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Performance Assessment of Intelligent Transportation Systems: Crew Rostering at Carris

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Avaliação de Desempenho de Sistemas Inteligentes de Transportes: um caso de estudo na Carris

Resumo

Este trabalho teve como objectivo avaliar o desempenho de um Sistema Inteligente de Transportes utilizado pela empresa de transporte público Carris, que opera em Lisboa, Portugal. O sistema escolhido foi o software de Escalonamento de Motoristas que a empresa usa para gerar escalas mensais de motoristas. Para avaliar o desempenho do sistema foi criada uma metodologia, composta por uma comparação entre as escalas para Fevereiro de 2008 e Fevereiro de 2010, sendo que na primeira ainda não existia o sistema e no segundo já o sistema estava em exploração. Para analisar a qualidade dos horários, foi utilizada uma adaptação de uma metodologia de Souza et al. ao caso de estudo da Carris. A avaliação de desempenho foi feita através da comparação da evolução de indicadores chave para o desempenho de escalas de motoristas observados em Fevereiro de 2008 e Fevereiro de 2010, nomeadamente indicadores relativos ao cumprimento de regras de trabalho, à minimização de horas extra, ao equilíbrio entre horas trabalhadas por cada motorista, e ao atendimento das preferências de motoristas, tendo em conta a importância relativa destes. As conclusões indicaram que todos os indicadores melhoraram com a introdução do sistema excepto um deles, o que quer dizer que o sistema está a corresponder na sua maioria aos objectivos pretendidos.

Palavras-chave: Avaliação de Desempenho; Sistemas Inteligentes de Transportes; Escalonamento de Motoristas; Gestão de Tripulações; Transporte Público; Companhia de Autocarros.

Performance Assessment of Intelligent Transportation Systems: Crew Rostering at Carris

Abstract

This work had the objective of assessing the performance of one Intelligent Transportation System used by the public transport bus company Carris, operating in Lisbon, Portugal. The ITS chosen was the Crew Rostering software that the company uses for the creation of monthly schedules for drivers to perform. A methodology for the performance assessment was created, consisting on a comparison between the schedules of February 2008 and February 2010, the former without the ITS application and the latter already with the ITS being deployed. For the analysis of the quality of the schedules, an adaptation of a methodology by Souza et al. to the Carris case study was used. The performance assessment was conducted comparing the evolution of the key indicators of performance for schedules of drivers from February 2008 to February 2010, namely the respect for working rules, minimization of extra hours, equilibrium of hours worked by each driver, and attendance to drivers' preferences, taking in account the relative importance of these. Conclusions indicate that all indicators considered improved with the introduction of the ITS except one, which means that the ITS is corresponding to most of the intended objectives.

Keywords: Performance Assessment; Intelligent Transportation Systems; Crew Rostering; Crew Management; Public Transport; Bus Company

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ABREVIATIONS

ACC – Adaptive Cruise Control

ACN – Automated Collision Notification

ADMS – Archived Data Management Systems

APC – Automatic Passenger Counters

APTS – Advanced Public Transportation Systems

ATIS – Advanced Travelers Information Systems

ATMS – Advanced Traffic Management Systems

AVL – Automated (or Automatic) Vehicle Location

BSC – Balanced Scorecard

CAD – Computer-Aided Dispatch

CAP – Crew Assignment Problem

CPP – Crew Pairing Problem

CSP – Crew Scheduling Problem

CST – Centre for Sustainable Transportation

CVO – Commercial Vehicles Operation

DEA – Data Envelopment Analysis

DEH – Drivers Extra Hours

DMS – Dynamic Message Signals

ESS – Environmental Sensor Stations

ETC – Electronic Toll Collection

FHWA – Federal Highway Administration

FO – Função Objectivo (portuguese for Objective Function)

$\mathbf{F_{RE}}$ – Função Requisitos Essenciais (portuguese for Essential Requisites Function)

$\mathbf{F_{RNE}}$ – Função Requisitos Não Essenciais (portuguese for Non Essential Requisites Function)

GIST – Gestão Integrada de Sistemas de Transportes (portuguese for Integrated Management of Transportation Systems)

GPS – Global Positioning System

HAR – Highway Advisory Radio

HAZMAT – Hazardous Materials

HOT lanes – High-Occupancy Toll lanes

I&D – Investigation and Development

ILS – Iterated Local Search

ITS – Intelligent Transportation Systems

KPI – Key Performance Indicator

MEH – Medium Extra Hours

MWT – Mean Work Time

OPT – Operação e Planeamento de Transportes, S.A. (Portuguese Company)

PPT – Personalized Public Transport

RD – Random Drop

RWIS – Road Weather Information Systems

SA – Simulated Annealing

SMS – Short Message Service

TMC – Transportation Management Center

TOC – Traffic Operations Center

U.S. DOT – United Stated Department of Transportation

VSL – Variable Speed Limit

1 INTRODUCTION

This section will present a brief description of the relevance of this work, explaining its justificative, its objectives, the methodology used, and a schematic framework of the main tasks.

