. “CO-ACT - Creating Viable Concepts for Combined Air/Rail cargo Transport “Project funded by the European Community under 5th Framework Programme. Project Co-ordinator AAS

- Cohen, J. (1985) "Can Fitness be Aggregated?", The American Naturalist, Vol 125, Issue 5, pp 716-729
- Colin, R. (2002) “Real world research”, Blackwell Publishing, Oxford, ISBN: 0631213058
- Conte, R.; Gilbert, N.; Sichman, J. (1998) “MAS and social simulation: A suitable commitment”, in “Lecture Notes in Artificial Intelligence, Vol. 1534 - Multi-Agent Systems and Agent-Based Simulation” Ed. Jaime Sichman, Rosaria Conte and Nigel Gilbert, Springer Verlag, Berlin (Germany), pp 1-9, ISBN: 978-3540654766
- Conway, P. (2004) “Diverging paths”, Airline Business, Vol 20, Issue 11
- Conway, P. (2005a) “Pulling together”, Airline Business, Vol 21, Issue 4
- Conway, P. (2006) “Does cargo count?”, Airline Business, Vol 22, Issue 11, pp 36-41
- Conway, P. (2007) “Sea change”, Airline Business, Vol 23, Issue 11
- Conway, P. (2007) “China concerns”, Airline Business, Vol 23, Issue 11, pp 40-45
- Conway, P. (2008c) “Air cargo faces security nail biter”, Airline Business, Vol 24, Issue 11
- Cooper, H. (1989) “Integrating research – a guide for literature research”, SAGE Conway, P. (2009a) “Bleak prospects for freight”, Airline Business, Vol 25, Issue 1
- Conway, P. (2009b) “Electric freight”, Airline Business, Vol 25, Issue 2
- Publications, Thousand Oaks, ISBN: 0803934300
- Cowan, G.; Pines, D.; Meltzer, D. (1994) “Complexity Metaphors, Models and Reality”, Addison-Wesley Publishing Company, Reading (United States), ISBN: 0201626063
- Crainic, T.; Laporte, G. (1997) “Panning models for freight transportation”, European Journal of Operational Research, Vol 97, pp 409-438
- Crisp, A. (2006) “Public enemy?”, Airline Business, Vol 22, Issue 6, pp 34
- Culliane, K.; Toy, N. (2000) “Identifying influential attributes in freight route/mode choice decisions: a content analysis”, Transportation Research Part E, Elsevier. Vol. 36, pp 41-53
- Dannegger, C.; Dorer, K. (2004) “Living agents”, in “Evolution of supply chain management: symbiosis of adaptive value networks and ICT”, Ed. Yoo Chang, Harris Maktsoris, Howard Richard, Kluwer Academic Publisher, Boston (United States), ISBN: 1402078129, DOI: 10.1007/b110025
- Darwin, C. (2007) "On the Origin of Species: By Means of Natural Selection Or the Preservation", Cosimo Classics, ISBN: 978-1602061446
- Davenport, T. (1992) “Process Innovation - Reengineering work through information technology”, Harvard Business School Press, Boston (United States), ISBN: 0875843662
- Davidsson, P.; Henesey, L.; Ramsted, L.; Törnquist, J.; Wernstedt, F. (2005) “An analysis of agent-based approaches to transport logistics”, Transportation Research Part C, Vol 13, pp 255-271
- Davidsson, P.; Holmgren, J.; Persson, J.; Ramstedt, L. (2008) “Multi agent based simulation of transport chains” 7th International Joint Conference on Autonomous Agents and Multi-Agent Systems, Estoril (Portugal), May 2008, pp 1153-1160

- Davidsson, P.; Holmgren, J.; Kyhlbäck, H.; Mengistu, D.; Persson, M. (2007) “Applications of Multi Agent Based Simulation”, Multi-Agent-Based Simulation VII, Lecture Notes in Computer Science, Springer Verlag, Vol. 4442, pp 15-27
- Davidsson, P.; Wernstedt, F. (2004) “A framework for evaluation of multi agent system approaches to logistics network management”, in “An Application Science for Multi-Agent Systems”, Ed Thomas Wagner, pp 27-39, ISBN: 978-1402078682, DOI: 10.1007/b109934
- D’Este, G. (1996) "An event-based approach to modelling intermodal freight systems", In: D. Hensher, J. King, and T. Oum, "Proceedings of the 7th World Conference on Transport Research", Sydney, 16-21 July. Vol. 4, pp. 3-13.
- De Maeyer, J.; Pauwels, T. (2003) “Mode choice Modelling - A literature review on the role of quality of service attributes and their monetary valuation in freight demand models”, Research Paper 2003-011, Faculty of Applied Economics UFSIA-RUCA, Unviersity of Antwerp, May 2003
- De Wit, R. (1995) “Multimodal Transport: Carrier Liability and Documentation”, Lloyd's of London Press, London (United Kingdom), ISBN: 1850448949
- Dimitris, T., Huub, V., Anna-Maria, L. (2007) " Assessment of a transport policy potential for intermodal mode shift on a European scale", Transportation Research Part A, Vol. 41, Issue 8, pp 715-733
- Dimitriou, L.; Tsekeris, T.; Stathopoulos, A. (2007) “Competitive network design in short-sea liner markets using agent-based game-theoretic models”, In Proceedings of the 1st International Conference “Competitiveness and Complementarity of Transport Modes - Perspectives for the Development of Intermodal Transport”. University of Aegean, Chios, Greece (Co-authored with L. Dimitriou and A. Stathopoulos)
- Doganis, R. (2002) " Flying Off Course", Routledge, ISBN: 978-0415213240
- Doganis, R. (2006) “The airline business”, Routledge, Oxon (United Kingdom, ISBN: 0415346150
- Dong, J-W.; Li, Y-J. (2003) “Agent based and organisation of intermodal freight transportation systems”, 2nd International Conference on Machine Learning and Cybernetics, Xi’an, November 2003, pp 2269-2274
- Douma, A.; Schuttena , M.; Schuur, P. (2008) “Waiting profiles: An efficient protocol for enabling distributed planning of container barge rotations along terminals in the port of Rotterdam”, Transportation Research Part C: Emerging Technologies
- Douma, M. (1997) “Strategic alliances: fit or failure”, Doctoral Research work, University of Twente (Netherlands)
- Douma, M.; Bilderbeek, J.; Idenburg, P.; Looise, J. (2000) “Strategic alliances: managing the dynamics of fit”, Long Range Planning, Vol 33, pp 579-598
- Downe-Wamboldt, B. (1992) " Content analysis: Method, applications, and issues", Health Care for Women International, Vol 13, Issue 3, pp 313 - 321
- Dubin, R. (1978) “Theory Building”, The Free Press, New York, ISBN: 002907620X
- Economist (2009) “Model Behaviour”, The Economist, March 5th 2009

- Eiband, A. (2009) “Market analysis for shifting goods from road to rail by means of combined transport in Germany”, Young Researchers Seminar 2009, June 3-5
- Epstein, J.; Axtell, R. (1996) “Growing Artificial Societies: Social Science from the Bottom Up”, MIT Press, Boston (United States), ISBN: 0262050536
- Eskafi, F.; Khorramabadi, D.; Varaiya, P. (1995) “An automated highway system simulator”,Transportation Research Part C: Emerging Technologies, Volume 3, Issue 1, February 1995, pp 1-17
- Espejo, R. (1994) “What is system thinking?”, System Dynamics Review, Vol. 10, Issue 2-3, pp 199-212
- European Commission (1997a) “COM(1997)243 - Intermodality and intermodal freight transport in the European Union - A system's approach to freight transport - Strategies and actions to enhance efficiency, services and sustainability”, Brussels (Belgium)
- European Commission (1997b) “The single market review, subseries III: impact on services, volume 2: air Transport”, Kogan Page, London (United Kingdom)
- European Commission (2001a) “COM(2001)264final - A sustainable Europe for a better world: a European Union strategy for sustainable development”, Brussels (Belgium)
- European Commission (2001b) “COM(2001)370final – White Paper - European transport policy for 2010: time to decide”, Link: http://ec.europa.eu/transport/strategies/2001_white_paper_en.htm (22 May 2009)
- European Commission (2001c) “COM (2001) 264 final - a sustainable Europe for better world: a European Union strategy for sustainable development”, Brussels (Belgium)
- European Commission (2003) “Freight Integrator Action Plan - Supporting the organisers of intermodal freight transport”, Directorate General for Energy and Transport, 1st October 2003, Link: http://ec.europa.eu/transport/logistics/documentation/freight_integrators/doc/freight_integrator_action_plan_consultation_document.pdf (21st July 2009)
- European Commission (2004) “COM(2004)361final - Amended proposal for a directive of the European Parliament and of the Council on intermodal loading units”, Brussels (Belgium)
- European Commission (2006) “COM(2006) 314 - Keep Europe moving - Sustainable mobility for our continent - Mid-term review of the European Commission’s 2001 Transport White paper”, Link: http://ec.europa.eu/transport/strategies/2006_keep_europe_moving_en.htm (22th May 2009)
- European Commission (2007) "COM(2007) 606 final - The EU's freight transport agenda: boosting the efficiency, integration and sustainability of freight transport in Europe", Link: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52007DC0606:EN:HTML:NOT (30th April 2010)
- European Commission (2009) " A sustainable future for transport: Towards an integrated, technology-led and user-friendly system", Luxembourg, ISBN: 978-9279131141
- European Conference of Ministers of Transport (2005) “CEMT/CM(2005)10 - Intermodal transport and logistics - "Model" Action Plans and Partnership

Agreements for the Development of Intermodal Transport at the Pan-European level", published on 28 April 2005, Link: http://www.internationaltransportforum.org/europe/ecmt/intermodal/pdf/CM200510e.pdf (22th May 2009)

- European Parliament (2002) "Regulation (EC) No 2320/2002 - establishing common rules in the field of civil aviation security", Brussels (Belgium), 16th December 2002
- Eurostat (2010), Link: http:// ec.europa.eu/eurostat (20th May 2010), European Commission
- Evers, P.; Harper, D.; Needham, P. (1996) "The determinants of shipper perceptions of modes. Transportation Modes", American Society Transportation Logistics, Vol. 36, Issue 2, pp 13-25
- Ezard, K. (2008) "Airlines vent green spleen", Airline Business, Vol 24, Issue 7
- Findler, N.; Lo, R. (1991) "Distributed artificial intelligence approach to air traffic control", Control Theory and Applications, Vol 138, Issue 6, pp 515 - 524
- Fisher, R. (1999) "The genetical theory of natural selection: a complete variorum edition", Oxford University Press, Oxford (United Kingdom), ISBN: 0198504403
- Fisher, K.; Kuhn, N.; Müller, J.; Pischel, M. (1995) "Sophisticated and distributed: the transportation domain", 5th European Workshop on Modelling Autonomous Agents in a Multi-Agent World, MAAMAW '93 Neuchâtel (Switzerland), August 25–27, Springer Verlag, pp 122-138
- Forrester, J. (1958) "Industrial Dynamics: a major breakthrough for decision makers", Harvard Business Review, Vol 36, Issue 4, pp 37 - 66
- Frederik, B., Woxenius, J. (2004) "Developing intermodal transport for small flows over short distances", Transportation Planning & Technology, Vol. 27, Issue 5, pp 403-424
- Gambardella, L.; Lilli, M.; Rizzoli, A.; Ffalon, M. (2001) "An optimization methodology for intermodal terminal management", Journal of Intelligent Manufacturing, Vol 12, Issue 5-6, pp. 521-534
- Garcia-Menéndez, L.; Martínez-Zarzoso, I.; De Miguel, P. (2004) "Determinants of mode choice between road and shipping for freight transport - evidence for four Spanish exporting sectors", Journal of Transport Economics and Policy, Vol 38. Issue 3, pp 447-466
- Gauch Jr.; H. (2003) "Scientific method in practice", Cambridge University Press, Cambridge, ISBN: 0521816890
- Gell-Mann, M. (1994) "Complex Adaptive Systems", in "Complexity Metaphors, Models and Reality", Ed. Cowan, George, Pines, David, Meltzer, David, Addison-Wesley Publishing Company, Reading (United States), ISBN: 0201626063, pp 17 - 45
- Good, D.; Roller, L-H.; Sickles, R. (1993) "US airline deregulation: implications for European transport", Economic Journal, Vol 103, pp 1028-1041
- Grefenstette, J. (1992) "The evolution of strategies for multi-agent environment", Adaptive Behavior, Vol 1, Issue 1, pp 65-90
- GRUPO CLASS (2000) "LOGIQ", project founded by the European Commission, under the 4th Framework Programme, May 2000

- Hall, R. (2001) “Truck scheduling for ground connectivity”, Journal of Air Transport Management, Vol 7, pp 331-338
- Hannah, D. (2006) “Keeping Trade Secrets Secret”, MIT Sloan Management Review, Vol. 47 Issue 3, pp 17-20
- Hayuth, Y. (1987) " Intermodality: Concept and Practice: Structural Changes in the Ocean Freight Transport Industry", Lloyds of London Press, London (United Kingdom), ISBN: 1850441464
- Helbing, D.; Farkas, I.; Vicsek, T. (2000) “Simulating dynamical features of escape panis”, Nature, Vol 407, September 2000, pp 487-490
- Hellermann, R. (2006) “Capacity options for revenue management: theory and applications in the air cargo industry”, Springer, Berlin (Germany), ISBN: 978-3540344193, DOI: 10.1007/3-540-34420-9
- Hensher, D.; Button, K. (2002) “Handbook of transport modelling”, Pergamon, ISBN: 978-0080435947”
- Heppenheimer, T. (1995) “ Turbulent skies: the history of commercial aviation”, John Wiley & Sons Inc, New York (United States), ISBN: 0471196940
- Hillier, F.; Lieberman, G. (2004) “Introduction to operations research”, McGraw Hill, Boston (United States), ISBN: 978-0071238281
- Hirankitti, V.; Krohkaew, J.; Hogger, C. (2007)” A Multi-Agent Approach for Intelligent Traffic-Light Control”, World Congress on Engineering 2007 (Volume 1), 2007, p116-121, 6p;
- Hoetjes, P. (2007) “Planning as a design science – design science as a methodology”, AESOP2007, Naples (Italy), July
- Hoffmann, M.; Riley Jr., J. (2002) “The Science of Political Science: Linearity or Complexity in Designing Social Inquiry”, New Political Science, Vol 24, Issue 2, pp 303-320, DOI: 10.1080/07393140220145289
- Holland, J. (1993) “Adaptation in natural and artificial systems”, Massachusetts Institute of Technology Press, Boston (United States), ISBN: 0262581116
- Holmgren, J.; Davidsson, P.; Persson, J.; Ramstedt, L. (2007) “An agent based simulator for production and transportation of products”, 11th World Conference on Transport Research, Berkeley (United States), June 2007
- Homans, G. (1975) “The human group”, Routledge & Kegan Paul, London (United Kingdom), ISBN: 0710082436
- Hong, S-J.; Jun, I-S. (2006) “An evaluation of the service quality priorities of air cargo service providers and shippers”, World Review of Intermodal Transportation Research, Vol. 1, Issue 1, pp 55-68
- Hoppin, D. (2005b) “Cargo counts”, Airline Business, Vol 21, Issue 9
- Hsu, C-I.; Li, H-C.; Liao, P.; Hansen, M. (2009) “Responses of air cargo carriers to industrial changes”, Journal of Air Transport Management, Vol. article in press, pp 1-7, DOI: 10.106/j.jairtraman.2009.06.002
- Hughes, D (2003) “Air Cargo Security Revisited”, Aviation Week & Space Technology, Vol 159, Issue 14
- Hughes, J. (1997) “The philosophy of social research”, Addison Wesley Longman, New York, ISBN: 0582311055

- Hunt, J.; Stefan , K. (2007) “Tour-based microsimulation of urban commercial movements”, Transportation Research Part B: Methodological, Volume 41, Issue 9, November 2007, pp 981-1013
- IATA (2009a) “Cargo Plummets 22.6% in December”, IATA Press Release n.º 4, 29th January 2009
- IATA (2009b) “Cargo Accounts Settlement Systems – CASS”, IATA website, Link: http://www.iata.org/ps/financial_services/cass/index.htm (10th August 2009)
- IATA (2009c) “IATA economic briefing”, IATA Press Release, 28th April 2009
- INRETS (2000) “IQ - Intermodal Quality”, project founded by the European Commission, under the 4th Framework Programme, July 2000
- International Railway Journal (2003) “Ikea rail to halt railfreight service”, December 2003
- International Standard Organisation (2008) “Quality management systems – requirements”, 3rd Edition, Geneva (Switzerland)
- Iordanova, B. (2003), “Air traffic knowledge management policy”, European Journal of Operational Research, Volume 146, Issue 1, 1 April 2003, pp 83-100
- Jacob, J., Bontekoning, Y. (2002) "Integration of small freight flows in the intermodal transport system", Journal of Transport Geography, Vol. 10, Issue 3, pp 221-229
- Jager, W. (2000) “Modelling consumer behaviour”, Doctoral Thesis, Groningen University, The Netherlands.
- Jang, J-S. (1993) “ANFIS: Adaptive-Network-Based Fuzzy Inference System”, IEEE Transactions on Systems, Man, and Cybernetics, Vol. 23, Issue 3, pp 665 - 685
- Janic, M. (2007) "Modelling the full costs of an intermodal and road freight transport network", Transportation Research: Part D, Vol. 12, Issue 1, pp 33-44
- Janic, M.; Reggiani, A. (2001) “Integrated transport systems in the European Union: an overview of some recent developments”, Transport Reviews, Vol 21, Issue 4, pp 469-47
- Jaržemskienė, I. (2007) "The evolution of intermodal transport research and its development issues", Transport, Vol XXII, Issue 4, pp 296-306, ISSN: 1648-3480
- Janssen, M.; Ostrom, E. (2006) “Empirically Based, Agent-based models”, Ecology and Society, Vol 11, Issue 2, pp: 37-49
- Jeffs, V.; Hills, P. (1990) “Determinants of modal choice in freight transport - a case study”. Transportation. Kluwer Academics Publishiers, Vol 17, Issue 1, pp 29-47
- Jennings, B., Holcomb, M. (1996) " Beyond containerization: the broader concept of intermodalism", Transportation Journal, Vol. 35, Issue 3, pp 5-13
- Jonge, J. (2008) “No break in the storm”, Air Cargo World, December 2008
- Kadar, M.; Larew, J. (2003) “Securing the future of air cargo”, Oliver Wyman, pp 1-9, Link: www.oliverwyman.com/de/pdf.../MOTL-SecuringFutureAirCargo.pdf (1st September 2009)
- Kahaner, L. (1998) “Competitive Intelligence: How to Gather, Analyze, and Use Information to Move Your Business to the Top”, Touchstone, ISBN: 0684844044

- Kalic, M.; Teodorovic, D. (2003) “Trip distribution modelling using fuzzy logic and a genetic algorithm. Transportation Planning and Technology”, Vol 26, Issue 3, pp 213-238.
- Katz, D.; Kahn, R. (1978) “The Social Psychology of Organizations – 2nd edition”, John Wiley & Sons, Ins., Hoboken (United States), ISBN: 0471023558
- Keller, Peter (2004) “Planning, Policy and Engineering Perspectives on Intermodal Transport Junctions”, edited book “Unconnected Transport Networks”, editor Dienel Hans-Liuder, Campus Verlag GmbH, Frankfurt (Germany), ISBN: 359337661X, pp 37-48
- Kikuchi, S. (1992) “Scheduling demand-responsive transportation vehicles using fuzzy-set theory”, Journal of Transportation Engineering, Vol 118, pp 391-409.
- Kim, D.; Barnhart, C.; Reinhart, G. (1999) “Multimodal express package delivery: a service network design application”, Transportation Science, Vol 33, pp 391-407
- Konings, R., Priemus, H., Nijkamp, P. (2008) " The Future of Intermodal Freight Transport: Operations, Design and Policy", Edward Elgar Publishing Ltd, Cheltenham (United Kingdom), ISBN: 978-1845422387
- Kramer, R. (2009) “Rethinking trust”, Harvard Business Review, Vol 87, pp 69-77
- Kreutzberger, E. (2008) " Distance and time in intermodal goods transport networks in Europe: A generic approach", Transportation Research Part A: Policy and Practice, Vol. 42, Issue 7, pp 973-993
- Kuhn, T. (1996) “The structure of scientific revolutions”, The University of Chicago, London, ISBN: 0226458083
- Kupfer, F.; Meersman, H.; Onghena, E.; Van de Voorde, E. (2009) “Air freight economics. Survival of the fittest?”, 2009 Air Transport Research Society Conference, Abu Dhabi (United Arab Emirates), 27th-30th June 2009
- Larkin, L. (1985) “A fuzzy logic controller for aircraft flight control”, in: Sugeno, M. (Editor), “Industrial applications of fuzzy control”, Elsevier Science, New York, pp 87-103, ISBN:
- Lawrence, P., Lorsch, J. (1969) “Developing organisations: diagnosis and action”, Addison-Wesley
- Lee, T.; Mokhtarian, P. (2008) “Correlations between industrial demands (direct and total) for communications and transportation in the US economy 1947-2007”, Transportation, Vol 35 pp 1-22
- Levitt, T. (1960) “Marketing Myopia”, Harvard Business Review, Vol 38, Issue 4, pp 45-56
- Lin, C.-T.; Lee, C. (1991) “Neural-network-based fuzzy logic control and decision system”, IEEE Transactions on Computers, Vol 40, pp 1320 - 1336
- Little, D. (1993) “Evidence and Objectivity in the Social Sciences”, Social Research - an international quarterly of the social sciences, ISSN: 1438-5627, Vol. 60, Issue 2, pp 363 – 396
- Lorsch, J.; Lawrence, P. (1972) “Managing group and intergroup relations”, Irwin-Dorsey