1.1 MOTIVATION

1.1.1 The importance of public transport in nowadays society

"*Mobility is vital for the internal market and for the quality of life of citizens as they enjoy their freedom to travel. Transport enables economic growth and job creation: it must be sustainable in the light of the new challenges we face*" (European Commission, 2011, p. 3).

In a time where the mobility needs are significantly increasing, motivated by the dynamic lifestyle of nowadays society, sustainable alternatives are necessary in all areas, from energy to transportation. Regarding this last one, it is clear that the use of the personal car inside a city is no longer an alternative if we want to do it in a sustainable way. At the same time that a transition to greener modes of transport should be done, such as light trains or bicycles, public road transport should also be improved to better perform and to provide personal car users with similar service at a lower cost. Great part of the responsibility for a greener, environmental friendly and safe transportation system relies on public transport, or transit.

Public transport is a part of the city and has to be connected with it according to supply and demand factors, geography of the city, necessities of users, and a variety of other factors. A city without an effective public transport system becomes unattractive, people will tend to avoid the city or only go there with personal car, which increases congestion which also increases its unattractiveness. On the other hand, a city with an appropriate public transport system, with good conditions of comfort and security, with a good frequency of service, fair prices, and coverage of the main hotspots, will have a more dynamic population, increased accessibility conditions, and therefore will be more attractive. This is supported by the European Commission's *White Paper on Transport* where the following can be read:

"*The quality, accessibility and reliability of transport services will gain increasing importance in the coming years, inter alia due to the ageing of the population and the need to promote public transport. Attractive frequencies, comfort, easy access, reliability of services and intermodal integration are the main characteristics of service quality. The availability of information over travelling time and routing alternatives is equally relevant to ensure seamless door-to-door mobility, both for passengers and for freight*" (European Commission, 2011, p. 12).

Public Transports play a fundamental role in nowadays society, with relevant impacts on the economics of each country. This is supported by Gwilliam on his paper on public transport economics, where he says that "*transit is critical to the achievement of a wide range of social, economic and environmental objectives and, therefore, needs appropriate institutions to ensure its integration with the strategic management of the rest of the urban development policy*" (Gwilliam, 2008, p. 4).

A constant improvement of public transport is necessary for the development of each country. With recent laws affecting levels of pollution and also with the levels of congestion verified in bigger cities, having an efficient public transport system may be one of the most crucial factors for lowering both pollution and congestion. If the public transport covers the whole city, with adequate timetables, and with appropriate opening and closing hours, people will increasingly tend to leave cars at home, reducing congestion and pollution.

1.1.2 ITS as a mean of improving public transport operation

"*Transport research and innovation policy should increasingly support in a coherent way the development and deployment of the key technologies needs to develop the EU transport system into a modern, efficient and user-friendly system*" (European Commission, 2011, p. 12)

Intelligent Transportation Systems, or ITS as they are commonly known, are systems that use technology such as informatics, electronics, or others, to improve the way transports and systems of transports work. A closer look at nowadays means of transport and transport infrastructures will reveal a variety of ITS systems, from electronic toll payment to traffic signals, from traveler information systems to public transport management systems.

In bigger cities, public transport companies are huge and have to deal with high numbers of vehicles, drivers, and backend staff. The high complexity of the system, along with the evident competition in between modes of transportation, makes it really hard for a company to succeed in the public transportation sector. The companies must be on a constant evolution, adapting to the new technologies available in order to provide the better service possible, with the lowest costs associated.

Intelligent Transportation Systems are crucial to the improvement of public transport systems, acting on multiple fronts of the public transport system structure. Management, improvement of reliability, timetable optimization according to demand, and automatic payment of trips are some examples of areas where ITS may help the public transportation system. The importance of ITS systems applied to public transport is emphasized by Gillen, Chang and Johnson, when they say that "*as transit agencies are pushed to produce greater ridership and hours of service while keeping costs down, technological advancements will help agencies be as efficient as possible with their resources*" (Gillen, Chang and Johnson, 2004, p. 551).

Over the past 30 years, public transport agencies have been using software, hardware, and communications technology to improve the service provided. These improvements have included better service reliability for passengers, better supervision of bus operations, improved scheduling, and timely passenger information about bus locations and travel times (Hickman, 2004).

According to Giuliano and O'Brien, public transport funders and providers see ITS technology as a means for improving efficiency, increasing service quality, and ultimately attracting more choice riders. Technologies such as automated passenger counters (APC) and automated vehicle location (AVL) systems may allow public transport operators to better balance supply and demand, improve schedule adherence, providing a more reliable service, improve fleet management and consequently reduce operating costs. Electronic fare cards provide a reduction on dwell time and make fare payment easier and more convenient, also reducing losses from fare evasion. Traveler information services can ease trip planning and provide important real time information to travelers, regarding for example schedules or delays. Signal priority systems can reduce travel time by reducing the amount of time that public transport vehicles loose on signalized intersections and consequently provide a faster trip. On the case of demand-responsive public transport, AVL and automatic dispatch may increase productivity and reduce passenger travel time (Giuliano and O'Brien, 2004).

The expected benefits of ITS for public transport are large, but public transport has some inherent barriers to successful implementation. One of them, and maybe the more important one, is the organizational structure of the industry, since large public transport organizations are heavily subsidized and subjective to restrictive labor contracts. These limit management flexibility in work assignments, work schedules, and in changes that could result in loss of jobs. Therefore technology applications that increase productivity by substituting capital for labor may not be feasible, and the expected benefits may not be achieved. Also, public transport agencies do not have the profit motive that often drives innovation adoption in the private sector (Giuliano and O'Brien, 2004).

1.1.3 The need of having performance assessment of ITS applications

The application of an Intelligent Transportation System is always preceded by the identification of a determined problem that the ITS is supposed to solve, minimize, or simply aid in the way it is dealt. As the ITS moves into deployment, the advantages of carrying out comprehensive impact and performance assessments are significant, since such assessments can validate initial assumptions and provide data to influence future deployment, both locally and within the ITS community more generally (Stevens, 2004).

ITS projects often represent a substancial expenditure of public funds and policymakers should ensure that they are getting the most out of their investment. Evaluation of ITS provides those who have to make the decision about whether to undertake the project or choose between competing projects with valuable information on the differences in their correspondent benefits. On the other hand, besides benefits ITS projects will also have negative consequences. The decision-maker may use the assessment of ITS projects to determine the appropriate design that maximizes the positive impacts and minimizes the negative ones. Performance assessment is a type of analysis that is undertaken after the project is already in use and consists of a summary of the main differences between a scenario with the ITS and other without the ITS.

The importance of having Performance Assessment on ITS projects is to understand if the objectives and initial assumptions are being met, if the system is performing according to the intended objectives. This analysis must be correctly structured to reflect objectives and its importance in an accurate way, since it provides useful guidance for planning and management decisions. If the analysis is not the appropriate for the project being assessed, the results will be incorrect and decision makers can misdiagnose problems, choosing to perform changes that could be bad decisions if the analysis was well structured.

1.2 OBJECTIVE

The objective of the present work is to assess the performance of an Intelligent Transportation System. From the beginning of the work it was decided to apply the performance assessment to a case study focused on one of the ITS currently used by the bus company Carris, which operates in the metropolitan area of Lisbon, capital of Portugal. After a meeting with responsibles from the company, it was decided that the ITS to be analysed would be their Crew Rostering method, which saw the introduction of a new software application in recent years. The objective of a crew rostering problem is to construct the work schedule of crews for a longer period of time, usually one month, using the minimum number of crews that covers a given set of duties respecting considered constraints. It is easy to understand that for a company with a considerable amount of workers this will be a hard task to perform, so many Public Transport companies use applications to generate crew schedules, which are considered ITS.

The work to be done consisted on developing a methodology that would be able to assess the performance of the crew rostering problem at Carris, taking in account two scenarios, respectively before and after the implementation of the new software. Taking as a start a methodology by Souza et al. (Souza et al., 2005) which was able to measure the static performance of one schedule for drivers along a month, a performance assessment methodology was developed for the specific case study at Carris. The methodology was later applied to data supplied by Carris referent to a month when the software was not in use (February 2008) and to a month with the ITS already in use (February 2010).

By comparing the results obtained on key performance indicators regarding the crew rostering problem on both months analysed, and taking in account the respective importance of the distinct indicators considered, one will be able to conclude about the quality of schedules with and without the ITS. In other words, comparing a scenario with the ITS and a scenario without the ITS will allow conclusions on the performance of the ITS, which is the objective of this dissertation.

1.3 STRUCTURE OF THE DISSERTATION

The work is divided on seven chapters that will be briefly described next. As a complement for better understanding of what was done, Figure 1.1 presents a schematic framework of the work performed, where the different chapters of the dissertation are connected.

The first chapter, Chapter 2, is a state of the art regarding Intelligent Transportation Systems. First there will be presented a definition of ITS, followed by an extensive description of the types of ITS that were found in the literature review. The chapter ends with a description of the objectives of ITS.

Chapter 3 refers to the use of ITS applied to the Crew Management of Public Transport. It starts converging to the scope of this work and a more detailed analysis will be provided for the areas of Management, Crew Rostering, and Crew Schedules. Some methods and models used on these areas and some examples of application will be given.

On Chapter 4 the topic is Performance Assessment. It starts with an approach to the importance of having performance assessment on ITS projects, as well as the presentation of some methodologies to measure performance. After that, the measurement of performance of public transport systems will be referred.