- Lotan, T.; Koutsopoulos, H., (1993) "Route choice in the presence of information using concepts from fuzzy control and approximate reasoning", Transportation Planning and Technology, Vol 17, pp 113-126.
- Lowe, D. (2005) "Intermodal freight transport", Elsevier, Oxford (United Kingdom), ISBN: 0750659351
- Macário, R. (2008) "Airports of the future: essentials for a renewed business model", European Journal of Transport and Infrastructure Research, Vol 8, Issue 2, pp 165-182, Link: http://www.ejtir.tbm.tudelft.nl/issues/2008_02/pdf/2008_02_07.pdf (1st September 2009)
- Macário, R. (2005) "Quality management in urban mobility systems: an integrated approach", PhD Research work, Instituto Superior Técnico, Technical University of Lisbon, Link: http://www.civil.ist.utl.pt/nispt/ficheiros/teses_dout/RM_eng.pdf (4th August 2009)
- Macário, R.; Reis, V.; Filipe, L. (2008) "ELOFRET - Elements for the optimization of intermodal chains in freight transport", Centre for Urban and Regional Systems, Instituto Superior Técnico, Technical Univeristy of Lisbon, Portugal, Project funded by the Portuguese National Science Foundation (POCTI/TRA/60585/2004)
- Macharis, C.; Bontekoning, Y. (2004) "Opportunities for OR in intermodal freight transport research: A review", European Journal of Operational Research, Vol 153, pp 400-416
- Macharis, C., Pekin, E. (2008) " Assessing policy measures for the stimulation of intermodal transport: a GIS-based policy analysis", Journal of Transport Geography, Vol. 17, Issue 6, pp 500-508
- Machlup, F. (1994) "Are the social sciences really inferior?", in "Readings in the philosophy of science", Martin and McIntyre (Editors), MIT Press, Cambridge, ISBN: 0262132966, pp. 5-19
- Manicas, P. (2006) "A realistic philosophy of social science“, New York, Cambridge University Press, ISBN: 9780521678582
- Matear, S.; Gray, R. (1993) "Factors influencing freight service choice for shippers and freight suppliers", International Journal of Physical Distribution & Logistics Management. Bradford, Vol. 23, Issue. 2, pg. 25-35
- Matthen, M., Ariew, A. (2002) "Two Ways of Thinking about Fitness and Natural Selection", The Journal of Philosophy, Vol 99, Issue 2, pp 55-83
- McGinnis, M. (1989) "A comparative-evaluation of freight transportation choice models. Transportation Journal", American Society Transportation Logistics, Vol. 29, Issue 2, pp 36-46
- McGinnis, M. (1990) "The relative importance of cost and service in freight transportation choice - before and after deregulation. Transportation", American Society Transportation and Logistics", Vol. 30, Issue 1, pp 12-19
- McKenzie, D., North, M., Smith, D. (1989) "Intermodal Transportation: the Whole Story", Simmons-Boardman, Cornwall (United Kingdom), ISBN: 0911382097, Books, Inc., Omaha, NE.
- McKinnon, A.; Button, K.; Nijkamp, P. (2002) "Transport Logistics", Edward Elgar Publishing Inc, Northampton (United States), ISBN: 978-1840645514

- Mes, M.; van der Heijden, M.; van Harten, A. (2007) “Comparison of agent-based scheduling to look-ahead heuristics for real-time transportation problems”, European Journal of Operational Research, Aug2007, Vol. 181 Issue 1, p59-75, 17p; DOI: 10.1016/j.ejor.2006.02.051
- Miller, J.; Page, S. (2007) “Complex Adaptive Systems: An Introduction to Computational Models of Social Life”, Princeton University Press, Princeton (Unites States), ISBN: 978-0691127026
- Mintzberg, Henry (2001) “Decision Making: It's Not What You Think”, MIT Sloan Management Review, Spring2001, Vol. 42, Issue 3
- Moorman, R. (2007) “Rejuvenating cargo”, Air Cargo World, May 2007
- Morrell, P. (2005) "Airlines within airlines: An analysis of US network airline responses to Low Cost Carriers", Journal of Air Transport Management, Vol 11, pp 303–312
- Muller, G. (1999) "Intermodal freight transportation", Eno Transportation Foundation and IANA, Virginia (United States), ISBN:
- Murphy, P.; Daley, J.; Hall P. (1997) “Carrier selection: do shippers and carriers agree, or not?”, Transportation Research Part E, Pergamon – Elsevier. Vol. 33, Issue 1, pp 67-72
- Murphy, P.; Hall, P. (1995) “The Relative Importance of Cost and Service in Freight Transportation Choice Before and After Deregulation: An Update”, Transportation. American Society Transportation and Logistics, Vol. 35, Issue 1, pp 10-38
- Myerson, R. (1997) “Game theory: analysis of conflict”, Harvard University Press, Boston (United States), ISBN: 0674341163
- Nachmias, D.; Nachmias, C. (1976) “Research Methods in the Social Sciences”, St. Martin’s Press Inc, New York
- Nadler, D. (1993) “Concepts for the management of organizational change”, in “Managing change – 2nd edition”, eds. Christopher Mabey, Bill Mayon-White, Paul Chapman, pp 85-98
- Nadler, D.; Tushman, M. (1980) “A model for diagnosing organizational behaviour”, Organizational Dynamics,
- Nakanishi, H.; Türksen, I.; Sugeno, M. (1995) “A comparison of direct fuzzy reasoning methods“, Proceedings of the International Joint Conference of the Fourth IEEE International Conference on Fuzzy Systems and The Second International Fuzzy Engineering Symposium.
- Nguyen-Duc, M.; Briot, J-P.; Drogoul, A. (2003) “An application of multi-agent coordination techniques in air traffic management”, Intelligent Agent Technology, October 2003, pp 622 - 625
- Niederkofler, M. (1991) “The evolution of strategic alliances: Opportunities for managerial influence”, Journal of Business Venturing, Vol 6, Issue 4, pp 237-257, DOI: 10.1016/0883-9026(91)90018-9
- Nijkamp, P. (1995) " From missing networks to interoperable networks: the need for European cooperation in the railway sector", Transport Policy, Vol 2, Issue 3, pp 159-167
- Nola, J. (1999) “Confidential: Business Secrets - Getting Theirs, Keeping Yours”, Yardley-Chambers, ISBN: Yardley-Chambers

- Norojono, O.; Young W. (2003) “A stated preference freight mode choice model”, Transportation Planning and Technology, Taylor & Francis Group, Vol. 26. Issue 2, pp 195-212
- North, M.; Macal, C. (2007) “Managing Business Complexity”, Oxford University Press Inc., New York (United States), ISBN: 978-0195172119
- Nwana, H. (1996) “Software agents: an overview”, Knowledge Engineering Review, Vol 11, Issue 3, pp 205 – 244
- O’Connor, W. (2001) “An introduction to airline economics, 6th edition”, Praeger Publishers, Westport (United States), ISBN: 027596118
- O’Farrell, P., Hitchens, D., Moffat, A. (1992) “The Competitiveness of Business Service Firms: A Matched Comparison between Scotland and the South East of England”, Regional Studies, Vol. 26, Issue 6, pp 519 -533
- O’Hear, A. (1989) “Introduction to the philosophy of science”, Oxford University Press, Inc., Oxford, ISBN: 019824813X
- OECD (2001) “Intermodal Freight Transport - institutional aspects”, OECD Publications, Paris (France), ISBN: 9264183949
- OECD (2002a) “Benchmarking intermodal freight transport”
- OECD (2002b) “Frascati Manual - proposed standard practices for surveys on research and experimental development”, OECD Publications, Paris, ISBN: 9264199039
- Oliver Wyman (2003) “The congruence model: a roadmap for understanding organizational performance”, Delta Organisation & Leadership LCC, Oliver Wyman Group
- Ortuzar, W. (2001) “Modelling transport”, John Wiley & Sons Ltd., Chichester (United Kindgom), ISBN: 978-0471861102
- Otto, A. (2005) “Reflecting the prospects of an air cargo carrier”, in “Strategic management in the aviation industry”, Ed. Werner Delfmann, Herbert Baum, Stefan Auerbach, Sacha Albers, Ashgate Publishing Limited, Hampshire (United Kingdom), ISBN: 0754645673, pp 451-472
- Oum, T. (1979) “Derived Demand for Freight Transportation and Inter-modal Competition in Canada," Journal of Transport Economics and Policy, pp 149-168
- Ozbay, K.; Bartin, B. (2004) “Estimation of economic impact of vms route guidance using microsimulation”, Research in Transportation Economics, Volume 8, 2004, pp 215-241
- Page, P. (2008) “Airlines into forward air”, Traffic World, August 2008, pp 29
- Panayides, P. (2002) “Economic organization of intermodal transport", Transport Reviews, Vol 22, Issue 4, pp 401 - 414.
- Pappis, C.; Mandami, E., 1977. “A fuzzy control for a traffic junction”. IEEE Transactions and Systems, Man and Cybernetics, Vol 7, pp 707-717
- Park, Y.; Choi, J.; Zhang, A. (2009) “Evaluating competitiveness of air cargo express service”, Transportation Research E, Vol. 45, pp 321-334, DOI: 10.1016/j.tre.2008.09.004
- Pascale, R. (1999) “Surfing the edge of chaos”, Sloan Management Review, Vol 40, Issue 3, pp 83-94

- Persson, J.; Davidsson, P. (2005) “Integrated optimisation and muti-agent technology for combined production and transportation planning”, HICSS-38, Hawaii International Conference on Systems Science, pp 1-9
- Persson, J.; Davidsson, P.; Johansson, S.; Wernstedt, F. (2005) “Combining Agent-Based Approaches and Classical Optimization Techniques”, Third European Workshop on Multi-Agent Systems, 7-8 December, Brussels, Belgium
- Peterson, D.; Eberlein, R. (1994) “Reality check: a bridge between systems thinking and system dynamics”, System Dynamics Review, Vol 10, Issues 2-3, pp 159- 174
- Peterson, I. (1996) “Science news”, Vol 150, pp 332-333, Link: http://www.jstor.org/stable/3980408 (5th August 2009)
- Phelan, P.; Reynolds, P. (1996) “Argument and Evidence - critical analysis for the social sciences”, Routledge, London, ISBN: 0415113733
- Plaut, P. (1997) “Transportation-communications relationships in industry”, Transportation Research Part A, Vol 31, Issue 6, pp 419-429
- Popper, K. (1961) “The logic of scientific discovery”, Science Editions Inc., New York.
- Porter, M. (1996) "What is strategy?", Harvard Business Review, November-December 1996, pp 61-79
- Portougal, V.; Sundaram, D. (2006) “Business Processes: operational solution for SAP implementation”, IRM Press, London (United Kingdom), ISBN: 1591406153
- Putzger, I. (2006) “Can cargo yield profits?”, Air Cargo World, June 2006
- Quinet, E., Vickerman, R. (2005) "Principles of transport economics", Edward Elgar Pub, ISBN: 978-1845422561
- Quadrado, J.; Quadrado, A. (1996) “Fuzzy modeling of accessibility: Case study: Lisbon metropolitan area”, Proceedings of the Fourth European Congress on Intelligent Techniques and Soft Computing, Aachen, Germany, pp 1307-1311.
- Ramstedt, L.; Davidsson, P.; Holmgren, J.; Persson, J. (2007) “On the use of micro-level simulation for estimation of the effects of governmental control policies”, 11th World Conference on Transportation Research, Berkeley (United States), June 2007
- Randers, J. (1976) “A framework discussion of model conceptualization”, in “The System dynamics methods – Proceedings of the 1976 international conference on system dynamics”, ed. Jorgen Randers, Leif Ervik, Geilo (Norway), August, pp 416-451
- Ray, T. (1997) “Evolution and complexity”, in “Complexity: metaphors, models and realty”, ed. George Cowan, David Pines, David Meltzer, Addison-Wesley Publishing Company, Reading (United States), ISBN:0201626063
- Reis, L. (2003) “Coordination in Multi-Agent Systems: Applications in University Management and Robotic Soccer”, Doctoral Thesis, Faculty of Engineering of University of Oporto
- Reis, V. (2005) “The performance of the European liberalisation process – an evaluation of the scheduled air transportation market”, MSc Thesis, Faculty of Engineering of Oporto University (Portugal)

- Reis, V.; Macário, R. (2008) “FITNESS: an agent based modelling approach to freight intermodal chains”, European Transport Conference, Leeuwenhorst (Netherlands), 6th-8th October
- Reis, V.; Macário, R. (2009a) “Intermodal Air Cargo Transport:agent based modelling”, presentation at the 5º Encontro Anual do Grupo de Estudos em Transportes, Mira (Portugal), 4th and 5th January 2009
- Reis, V.; Macário, R. (2009b) “Spectrum of Competitiveness of Passenger Airlines in the Air Cargo Market”, 2009 Air Transport Research Society Conference, Abu Dhabi (United Arab Emirates), 27th-30th June 2009
- Resnick, S.; Wolff, R. (1993) “Knowledge and class: a Marxian critique of political economy”, University Chicago Press, Chicago (United States), ISBN
- Rhoades, D. (2008) “Evolution of international aviation – phoenix rising”, Ashgate, Hampshire (United Kingdom), ISBN: 978-0754673897
- Richards, R. (2004) "A fitness modal of evaluation", The Journal of Aesthetics and Art Criticism, Vol 62, Issue 3, pp 263-275
- Richardson, G. (1999) “Feedback thought in social science and systems theory”, Pegasus Communications, Waltham (United States), ISBN: 1883823463
- Riley, J. (1999) “Process management”, in “Juran’s Quality Handbook - Fifth Edition”, ed. Joseph Juran and A. Blanton Godfrey, McGraw-Hill, London (United Kingdom), ISBN: 007034003X, p. 6.1 - 6.21.
- Roorda, M.; Miller, E.; Habib, K. (2008) “Validation of TASHA: A 24-h activity scheduling microsimulation model”,Transportation Research Part A: Policy and Practice, Volume 42, Issue 2, February 2008, Pages 360-375
- Rosenberg, A. (1983) "Fitness", The Journal of Philosophy, Vol 80, Issue 8, pp 457-473
- Rossetti, R.; Ronghui L. (2005) “An Agent-Based Approach to Assess Drivers' Interaction with Pre-Trip Information Systems”, Journal of Intelligent Transportation Systems, Jan-Mar2005, Vol. 9 Issue 1, p1-10, 10p; DOI: 10.1080/15472450590912529
- Roth, A.; Erev, I. (1995) “Learning in extensive-form games: Experimental data and simple dynamic models in the intermediate term”, Games and Economic Behavior, Vol 8, Issue 1, pp 164-212
- Runkler (1996) “Extended defuzzification methods and their properties”, proceeding of the 5th IEEE International Conference on Fuzzy Systems, 8-11 September, pp 694-700
- Rushton, A., Croucher, P., Baker, P. (2000) " The Handbook of Logistics and Distribution Management", Kogan Page, London (United Kingdom), ISBN: 0749446692
- Russel, S.; Norvig, P. (2003) “Artificial intelligence –a modern approach, 2nd edition”, Prentice Hall, Upper Saddle River (United States), ISBN: 0130803022
- Rutten, B. (1999) "The design of a terminal network for intermodal transport", Transport Logistics, Vol. 1, Issue 4, pp 279-298
- Sage, D. (2001) “Express deliver”, in “Handbook of logistics and supply chain management” Ed. A. Brewer, Kenneth Button, David Hensher, Pergamon, Amsterdam (The Netherlands), ISBN: 0080435939

- Salomon, I. (2000) "Can telecommunications help solve transportation problems?", in handbook of Transport Modelling, Ed. David Hensher and Kenneteh Button, Emerald Group Publishing, ISBN: 0080453767, pp 449-462
- Samuelson, D.; Macal, C. (2006) "Agent-based simulation comes of age", OR/MS Today, August 2006, Link: www.lionrpub.com/orms/orms-8-06/fragent.html (27th January 2009)
- Sandholm, T. (1999) "Distributed rational decision making", in "Multi-agent systems: a modern approach to distributed artificial intelligence", ed. Gerhard Weiss, MIT Press, Boston (United States), pp 1-58, ISBN: 0262232030
- Schleiffer, R. (2002) "Intelligent agents in traffic and transportation", Transportation Research: Part C, Oct2002, Vol. 10 Issue 5/6, p325, 5p
- Seiler, J. (1967) "Systems analysis in organisational behaviour", Irwin-Dorsey
- Selltiz, C.; Jahoda, M.; Deutsch, M.; Cook, S. (1963) "Research Methods in Social Relations", Holt, Rinehart and Winston, Inc., Westerville
- Serpen, E.; Mirza, A. (2009) "The world economy and air cargo business", presented at 7th Annual Cargo Aircraft & Operations Conference, Brussels (Belgium), April 1-2 2009
- Serway, R.; Jewett, J. (2004) "Physics for scientists and engineers – 6th edition", Thomson, ISBN: 0534408427
- Shinghal, N.; Fowkes T. (2002) "Freight modal choice and adaptive stated preferences", Transportation Research Part E, Pergamon - Elsevier. Vol. 38, pp 367-378.
- Shipping Digest (2008) "Air cargo industry group says security should not hinder trade", issued on 22nd December 2008
- Shucker, B.; Murphey, T.; Bennett, J. (2008) "Convergence-Preserving Switching for
- Simon, H. (1996) "The sciences of the artificial", MIT Press, Boston (United States), ISBN: 0262691914
- Sinha, D. (1999) "The regulation and deregulation of US airlines", The Journal of Transport History, Vol 20, Issue 1, pp 46-64
- Sinha, D. (2001) "Deregulation and liberalisation of the airline industry", Ashgate, Hampshire (United Kingdom), ISBN: 1840148357
- Slack, B. (2001) "Intermodal transportation", in "Handbook of Logistics and Supply Chain Management", editors Ann Brewer, Kenneth Button, David Hensher, Elsevier, New York (United States), ISBN: 0080435939, p 141-154
- Smith, P. (1993) "Fuzzy evaluation of potential suburban railway station locations", Journal of Advanced Transportation, Vol 27, pp 153-179
- Sterman, J. (1994) "Learning in and about complex systems", System Dynamics Review, Vol 10, Issue 2-3, pp 291-330
- Sterman, J. (2000) "Business Dynamics: Systems thinking and modeling for a complex world", Irwin McGraw-Hill, Boston (United States), ISBN: 978-0072389159
- Taylor, M.; Hallsworth, A. (2000) "Power relations and market transformation in the transport sector: the example of the courier services industry", Journal of Transport Geography, Vol 8, pp 237-247

- Teichert, T.; Shehu, E.; von Wartburg, I. (2008) “Shipper segmentation revisited: the case of airline industry”, Transportation Research Part A, Vol 42, pp 227-242
- Teodorovic, D. (1999) “Fuzzy logic systems for transportation engineering: the state of the art”, Transportation Research Part A, Vol 33, pp 337 - 364
- Teodorovic, D.; Babic, O. (1993) “Fuzzy inference approach to the flow management problem in air traffic control”, Transportation Planning and Technology, Vol 17, pp 165 - 178
- Teodorovic, D.; Kalic, M.; Pavkovic, G. (1994) “The potential for using fuzzy set theory in airline network design”, Transportation Research Part B, Vol. 28B, Issue 2, pp 103 - 121
- Teodorovic, D.; Pavkovic, G. (1996), “The fuzzy set theory approach to the vehicle routing problem when demand at nodes is uncertain”, Fuzzy Sets and Systems, Vol 82, pp 307-317.
- Tesfatsion, L.; Judd, K. (2006) “Handbook of Computational Economics, Volume 2: Agent-Based Computational Economics”, Elsevier, Amsterdam (The Netherlands), ISBN: 978-0444512536
- TNO INRO (1999) “TRILOG – Europe Summary Report”, project manager: TNO
- Truszkowski, W (2006) "What is an agent? And what is an agent community?", in "Agent technology from a formal perspective", edited by Christopher Rouff, Michael Hinchey, James Rash, Walter truszkowski, Diana Gordon-Spears, Springer-Verlag London Limited, London (United Kingdom), ISBN: 1852339470
- Twomey, P.; Cadman, R. (2002) “Agent-based modelling of shipper behaviour in the telecoms and media markets”, info, Vol 4, Issue 1, DOI: 10.1108/14636690210426640
- Tzeng, G.H.; Teng, J.-Y. (1993) “Transportation investment project selection with fuzzy multi-objectives”, Transportation Planning and Technology, Vol 17, pp 91 - 112
- UIC (2009) “DIOMIS - Developing Infrastructure and Operating Models for Intermodal Shift”, Union Internationale des Chemins de Fer, Paris (France), ISBN: 978-2746116054
- United Nations (1980) “Convention on International Multimodal Transport”, TD/MT/CONF/17, New York (United States), Link: http://r0.unctad.org/ttl/docs-legal/unc-cml/status/UNConventionMTofGoods,1980.pdf (accessed on 17 July 2009)
- United Nations (2001) “Terminology on combined transport”, Geneva (Switzerland), Link: http://www.unece.org/trans/wp24/documents/term.pdf (accessed on 22 May 2009)
- Unknown Author (1995) “Introduction to Fuzzy Systems”, Proceedings of the Electronic Technology Directions to the Year 2000, May 23-25, Adelaide, Australia, pp 94 - 103, ISBN: 0818670851
- Van der Leeuw, S. (2004) “Why Model?”, Cybernetics & Systems, Vol 35, Issue 2-3, pp 117-128, DOI: 0.1080/01969720490426803
- Van der Vaart, E.; Verbrugge, R. (2008) “Agent-based Models for Animal Cognition: A Proposal and Prototype”, in “Proceeding of 7th Int. Conf. On Autonomous Agents and Multiagent Systems (AAMAS 2008)”, ed Padgham, Parkes,

Müller and Parsons (eds.), May, 12-16., 2008, Estoril, Portugal, pp. 1145-1152, ISBN: 0981738133

- Vodovotz, Y.; Constantine, G.; Rubin, J.; Csete, M.; Voit, E.; An, G. (2009) “Mechanistic simulations of inflammation: Current state and future prospects”, Mathematical Biosciences, Vol 217, Issue 1, pp 1-10
- Von Bertalanffy, L. (1968) “General System Theory”, Allen Lane The Penguin Press, ISBN: 0713901926
- Wang, L-X.; Mendel, J. (1992) “Generating fuzzy rules by learning from examples”. IEEE Transactions on systems, Man and Cybernetics, Vol 22, pp 1414-1427
- Wedel, M.; Kamakura, W. (2002) “Introduction to the Special Issue on Market Segmentation”, International Journal of Research in Marketing, Vol 19, Issue 3, pp 181-183
- Wehmeier, S. (2000) “Oxford Advanced learners’ dictionary”, Oxford University Press, Oxford (United Kingdom), ISBN: 0194315851
- Weiss, G. (1999) “”, Massachusetts Institute of Technology Press, Boston (United States), ISBN: 0262232030
- Wensveen, J. (2007) “Air transportation: a management perspective”, Ashgate, Hampshire (United Kingdom), ISBN: 978-0754671718
- Wiest, J.; Levy, F. (1969) “Management Guide to PERT/CPM”, Prentice Hall, New Jersey (United States), ISBN: 0135485118
- Wilding, R. (1998) “Chaos theory: implications for supply chain management”, International Journal of Logistics Management, Vol. 9, Issu 1, pp 43-56
- Williams, M.; May, T. (1996) “Introduction to the Philosophy of Social Research”, University College London Press, London, ISBN: 0203561120 (ebrary)
- Witlox, F.; Vandaele E. (2005) “Determining the monetary value of quality attributes in freight transportation using stated preference approach”, Transportation Planning and Technology, Taylor & Francis Group, Vol 28, Issue 2, pp 77-92.
- Wooldridge, M. (2006) “An introduction to multi agent systems”, John Wiley & Sons Ltd., Chichester (United Kindgom), ISBN: 978-0471496915x
- Woxenius, J. (1998) "Development of small scale intermodal freight transportation in a systems context", Doctoral Thesis, University of Chalmers, Gothenburg (Sweden)
- Woxenius, J. (2007) " Generic framework for transport network designs: applications and treatment in intermodal freight transport literature", Transport Reviews, Vol 27, Issue 6, pp 733-7499
- Wyner, G. (2006) “Why Model?”, Marketing Research, Vol 18, Issue 1, pp 6-7
- Xu, W.; Chan, Y. (1993) “Estimating an origin-destination matrix with fuzzy weights”, Transportation Planning and Technology, Vol 17, pp 127-144.
- Yin, R. (2003) “Case study research - design and methods, 3rd edition”, SAGE Publications, London, ISBN: 0761925538
- Yuhara, N.; Tajima, J. (2006) “Multi-driver agent-based traffic simulation systems for evaluating the effects of advanced driver assistance systems on road traffic accidents”, Cognition, Technology & Work, Nov2006, Vol. 8 Issue 4, p283-300
- Zadeh, L. (1965) “Fuzzy Sets”, Information and Control, Vol 8, pp 338 - 353.