Chapter 5 begins with a presentation of Carris, containing a brief history of the company and references to the ITS used by them. The presentation of the methodology to be used on this work follows, along with the explaining of all the modifications and adaptations to the case study.

The case study at Carris will be developed on Chapter 6. The results obtained for each indicator in analysis are presented, as well as the overall results of the methodology.

Finally, Chapter 7 presents the final conclusions of this work, as well as indications to future works related with the topic.

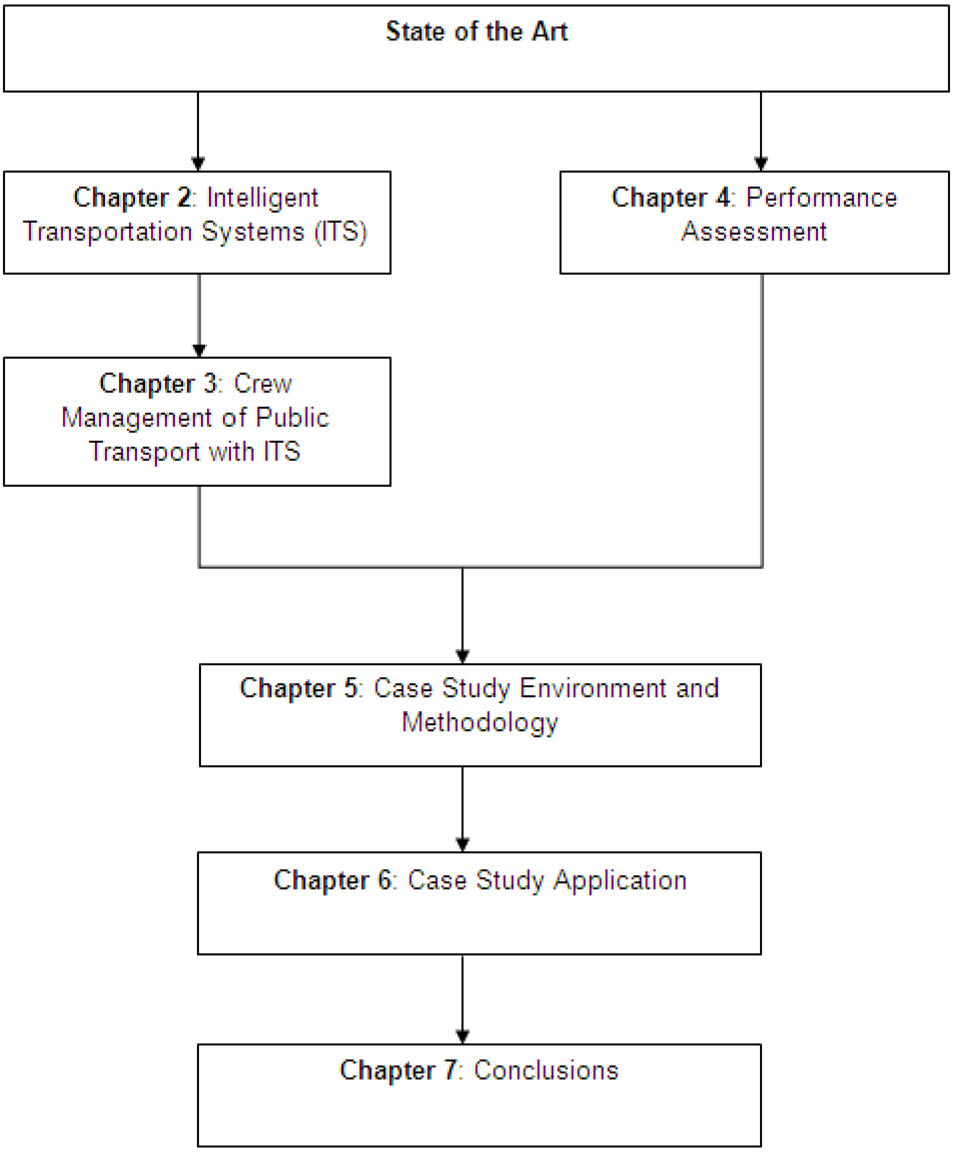

Figure 1.1 – Framework of the dissertation

2 INTELLIGENT TRANSPORTATION SYSTEMS

2.1 INTRODUCTION

If we take a look at the last decades, the substancial impact that transportation systems have in the way people's life has changed is evident. We use transports and transportation systems for almost every single move we make and because of that, roads, stations and public transports suffer from a high level of occupation and, consequently, problems in their utilization. Traffic congestion, traffic accidents or delays, and pollution increase are familiar examples of it. Intelligent Transportations Systems were created with the purpose of minimizing the problems related with the transportation networks, improving the way the whole environment works.