- Zadeh, L. (1975) “Calculus of fuzzy restrictions”, in “Fuzzy Sets and their applications to cognitive and decision processes”, Editors Lofti Zadeh, King-Sun Fu, Kokichi Tanaka, Masamichi Shimura, Academic Press Inc., New York (United States), ISBN: 0127752609
- Zalk, S.; Gordon-Kelter, J. (1992) “Revolutions in knowledge: feminism in social sciences”, Westview Pr, ISBN: 0813305845
- Zangh, H.; Liu, D. (2006) “Fuzzy modeling and fuzzy control”, Birkhäuser Boston, Boston (United States), ISBN: 9780817645397
- Zhang, A. (2003) “Analysis of an international air-cargo hub: the case of Hong Kong”, Journal of Air Transport Management, Vol 9, pp 123-138
- Zhang, A.; Lang, C.; Hui, Y.; Leung, L. (2007) “Intermodal alliance and rivalry of transport chains: The air cargo market”, Transportation Research Part E, Vol 43, Issue 3, pp 234-246, DOI: 10.1016/j.tre.2006.10.003
- Zhang, A.; Hui, G.; Leung, L.; Cheung, W.; Hui, Y. (2004) “Air Cargo in Mainland China and Hong Kong”, Ashgate Publishing Limited, Hants (United Kingdom), ISBN: 075464216X
- Zhang, A.; Zhang, Y. (2002) “Issues on liberalisation of air cargo services in international aviation”, Journal of Air Transport Management, Vol 8, pp 275-287
- Zhu, K.; Bos, A. (1999) “Agent-based design of intermodal freight transportation systems”, NECTAR Conference, Delft, October 1999, pp 1-18
- Zhu, K.; Ludema, M.; van der Heijden , R. (2000) “Air cargo transport by multi agent based planning”, Proceeding of the 33rd Hawaii Conference on System Sciences, pp 1-10
- Zimmermann, H. (1987) “Fuzzy Sets, Decision Making, and Expert Systems”, Kluwer Academic Publishers, Dordrecht (The Netherlands), ISBN: 0898381495
- ZLU, ISF, EIA, KRAVAG, ELA (2003) “Study on Freight Integrators to the Commission of the European Communities”, Berlin, 16th September 2003, Link: http://ec.europa.eu/transport/logistics/freight_integrators/doc/final_report_freight_integrators.pdf (21st July 2009).
- Zografos, K.; Regan, A. (2004) “Current Challenges for Intermodal freight Transport and Logistics in Europe and the US”, Transport Research Board Annual Meeting, Washington (United States).
- Zondag, W-J. (2006) “Competing for air cargo – a qualitative analysis of competitive rivalry in the air cargo industry”, Master Thesis, Free University of Amsterdam, Amsterdam (The Netherlands), Link: http://www.tiaca.org/images/TIACA/PDF/Competing%20for%20Air%20Cargo.pdf (5th September 2009)

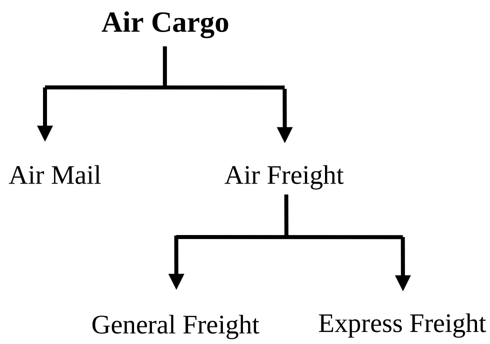
ANNEX I – A TAXONOMY FOR AIR CARGO

A reading on the literature reveals a lack of harmonisation and rigour on the utilisation of the terms for designating the various types of freight moving by air transport. Such absence is visible on both academic (Otto, 2005, Zhang et al, 2004, Zhang, 2003, Wensveen, 2007, O'Connor, 2001, Button and Stough, 2000) and specialised (Conway, 2007, Allaz, 2004) streams of literature. Terms such as air cargo, air freight or express freight are used interchangeably or referring to different concepts, and often without an adequate definition. A possible reason for this situation lies on a non-existence of a dedicated theoretical body that could provide definitions, hypothesis, definitions and concepts.

This ambiguity is not acceptable in scientific endeavour as it brings noise into the process analysis and it makes difficult to conduct research. In order to avoid misinterpretations of concepts, Figure 8.1 presents the segmentation[273] of air cargo as considered on this research work. This is a two tier segmentation: the criterion of the first tier is regulation, whereas the criteria of the second tier criterion are good's market and physical properties[274].

[273] In 1956, W. Smith firstly introduced the concept of segment as "involving viewing a heterogeneous market as a number of smaller homogeneous markets, in response to differing preferences (cited in Wedel and Kamakura, 2002, 181).

[274] There was a concern for aligning (at maximum possible extent) the terms with the typical meaning found in literature, in order to reduce misinterpretations.



Source: author

Figure I.1 – Taxonomy for Air Cargo

Air cargo is considered any freight being conveyed under the terms of an airway bill[275]. Air cargo is thus the most general term, embracing every freight moving by air. A caveat should be made on this definition: air cargo does not necessarily entail movement by air, but only that the transport provider is an air transport company[276]. This has implications on the market for air cargo transport services, since a replacement of air movement by any other does not change the designation as air transport service.

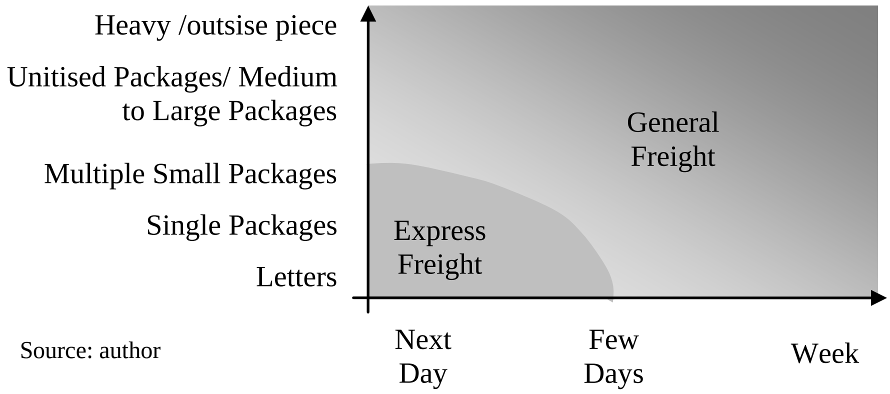
Air cargo is then considered to be divided in two major groups: *air mail* and *air freight*. The reason for this division lies on the specific legal nature of mail. Mail is defined as being "all correspondence and other objects tendered by and intended for delivery to postal administrations"[277.] Therefore, only postal offices may label freight as mail. Mail has for a long time been the principal mean of communication and thus of crucial importance on the early development of countries (Figure 1.3). Governments aware of such relevance have designed a set of regulations to protect national and international transport of mail (Allaz, 2004, pp 45, Sinha, 1999, pp 50). Air freight is thus defined in negative terms: all air cargo not labelled as air mail.

---

275 IATA defines airway bill as "a contract between the shipper and airline that states the terms and conditions of transportation".Link: http://www.iata.org/whatwedo/cargo/standards/air_waybill.htm (11th April 2009)
276 Issuing an airway bill requires designating an air transport company.
277 International Civil Aviation Organisation (ICAO) terminology, Link: http://icaodata.com/Terms.aspx (1st May 2009).

Air freight is in turn considered to be divided in two other groups, being: *general freight* and *express freight*. The term express freight refers to the freight traditionally carried by the Integrators[278], and the term general freight is used to designate the remaining air freight.

The term express freight[279] gained widespread recognition as of seventies for designating the air freight carried by the Integrators. Integrators offered a short transit time and only accepted small sized (and weighted) freight. Therefore, the differentiation between express and general cargo is normally done upon these two main characteristics: transit time and size (and weight). Figure 8.2 sketches the domains of express and general cargo.



Source: author

Figure I.2 – Parameter for the segmentation of air freight

It is not possible to define the exact limits of each one for several reasons. First, the exact conditions of service provided by Integrators slightly varies among them, both in terms of the maximum accepted size (or weight) and in terms of transit times. Second, over time, other companies than Integrators started offering express services also with some differences[280]. Third, over time, Integrators started offering non-express carrying both express and general freight. Consequently the division between these two types of air freight is blurring. Nonetheless, it is commonly accepted to consider express cargo

[278] The definition of Integrators is provided in Annex II.

[279] It should be mentioned that express freight already existed before the seventies, yet, it was rather incipient with no practical relevance. It was only with deregulation of the United States air transport market that Integrators could develop and express freight gained relevance (Wensveen, 2007, pp 322).

[280] Like for example the air transport company Lufthansa with its express service Td Pro and Td Flash (Information at Lufthansa's Cargo Website, http://www.lufthansa-cargo.com, 1st May 2009)

as having maximum size of few metres of length (summing all directions), maximum weight of some tens of kilograms, and a maximum transit time of few days. The rationale for considering these two types of air freight lies on the fact of much literature still referring to them (Boeing, 2008b, Hall, 2001, Kim et al, 1999), although scarcely there is reference to the exact properties of such air freight.

ANNEX II – THE AGENTS IN THE AIR CARGO SECTOR

In the air cargo market there are a large set of agents performing different roles and interacting in different ways, such as: cooperation, competition, negotiation, verification or regulation. Within the scope of this research work there are three agents with particular relevance, being: freight forwarder, air transport companies and integrators. The remaining ones, notwithstanding playing key roles on the market, these are not so relevant for the purposes of this research work, such as: functions of facilitator, supplier, supporting or regulation. These agents are: customs authorities and other governmental agencies, national and international regulatory agencies, airports and cargo terminal, handling companies and other mode of transport companies. Follows a list of the agents in the air cargo market:

Freight Forwarders

Freight forwarder is a servicing intermediary agent between the shippers and the air cargo market. Their portfolio of services is vast and includes, for example: arranging and managing transport services, processing and issuing documentation (such as: invoices, bills, contracts or certificates), transport insurance and customs clearance, or provision of other added value services (such as: kitting, labelling, warehousing, or inventory control).

The main sources of competitive advantage of the freight forwarders are: organisation, know-how and costs (Zondag, 2006, pp 24). Freight forwarders are in practical terms the ‘architects’ of the transport service. Commonly, they negotiate the terms of the contracts of carriage and they manage the transport process afterwards. In order to provide these services, they have an extensive knowledge of the market, which enable them to identify the most suitable combination of modes of transport.

Freight forwarders are in their very essence service providers. They need to own no kind of assets (such as: vehicles or terminals), but can hire out in the market all they need from third parties. Freight forwarders are thus very flexible, as they can easily customise the different transport-related services (such as: transporting or warehousing) in function of the shippers’ demands. Additionally, when compared with other transport providers they have a more variable cost structure (as they are essentially service providers) enabling them to better adapt to market demands fluctuations (Zondag, 200, pp 25). Their revenues are generated from the fees charged for doing the various services[281].

Traditionally, freight forwarding sector was highly fragmented and local oriented. Over the past decades, there is a trend towards consolidation on this sector, having emerged some (few) Global players (Clancy et al, 2008, pp 36, Bowen and Leinbach, 2004, pp 179-180). The Global freight forwarders are able to offer integrated services. This is in opposition to smaller freight forwarders that only offer local services and thus non-integrated services. Clancy et al (2008, pp 36) refer that in 2007 the top 20 freight forwarders controlled around sixty six percent of the total intercontinental air freight (measured in tonnes).

Finally, it should be mentioned that the negotiation of air transport services, and in particular the issuing of airway bills, depends upon the accreditation from IATA. Other agents than air transport companies are generally designated as Cargo Agents.

---

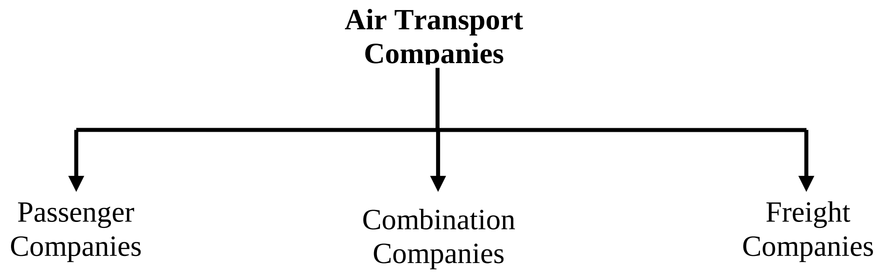
[281] It should be noted however that, over time, some freight forwarders have developed interest in the freight transport business. The typical business consists in the consolidation of consignments. The freight forwarder buys bulk capacity to transport providers (act as a wholesaler) and sells retail capacity to shippers (act as a retailer). Profits, and competitiveness, are generated from the fact of the unitary cost of bulk capacity being lower than the unitary cost of the retail capacity. Consolidation however tens to increase transit time, since consignments have to wait until consolidation process is completed.

Air Transport Companies

An air transport company is a transport provider of air transport services in-between airports. Air transport services can be of people or freight. Figure 9.1 presents a possible classification of the air transport companies:

- passenger companies, when only offering passenger transport services,
- combination companies when offering both passenger and freight transport services, and
- freight companies, when offering only freight transport services.

Combination companies can transport freight and passengers simultaneously on a same aircraft designated as passenger aircraft, or on dedicated freight aircrafts designated as full freighters. A flight served by a passenger aircraft holding air cargo only on the lower deck (belly) is designated as passenger flight; otherwise if the air cargo shares the upper deck with the passengers, the flight is then designated as combi flight.



Source: author

Figure II.1 – Types of Air Transport Companies

The share of the combination companies in the intercontinental air cargo traffic was, in 2007, of 32%; while the freight companies accounted for a total of 68% (Clancy et al, 2008, pp 43).

The typical cargo segments of the air transport companies are the general freight and the mail cargo; and to a very less extent, the express freight.

The passenger companies lie outside the scope of this research work. The freight companies can be clustered into three main groups: global operator, niche operator or ACMI operator. Global operator provides airport-to-airport only air cargo services. It can have either regular schedules or, alternatively, offer charter services. Niche operators are specialised on specific needs of the market, namely: transport of outside or heavy weight air cargo, or operating of specific geographic regions (Button and Stough, 2000, pp 6-7). ACMI[282] operators are wet leasers of aircrafts for combination or freight companies. Payment is commonly hourly and contract commonly involves a minimum number of block hour per month (Zondag, 2006, pp 40).

Integrators

An Integrator is a freight transport provider that offers “unbroken custodial control” (Clancy et al, 2008, pp 34) and door-to-door transport services. Additionally, they provide an array of transport related services, likewise freight forwarders. Integrators offer customers a one-stop-shop of tailored transport services.

The distinguishing features of the services provided by the integrators are: promptness, accuracy, safety, convenience, economic efficiency, and dependability (Park et al, 2009, pp 323). Integrators deliver high quality transport services based on: time definitive deliver (in case of non-compliance customer is compensated), high levels of reliability, track and trace of goods, and short transit times (as short as: next day deliver) (Sage, 2001, pp 456).

To achieve such levels of service, integrators run proprietary integrated transport system, including: infrastructure (warehouses and terminals), fleets (trucks, aircrafts and others) and communications. Integrated is required to streamline the transport system, for example: coordination of transport services’ schedules, interoperability amongst mode of transport, common processes and procedures, identical equipment, or dedicated facilities.

The core cargo segment of the integrators is express freight (Clancy and Hoppin, 2002). Recently they have been marketing and entering into general freight (Clancy et al, 2008, pp 36).

Air transport is fundamental in Integrators’ operations for reducing transit times. Thus, although not being pure air transport services providers, they are direct competitors of air transport companies and, commonly, considered a player on the air cargo market.

---

[282] ACMI stands for: Aircrafts, Crew, Maintenance and Insurance

Integrators' business presents however some drawbacks. First, significant capital investment is required for establishing and maintaining the transport network. This is a business with significant fixed costs. Second, flexibility level is low: services are standardised (limitations on the maximum size and weight), time schedules are rigid, and geographic coverage is predetermined (Clancy et al, 2008, pp 34, Clancy and Hoppin, 2002). Standardisation is required to increase performance of transport services and to drive down unit costs.

Nowadays, Integrators' business segment is considerably consolidated. The initial investments to establish an Integrator business, and the know-how and time required to establish an efficient transport network act as barriers to enter the market (Zondag, 2006, pp 46). There are four truly Global agents, being: FedEx, UPS, TNT and DHL, and then some with a continental geographic scope.

It should be mentioned that there is no formal or universally accepted definition on Integrator. As a matter of fact they are also designated by other terms such as: Freight Integrators, Courier or Express Operator.

Customs authorities and other governmental agencies

Customs authorities and other governmental agencies are based at the airports and are responsible for ensuring transport services and goods comply with both national and international regulations. Their work entails verifying both the validity and accuracy of the information written on the documents accompanying goods and the suitability of the conditions of the goods, which often is done through visual inspection. In case of any non-compliance they have the authority to arrest the goods.

The agencies are also responsible for the surveillance and control of illegal or unlawful activities such as: smuggling, terrorism activity or traffic.

National and international regulatory agencies

The national and international regulatory agencies are responsible for establishing the legal environment governing air transport sector, in fields such as: competition, safety and security, operations standards and procedures or labour. They normally have to power (at least the national ones) for monitoring and enforce the compliance of the rules. There are various regulatory agencies, each one with a specific scope and goal.

For example, the Federal Aviation Agency, in the United States, or ICAO and International Air Transport Association (IATA) at international level.

Airports and cargo terminal

Airports are locals where a large set of aeronautical and transport-related activities take place (Ashford et al, 1997, pp 2). Those directly related with air cargo transport are: freight handling operations, warehousing and cargo related activities (such as: consolidation), customs related activities and transport services related activities (such as: offices for transport providers and the other agents).

Adequate airport conditions may foster the performance of air transport providers, since handling operations and other activities may be better performed.

Handling companies

Handling companies work at the airport and are responsible for the transhipment operations of air cargo. These agents perform operations of loading and unloading aircrafts and other vehicles, namely: trucks. Also, they are responsible for lashing down air cargo on pallets or into containers, so that it could be safely transported and without incurring in damaging.

Handling companies work on behalf of an air transport providers. The performance of these agents thus has a direct influence on the competitiveness of air transport providers.

Other mode of transport companies

Other mode of transport companies represent those transport provider agents that make use of other modes of transport such as: road, rail or sea transport. They can be competitors, when provide alternative transport services; or cooperatives when provide complementary transport service either in-between airports (replacing air links), or between the shipper’ locations and airports.

ANNEX III – THE LIST OF INTERVIEWS

Listed below are the interviews[283] conducted in the prosecution of this research work (the position was the current at the of the interview):

- Mr. Pereira Countinho, former Director of KLM Cargo Portugal, 16th August 2005;
- Mr. Américo Costa, Director of cargo division at TAP Portugal, 29th September 2005;
- Mr. Costa Faria, Director of EXEL Logistics Portugal, 31st October 2005;
- Mr. Rogério Alves, president of the Portuguese Association of Freight Forwarders, 3rd October 2005;
- Mr. Johan Vandewalle, Operational Planning & Capacity, Hesse-Noord Natie N.V. (Port of Antwerp, Belgium), 2nd July 2006;
- Ms. Hilde Meersman, Full Professor at the University of Antwerp (Belgium), several interviews as of 2006;
- Mr Lopes Bastos; Director of Intermodal Transport Operations, Grupo Luís Simões Portugal, several interviews 2006
- Mr Amilcar Horta, Air France Cargo-KLM Cargo Cargo Sales Manager Portugal, as of 2006;
- Mr. John Hansman, Professor of Aeronautics and Astronautics at the Massachusetts Institute of Technology (United States), February 2008;
- Mr. Sgouridis Sgouris, MIST Assistant Professor at the Massachusetts Institute of Technology (United States), March 2008;

[283] This list only includes the appointed interviews, many others have been conducted on an informal basis.

- Ms. Helena Rosa, Business Unit Manager, Head of Operations of PANALPINA Portugal, April 2009;
- Mr. Thilo Schmid Executive Vice President & Partner of Lufthansa Consulting GmbH, 1st April 2009;
- Mr. Mário Sousa, Director of PortoCargo, 23rd July 2009;
- Mr. Alberto Silveiro, Garland Transports, 23rd July 2009;
- Mr. Luís Monteiro, Sunvilog, 23rd July 2009;
- Mr. João Araújo, former Director of SeaRoad company, 23rd July 2009;
- Mr. Mário Simonette, Ground Force Portugal, August 2009;

ANNEX IV – THE GLS CASE STUDY

Paper presented at the European Transport Conference, 6th-8th October 2008, Leeuwenhorst, Netherlands

ANNEX V – ELEMENTS OF FUZZY SET AND FUZZY LOGIC

Fuzzy set theory was firstly introduced, in 1965, by Lofti Zadeh (1965), in the seminal paper entitled: Fuzzy Sets. Zadeh defines fuzzy set as a “class of objects[284] with a continuum of grades of membership. Such set is characterized by a membership (characteristics) function which assigns to each object a grade membership ranging between zero and one” (Zadeh, 1965, pp 338). The theory extends the classical theory of sets, through the introduction of the concept of membership, which extends the traditional concept of state[285] to a virtually infinite array or possibilities. Zadeh (1965, pp 339) writes that fuzzy set theory “provides a natural way of dealing with problems in which the source of imprecision is the absence of sharply defined criteria for class membership rather than the presence of random variables”. Additionally, the author argues that fuzzy set theory introduces a new framework for handling with situations where uncertainty, subjectivity, ambiguous or vagueness are relevant. In the real world,

[284] A class is a group or cluster of objects, of any nature, that share a common property (e.g.: the class of birds or mammals; the class of numbers great than 1 or odd numbers; or the class of tall men, or young people).

[285] In classical normative theory the state of a variable is of Boolean type: zero or one, or true or false states (Zhang and Liu, 2006, pp 3). Uncertainty is introduced by considering a level probability of occurring or not the state; thus, “uncertainty concerns the happening of a state or event and not the event itself” (Zimmermann, 1987, pp 10).

many classes[286] of objects do not show clear or sharp divisions or segmentation, instead the boundaries tend to be blurred or of hard identification (for example, in the transportation sector the classification of the price of a service as expansive, acceptable or cheap; or the classification of the level of reliability of a transport agent as high, moderate or low).