On the first part of this chapter some definitions of ITS will be presented, on the second part the different types of ITS will be discussed with the presentation of some examples and finally, on the third part, the objectives of ITS will be explained.

2.2 DEFINITION OF ITS

The term ITS refers to the multimodal package of innovations in transportation that use advanced technologies in electronics and information to meliorate the performance of vehicles, highways, and public transport systems. The name "Intelligent Transportation Systems" says it all, ITS stand for intelligent systems used to somehow improve the efficiency, security and functioning of the transports network. According to Jana Gurínová, "*ITS refers to a variety of tools, such as traffic engineering concepts, software, hardware and communications technologies, that can be applied in an integrated fashion to the transportation system to improve its efficiency and safety*" (Gurínová, -, p. 1). In other words, it can be said that an ITS uses intelligence to enhance the operation of the transportation system, minimizing its impacts on the environment and also minimizing the problems on the network such as traffic congestion and accidents.

As it can be read on the report "ITS – Benefits, Costs, Deployment and Lessons Learned (2008 Update)", "*ITS improve transportation safety and mobility, and enhance productivity through the use of advanced communication sensors, and information processing technologies encompassing a broad range of wireless communications-based information and electronics*" (U.S. DOT, 2008, p. XV). ITS are integrated in the new transportation networks being constructed but they may also be applied on old networks, improving the efficiency of both new and existing transportation systems. This includes the improvement of all transportation modes (Benouar, 2001).

Since the transportation network plays a fundamental role in nowadays lifestyle, it is of major importance that the whole systems works on the best way possible, avoiding congestions and delays, increasing mobility and accessibility, and at the same time respecting the environmental rules and contributing for a better planet. These topics will be better explained on the section 2.4., which deals with the purpose of ITS.

According to these definitions we can conclude that the ITS system is composed by 3 elements, the driver, the infrastructure and the vehicle, interacting between them to achieve the objectives purposed. This is expressed by Benouar when it is said that "*ITS is a system of systems which includes the driver (behavioral characteristics, human machine interface, etc), the vehicle (personal, transit, etc) and the infrastructure*" (Benouar, 2001, p. 1012). Figure 2.1 illustrates the described system.

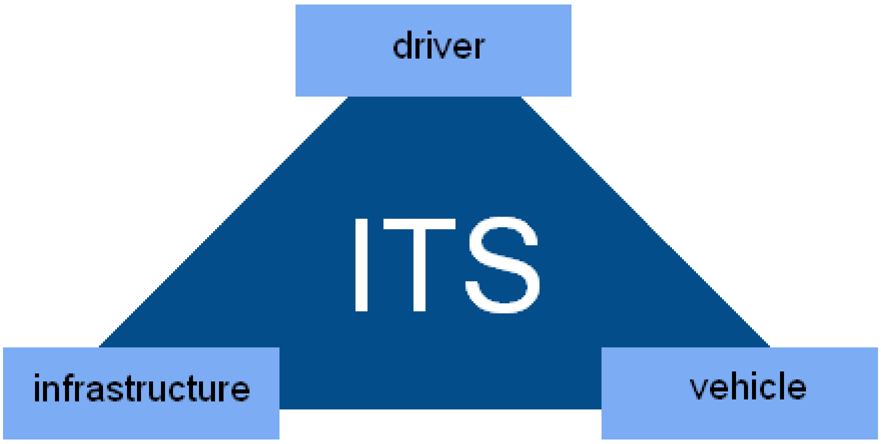

Figure 2.1 – Relation between the three main entities of ITS

It is also interesting the fact that ITS have different definitions depending on the country they refer to. For example, on the paper "Conceptual study on evaluation of advanced public transportation systems" (Yang and Zhou, 2003), the authors present 3 different definitions for ITS on 3 different countries, U.S.A., Japan and China. The definitions are the following:

United States of America – ITS have been defined as "*the application of advanced sensor, computer, electronics and communication technologies and management strategies in an integrated manner to improve the safety and efficiency of the surface transportation system*".

Japan – ITS have been defined as "*to deal with a variety of problems – traffic accidents, traffic congestion, environmental pollution and massive consumption of fossil fuels, to name a few – are becoming serious global problems and critical issues for all humankind. Across the world research and development is underway into systems that link road infrastructure and telecommunications using computers, electronics and advanced sensing technologies*".

China – ITS have been defined as "*based on electronics, information, communication, computers, GIS (Geographic Information Systems) and GPS (Global Positioning Systems)* *technologies to solve the traffic problems for all humankind, a new traffic science and technology systems*" (Yang and Zhou, 2003, p. 121).

These different definitions are interesting because they reflect somehow the way these countries feel about ITS systems, reflecting also their priorities in terms of objectives to achieve and perspectives of change.

For being the most relevant regarding the work to be done on this dissertation, the definition of Intelligent Transportation Systems that will be used on this dissertation will be the one by Jana Guirínová (Gurínová, -), refered on the beginning of this section.

2.3 TYPES OF ITS

The Intelligent Transportation Systems may be of different types and forms. It can be a simple traffic sign or a complex program that regulates the whole network, presenting a considerable set of outputs about traffic conditions, traffic accidents, delay times, etc.

A proper division of ITS systems is suggested by the U.S. Department of Transportation (2008), which was the base for the construction of Table 2.1. For being the most relevant for the presented work, the Public Transport section was further divided in four categories that were suggested by Chowdhury and Sadek (Chowdhury and Sadek, 2003), which are also represented on Table 2.1.

On this chapter a brief description of each of these types will be made, focusing on their more important characteristics and giving some examples of application, not only taking in account the information given on the U.S. DOT document (U.S. DOT, 2008), but also considering information from other bibliography found on this subject.

2.3.1 Intelligent infrastructure

2.3.1.1 Roadways

2.3.1.1.1 Arterial Management

The arterial management systems manage traffic along arterial roadways using devices such as vehicle detectors, traffic signals and various means of communicating information to travelers. These systems use the information collected by traffic surveillance devices to improve the way drivers use travel corridors. It is also part of these systems the dissemination of information about traffic conditions and other important information through dynamic message signals (DMS) and radio broadcast.

Table 2.1 – Division of ITS systems

Intelligent Infrastructure	**Roadways**	Arterial management
		Freeway management
		Crash prevention and safety
		Road weather management
		Roadway operations and maintenance
	Public transport	Public transport management; En-Route Transit Information; Personalized Public Transit; Public Traffic Security
	Management and Operations	Transportation management centers
		Traffic incident management
		Emergency management
		Electronic payment and pricing
		Traveler information
		Information management
	Freight	Commercial vehicles operation
		Intermodal freight
Intelligent Vehicles	**Vehicles**	Collision avoidance
		Driver assistance
		Collision notification

The system is composed by 3 main elements: Collection Data Team, Support Systems and Real Time Traffic Control Systems (Figueiredo et al., 2001). The first is the responsible for the monitorization of the traffic conditions. The Support Systems are the instruments that help the system operators managing and controlling real time traffic, such as cameras, sensors, semaphores, and other electronic systems. The Real Time Traffic Control Systems use the information provided by the first two elements and control the traffic changing semaphores, sending messages to the electronic displays and controlling the accesses.

Some examples of arterial management systems are traffic signal control systems, adaptive signal control systems, pedestrian detectors and others. The traffic signal control systems are very important because they improve significantly the traffic flow and the safety to road users. Adaptive signal control systems help the coordination and control of traffic signals along arterial corridors, adjusting the length of the different signal phases according to the traffic conditions at the moment. To improve the safety of all road users at signalized intersections many different tools may be used, such as pedestrian detectors, specialized signal heads or bicycle-actuated systems.

Arterial management systems may be also connected with automated enforcement programs to increase the respect for speed limits, traffic signals or traffic control devices.

2.3.1.1.2 Freeway Management

The freeway management systems are ITS strategies used to improve the operation on freeways. These systems may be divided in 6 different categories: surveillance, ramp control, lane management, special event transportation management, information dissemination and enforcement.

In terms of surveillance, vehicle detectors and cameras are used to support freeway management applications. The ramp control systems are traffic control measures on freeway entrance ramps to optimize travel speeds and ramp waiting times. Some examples of these systems are ramp meters, ramp closures and priority accesses. As for lane management applications, these lead to a more appropriate use of the available capacity on freeways increasing their level of service. For example, there is the possibility of using reversible flow lanes on peak hours in order to have more lanes on the direction with greater demand, avoiding congestion.

On special occasions that may cause extra congestion, like sport events, expositions and convention centers, special event transportation management systems play an important role in terms of controlling the negative impacts on traffic. In areas where these events occur frequently some devices may be installed, like large changeable destination signs and other lane control equipment. For sporadic events, portable equipment is used to help the achievement of a smooth traffic flow.

Also an important ITS category on freeways is the dissemination of important information about traffic conditions and other relevant issues. This act of sharing information with the travelling public has been improved with the new advanced communication technologies and nowadays' drivers can count on information on location-specific traffic conditions via dynamic message signals (DMS), radio broadcast or even through in-vehicle devices. There are other modes of transmitting information to the drivers but those will be referred on section 2.3.1.3.5, which refers to Traveler Information.

The automated systems enforcing speed limits and aggressive driving laws are important because they lead to a more respectful behavior by the drivers, achieving obvious safety benefits. Examples are radars or speed detectors installed on the roadside that warn drivers who are exceeding the speed limits. These systems are often equipped with cameras that allow a recording of vehicles not respecting the speed rules.

There are other different (and still important) types of ITS used on freeways, but those will be referred on following sections like Crash Prevention and Safety (section 2.3.1.1.3) and Electronic Payment and Pricing (section 2.3.1.3.4).