The concept of membership - commonly denoted by the Greek letter μ - is the cornerstone on Zadeh's theory. The level of membership, which defines the state of a variable, indicates the level of belonging or similarity of that variable towards a given class or object (represented by a fuzzy set). The level ranges between zero - denoting no similarity - to one - indicating full similarity. Membership in-between zero and one means the object partially belongs to, or shares to some extend properties of the class. Consequently, an object can belong to more than one class, with a specific level of membership for every class[287].

Throughout time, fuzzy set theory has evolved into a large body of knowledge embracing concepts, models and techniques. Additionally, a thorough mathematical body has been developed to support the conceptual framework, able to handle the vagueness or impreciseness within the problems with the necessary mathematical rigour and strictness (Zimmermann, 1987, pp 11, Zadeh, 1965).

Fuzzy set theory has been applied to a wide range of domains, namely: artificial intelligence, computer science, control engineering, decision making, transportation, or operations research (Zimmermann, 1987, pp vii). Particularly in the transportation domain, fuzzy set theory and fuzzy logic has been applied with some success for a long time now. One of the first applications was carried in 1977 by Pappis et al. (1977) in the field of traffic control. Example of other applications[288] include fields such as trip

[286] A class is a group or cluster of objects, of any nature, that share a common property (e.g.: the class of birds or mammals; the class of numbers great than 1 or odd numbers; or the class of tall men, or young people).

[287] A note should be made about the difference between level of membership and probability. Although the concept of probability also ranges from zero to one; the meaning is different from level of membership. Probability only indicates the level of possibility of an object to belong or not to a class. Therefore, the object either belongs or not, there is no middle term (the level of membership). Moreover, the nature of fussy set is totally non-statistical in nature (Zadeh, 1965, pp 340).

[288] Teodorovic (1999) produced a thorough review of the application of fuzzy logic to transportation domain.

generation (Chan et al, 1986, Kalic and Teodorovic, 2003, Wang and Mendel, 1992, or Xu and Chan, 1993), modal split (Quadrado and Quadrado, 1996), route choice (Lin and Lee, 1991, Lotan and Koutsopoulos, 1993), transportation investment projects (Tzeng and Teng, 1993, Smith, 1993), vehicle and crew routing, scheduling and dispatching problems (Kikuchi, 1992, Teodorovic and Pavkovic, 1996), and air transportation (Larkin, 1985, Teodorovic and Babic, 1993, Teodorovic et al., 1994).

Despite the potentials and capabilities of fuzzy set concept several critics and fragilities may be pointed out, namely (Jang, 1993, pp 665, Unknown Author, 1995, pp 97): the lack of standard methods to translate human knowledge or experience into rule base of a fuzzy inference system; or the lack of effective methods for tuning membership function. Nonetheless, the apparent advantages surpass these disadvantages, being therefore decided to use fuzzy set in the current research work.

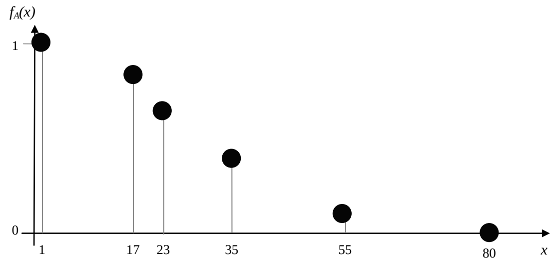
A fuzzy set class can be defined as follows. Let X be a set of objects with each element denoted by x. Thus X= $\{x\}$. A fuzzy set class, A, in X is characterised by a membership function, $\mu_A(x)$, for all x. $\mu_A(x)$ represents the level of membership of x and is a number in the interval [0, 1]. If $\mu_A(t)$= 0, then t does not belong to the fuzzy set class A; while if $\mu_A(t)$= 1, then t fully belongs to the fuzzy set class A. A fuzzy set is represented as follows:

$$A = x_0 / \mu_A(x_0) + x_1 / \mu_A(x_1) + \ldots + x_n / \mu_A(x_n); \text{ with } X = \{x\} = \{ x_0, x_0 \ldots, x_n\}$$

As an example, lets consider the following set of ages X= {1, 17, 23, 35, 55, 80}, a fuzzy set class A= {class of young people}, a possible fuzzy set would be:

$$\mu_A(1)= 1;\ \mu_A(17)= .85;\ \mu_A(23)= .65;\ \mu_A(35)= .40;\ \mu_A(55)= .10;\ \mu_A(80)= 0; \text{ or}$$

$$A= 1 / 1 + 17 / .85 + 23 / .65 + 35 / .40 + 55 / .10 + 80 / 0; \text{ or graphically}$$



Source: author

Figure V.1 - Membership function

Usually, membership levels of zero are not represented in a fuzzy set.

As written above, a set of rules and properties have been defined to operate with fuzzy set, the basic ones (and most relevant for the thesis) as presented here in[289].

Empty Fuzzy Set

A fuzzy set class A is empty if an only if and only if for all x of X={x}, $\mu_A(x) = 0$.

Equality of Fuzzy Sets

Two fuzzy sets, A and B, are equal if and only if for all x of X={x}, $\mu_A(x) = \mu_B(x)$.

Containment of Fuzzy Sets

A fuzzy set, A, is contained in another fuzzy set, B, if and only if for all x of X={x}, $\mu_A(x) \leq \mu_B(x)$, which is equivalent to write $A \subset B$.

Union of Fuzzy Sets

The union of two fuzzy sets, A and B, with respective membership functions $\mu_A(x)$ and $\mu_B(x)$ is a fuzzy set C, written as C = A ∪ B whose membership is defined as:

$\mu_C(x)$ = Maximum[$\mu_A(x)$, $\mu_B(x)$], for all x of X={x}

Intersection of Fuzzy Sets

The intersection of two fuzzy sets, A and B, with respective membership functions $\mu_A(x)$ and $\mu_B(x)$ is a fuzzy set C, written as C = A ∩ B whose membership is defined as:

$\mu_C(x)$ = Minimum[$\mu_A(x)$, $\mu_B(x)$], for all x of X={x}

---

289 For more details of each property or for other properties see for example: Zadeh (1965), Zadeh (1975) or (Zhang and Liu, 2006).

Algebraic product of Fuzzy Sets

The product of two fuzzy sets, A and B, with respective membership functions $\mu_A(x)$ and $\mu_B(x)$ is denoted by $A^{\cdot}B$:

$\mu_{A.\cdot B}(x) = \mu_A(x) * \mu_B(x)$, which is equivalent to write $A^{\cdot}B \subset A \cap B$

Algebraic sum of Fuzzy Sets

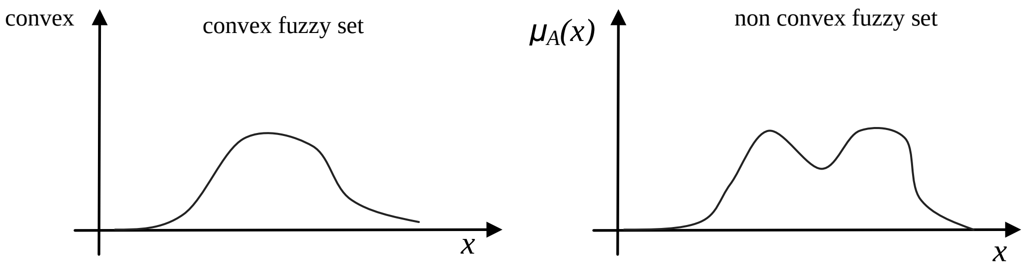
The sum of two fuzzy sets, A and B, with respective membership functions $\mu_A(x)$ and $\mu_B(x)$ is denoted by $A + B$:

$\mu_{A.+B}(x) = \mu_A(x) + \mu_B(x)$, if $\mu_{A.+B}(x) \leq 1$ for all x X={x}

Algebraic sum is only meaningful if the sum of the membership levels is equal or inferior to 1.

Convexity of a Fuzzy Set

A fuzzy set, A, is convex if an only if the sets Γ_α defined by, $\Gamma_\alpha = \{ x \mid \mu_A(x) \geq \alpha\}$, are convex for all α in the interval (0, 1]; or graphically:



Source: author

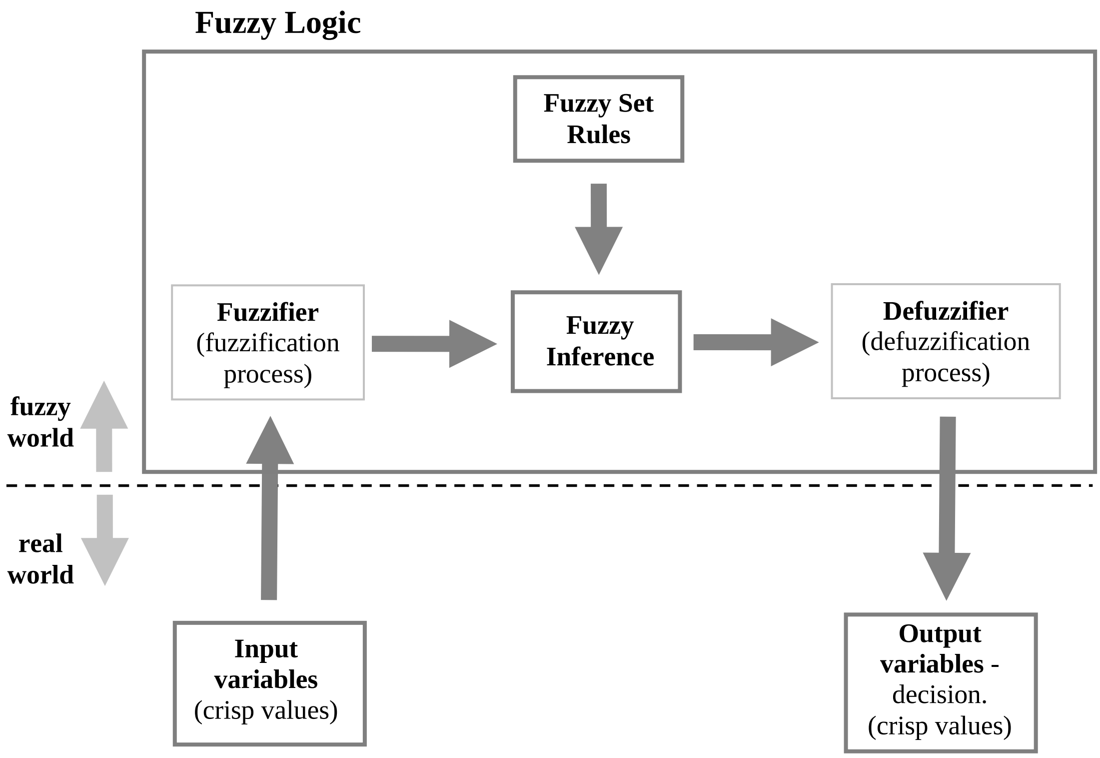
Figure V.2 - Convex and non-convex fuzzy

Fuzzy Logic

The capability of handling with uncertainty and imprecise knowledge has made fuzzy set a concept with major applications on those domains or cases where behaviour of the systems' elements plays an important role. In particular, fuzzy set concept has revealed being particular suitable to be applied for the implementation of automatic decision making systems, and to some extend (and in the current thesis) to simulate human reasoning and decision making process. Concomitantly, frameworks for decision making process have been developed and implemented in diverse practical situations[290]. Those frameworks are generically called as fuzzy systems, fuzzy logic or, even, fuzzy control.

Fuzzy systems show some interesting properties. Firstly, they inherit the ability of coping and handling with imprecise situations where the transition between states is not sharp from the very concept of fuzzy set. Secondly, fuzzy systems' mathematics are not as complex as traditional tools (e.g.: differential equations) to deal with similar problems, which reduced computational burden and increases the capability of analysing complex systems and situations (Unknown Author, 1995, pp 97, Jang, 1993, pp 665).