2.3.1.1.3 Crash Prevention and Safety

One of the main purposes of ITS is to prevent crashes and accidents on the transportation environment, improving safety and reducing risk for system users, including pedestrians, cyclists, operators and occupants of all vehicles. This is a matter of most importance worldwide, but if we look at Portugal's specific case we notice that many people lost their life on road accidents in recent years. ITS play an important role on the reduction of crashes and consequently on the reduction of accident victims.

Examples of ITS for crash prevention and safety are:

- Road geometry warning systems, used to warn drivers of potentially dangerous conditions that may lead to accident situations on ramps, curves or downgrades. These systems are also used to provide overweight warnings at tunnels and overpasses;

- Highway-rail crossing warning systems: when a road intersects a railway there's a potential point of collision, so these systems help reducing the potential for collisions, improving safety for drivers who cross these points;

- Intersection collision warning systems: on problematic roadway intersections these systems may be used to monitor traffic approaching the intersection and transmit this information to other vehicles that are reaching the same point. Technologies such as in-vehicle displays or roadside message signals are used.

As for pedestrian safety systems, these increase the safety for pedestrians in numerous ways. As it can be read on the U.S. DOT 2008 Report, "*pedestrian safety systems can adjust traffic signal timing to provide an appropriate WALK phase or activate in-pavement lightning or roadside warning messages to alert drivers of pedestrians present*" (U.S. DOT, 2008, p. 41). Similar systems like bicycle warning systems and animal warning systems are also used nowadays, being the former responsible for the increase on the safety of cyclists and the latter responsible for the detection of large animals in rural areas near the roadway and prevent drivers about it.

2.3.1.1.4 Road Weather Management

When the weather conditions are adverse, the road network experiences significant reductions on the quality of its operation, which leads to significant delays. Rain, which occurs more frequently than snow, ice or fog, leads to greater delays. On the U.S. DOT 2008 Report (U.S. DOT, 2008), it can be read that "*an investigation of vehicle crashes from 1995 through 2005 show that each year more than 673,000 people are injured and nearly 7,400 are killed in weather-related crashes"* (U.S. DOT, 2008, p. 55) and that *"the estimated cost of weather-related crashes ranges from $22 billion to $51 billion annually. These costs include travel delay, emergency services, property damage, medical and rehabilitation costs, productivity losses, insurance administration costs, legal and court costs, and the costs to employers*" (U.S. DOT, 2008, p. 55). These impacts of adverse weather may be smoothed by strategies, tools and technologies that are in development by the Road Weather Management program in the US with the objective of promoting safety, increase mobility, improve productivity and protect the environment.

Some systems of road weather management already in use are environmental sensor stations (ESS) and road weather information systems (RWIS), which provide transportation managers and maintenance personnel data about pavement condition and forecast weather. This is important because this data can be used to implement advisory, control and treatment strategies. The dissemination of information collected about weather and pavement conditions is done using dynamic message signals (DMS) or through the internet.

When adverse weather conditions occur, some traffic control technologies are used to alter the state of roadway devices to permit or restrict traffic flow and regulate roadway capacity. Some examples of these control strategies are the reduction of speed limits with variable speed limit (VSL) signals and modifying traffic signal timing based on pavement conditions.

2.3.1.1.5 Roadway Operations and Maintenance

The costs of operating and maintaining transportation systems are substancial. Intelligent transportation systems may be applied to better manage and maintain a roadway system and, consequently, enhance safety and mobility with less costs (or at least better applied costs). "*ITS applications in operations and maintenance focus on integrated management of maintenance fleets, specialized service vehicles, hazardous road conditions remediation and work zone mobility and safety*" (U.S. DOT, 2008, p. 69).

On work zones, ITS can be used to increase safety of workers and travelers, while helping maintaining a smooth traffic flow around the construction area. There applications in work zones include the temporary implementation of traffic management or incident management capabilities, which may be stand-alone implementations or complements of existing systems. Other applications in work zones are systems to control vehicle speeds and devices to notify drivers of lane configuration changes or even travel times and lengths of the work zone. The dissemination of this information may be done using portable DMS signals or similar devices.

2.3.1.2 Public Transport

"*The transit industry in the United States consists of over 140,000 vehicles, 48 billion passenger miles of travel and $8.5 billion in passenger fares. Over the past 10 years the transit industry has grown by over 20 percent – faster than either highway or air travel*" (U.S. DOT, 2011).

According to Chowdhury and Sadek, there are four main areas of research for ITS applied to public transportation operations, concerned with the improvement of service quality and thus encouraging their use. These four types are: i) Public Transportation Management; ii) En Route Public Transport Information; iii) Personalized Public Transport; and iv) Public Travel Security (Chowdhury and Sadek, 2003).