The general architecture of a fuzzy logic system is laid down in the following figure:



Source: author

Figure V.3 - Architecture of a fuzzy logic system

A fuzzy system works essentially as follows: real world variables or attributes (normally denominated as crisp variables) are converted into fuzzy input variables -

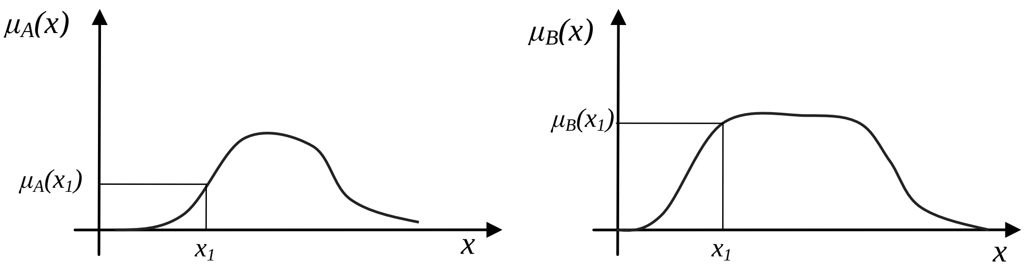
[290] Unknown Author (1995, pp 98) presents a list of some practical applications in the real world.

fuzzification process - subsequently, based on a previously defined set of if-then rules - *fuzy rules set* - the decision making process takes place - *fuzzy inference* - resulting in one or more fuzzy output variables, which have to be converted into real world or crisp variables - *defuzzification process* - in order to be used. Therefore, a fuzzy system is compound of four major building blocks:

1. Fuzzification process;
2. Fuzzy rules set;
3. Fuzzy inference;
4. Defuzzification process.

Fuzzification process

The fuzzyfication process corresponds to the transformation of crisp (real world) variables into fuzzy variables. This is processed using a set of class. As an example, let us assume the existence of tow fuzzy classes, *A* and *B* which have to be defined. The fuzzification process consists in determining the membership level of every crisp value for all the classes. The following figure shows the determination of the membership levels for one of the variables, x_1. For class *A* the membership level of x_1 is $\mu_A(x_1)$, and for class *B* is $\mu_B(x_1)$.



Source: author

Figure V.4 - Fuzzification process

Fuzzy set rules define the transformation rule or pattern of the premises - fuzzy input variables - into the consequence - fuzzy output variables or others. Fuzzy set rules are intended to emulate the decision making process or (human) reasoning. The particularity of fuzzy set rules is that they are defined in an *if - then* format using human language. Examples of fuzzy rules are:

if *<system perception (premises) >* then *<preferences towards alternatives (consequences) >;*

if *A* then *C;* if *person is young* then *pay high tax*;

if *A* and *B* then *C*; if *person is young* and *person has low income* then *pay low tax;*

if *A* or *B* then *C*; if *person is young* or *person has low income* then *pay low tax;*

Any other combination is permitted, as long as a cause effect is established.

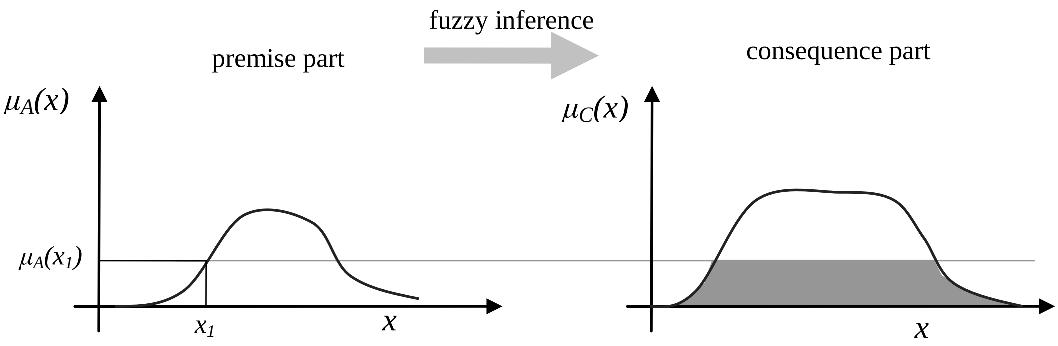
Fuzzy inference

Fuzzy inference is the engine that processes the input variables into output variables using the set of fuzzy rules. Depending upon the nature of the consequence part, the inference process is carried out differently. There are several inference methods, which can be clustered differently. Considering the nature of the consequent part, three main types can be identified: monotonically strictly increasing functions, bell shaped membership, or crisp function. These type of inferences consider a fixed shape for the consequent part. In order to overcome the somewhat rigidity of these approaches, other types have meanwhile been developed. One well known has been developed by Jyh-Shing Jang based on an adaptive network with supervised learning capability[291] (Jang, 1993, pp 666). The nature of the consequence part defines as it will be explained in the next section the deffuzification process. In this thesis, only bell shaped membership functions will be used[292].

If a fuzzy rule simply consists in one premise, the transformation is straightforward, being only necessary to compute the consequence value (either fuzzy or crisp).

[291] The inference engine is based on a neural technique. This type of consequence membership function does not have any predefined inference engine; instead, it uses a set of input and output variables to learn and define the inference rules that best fit. Therefore, in each case the inference rules are generated being able, at least theoretically, to achieve better results.

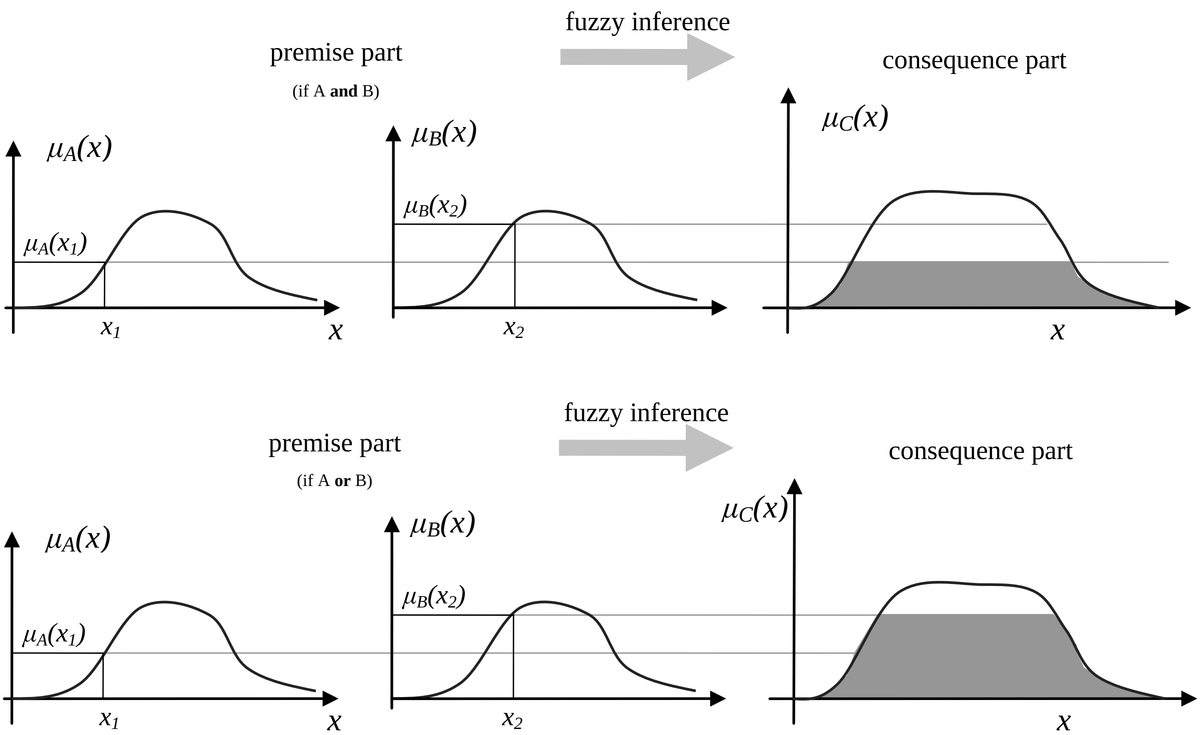
[292] More information on inference methods can be found in Nakanishi et al.(1995). The authors review and compare, in terms of precision and execution time, eight alternatives for five inference methods.



Source: author

Figure V.5 - Fuzzy inference

If, on the other hand, the premise of a fuzzy rule consists in a joint combination of more than one class, the transformation requires firstly computing the outcome of that joint combination. The ***and*** operator implies an intersection of fuzzy sets, while the ***or*** operator implies a union of fuzzy sets. The following to figures exemplify the fuzzy inference for a fuzzy rule of the type if *A* and *B* then *C*, and if *A* or *B* then *C*, with a consequent part being a bell-shaped membership, respectively.



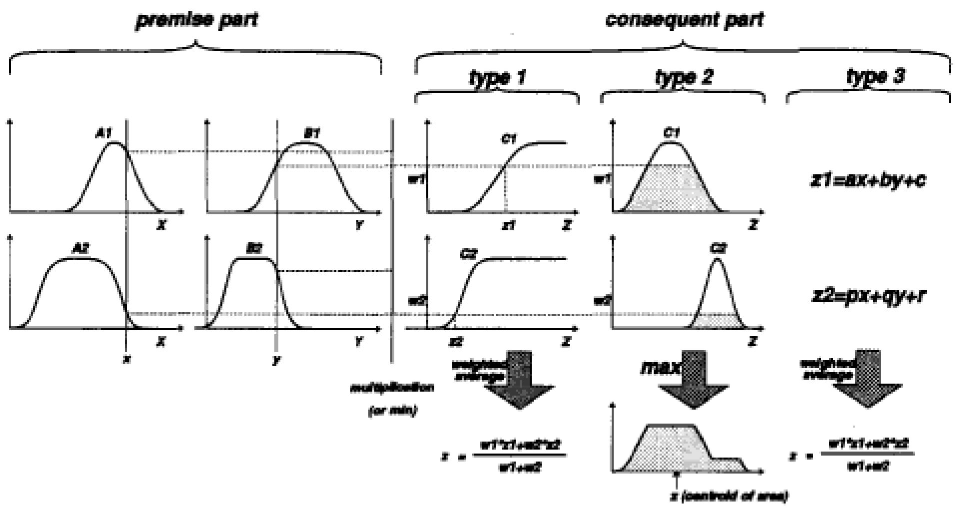
Source: author

Figure V.6 - Fuzzy inference of multiples classes

This procedure is repeated for every fuzzy rule. If the consequence part has any other shape the process is the similar, just instead of the bell shaped membership, other membership function is used.

Defuzzification process

Defuzzification process is the final process in a fuzzy logic approach and "is the selection of a significant crisp value with respect to a fuzzy set" (Runkler, 1996, pp 694), which in the decision making process would correspond to the outcome of the process. The process consists in determining a weighted average of the various consequent, although the specific method depends upon the specific nature of the consequence part (or parts). The following scheme presents the defuzzification processes for the three types referred above: monotonically non-decreasing, bell shaped membership and crisp function. Different types of fuzzy inference processes would require different defuzzification process.



Source: Jang (1993)

Figure V.7 - Defuzification process

ANNEX VI – COMPACT DISK WITH AFETAS MODEL

A Compact Disk (CD) was attached to the back cover, with additional information on several topics. The folder structure of the CD is as follows;

- **Folder: ROOT**
  - Contains a help file about the contents of the CD
- **Folder: ANYLOGIC**
  - Contains the a trial version of the commercial software AnyLogic (downloaded from www.xjtek.com, 20th June 2010);
- **Folder: AFETAS**
  - Contains the AnyLogic file of the model AFETAS;