ITS applications to public transport operations and fleet management help the improvement of its reliability with the use of automated vehicle location (AVL) and computer-aided dispatch (CAD) systems to reduce passenger wait times. Automated passenger counters on achieving a better management and planning of public transport systems since it allows the gathering of better information about whether is necessary more or less vehicles, regarding an improvement on systems' operation. Automatic payment systems are used to improve the payment method making it simpler and more efficient for users and at the same time offering significant benefits for public transport agencies. However, these systems will be better analysed on the Electronic Payment and Pricing section.

En Route Public Transport Information refers to information provided to passengers during the journeys, for example information on expected arrival times of vehicles, transfers, connections, and ride-share opportunities. Advanced Public Transportation Systems (APTS) use technologies of Advanced Traffic Management Systems (ATMS) and Advanced Travelers Information Systems (ATIS) to provide information about travel schedules, route information, costs or real time information about the changes in the public transport system. The main objectives of this area are providing information to travelers in order to optimize their choices and decisions regarding the use of public transport, increasing their level of comfort and perception of level of service. This information can be disseminated through electronic panels on bus stops, interactive displays inside the modes of transport, or interactive kiosks at key locations.

Figure 2.2 – Example of an ATIS system (Electronic panel at Carris bus stop)

Public access to bus location data and schedule status with information of possible delays is becoming a usual feature on agencies' nowadays websites. Passengers can confirm online if the schedule of a specific transport mode will be or not respected and save time, improving transfer coordination also. One example of these systems is the Washington's BUSVIEW, which provides online the live location of some selected bus routes in the city, allowing customers to know where is each bus, minute by minute. The buses have a locator installed that transmits its exact position to the website, where this information may be consulted through an attractive interface (BUSVIEW, 2011). In addition to this, electronic signals with public transport status information may be installed at bus stops to help passengers on the management of their time.

Personalized Public Transport (PPT) is based on the idea of providing a flexible route service that adapts to users' needs. There are two ways to work a PPT environment: flexibly routed operations, where vehicles are allowed to deviate their main route to pick and drop passengers, and random route operations, where the route is defined by requests received from users.

Finally, to increase safety in public transports one can once again rely on the help of ITS. These systems include vigilance cameras (inside the vehicles and on the stations and bus stops), which provide surveillance and information to the central to detect forbidden and suspicious activities, allowing a better reaction to problematic behaviors. Security and incident management are also improved through vehicle-to-dispatch communications, which facilitate a faster response to aggressions, accidents and other problems.

Figure 2.3 – Washington's BUSVIEW layout

2.3.1.3 Management and Operations

2.3.1.3.1 Transport Management Centers

Transportation Management Centers (TMCs), which may be also called Traffic Management Centers and Traffic Operations Centers (TOCs), coordinate ITS operations and can be owned by a single agency or shared with other agencies. There are many functions performed at these centers such as data acquisition, command and control, computing and communications on a large range of ITS applications. TMCs figure in a variety of management and operations strategies presented before and some that will be presented next: traffic incident management, emergency management, electronic payment and congestion pricing, traveler information and information management. The coordination of ITS strategies through a TMC can improve their performance, since TMCs are often propitious to instantaneous communication and coordination among the different organizations on the TMC.

As for the operation of a TMC, on the U.S. DOT 2008 Report it can be read that "*TMCs can be operated under several different business models. TMCs operated by a single agency have the simplest business model. These TMCs are able to focus resources on specific agency goals, coordination requirements and explicit performance measures. Joint TMCs, however, are more complex. Joint operations of TMCs by multiple agencies complicate the task of TMC stakeholders and decision-makers charged with developing realistic planning and performance measures needed to rationalize TMC investments*" (U.S. DOT, 2008, p. 95).

2.3.1.3.2 Traffic Incident Management

Traffic crashes are deeply related with congestion problems and delay, so the use of traffic incident management systems is the better way to deal with these situations. In metropolitan areas of the US these systems are already widely deployed and they're now being applied to rural areas as well. These management programs use various ITS technologies to detect, manage and clear traffic accidents, improving safety for travelers by avoiding secondary crashes. These systems also help reducing time lost and waste of fuel on traffic congestions derived from accidents. Some ITS systems used on traveler information, freeway management and arterial roadway management may be used to complement traffic incident management programs.

In order to detect incidents in a faster way than the regular one, surveillance and detection technologies are used, including inductive loop, microwave or acoustic vehicle detectors, and camera systems providing video surveillance of roads. Automated collision notification (ACN) systems and roadside call boxes also help the faster detection of accidents, and consequently a faster response. This response uses AVL and CAD systems, as well as response routing systems.

Traffic incident management systems may be incorporated with traveler information, helping on drivers' decision process or even forcing drivers to go around incidents in order to allow a faster clearance of the accident area. This can be done using dynamic message signals (DMS) or highway advisory radio (HAR). Temporary traffic control devices may also be used to ensure the safety of incident responders and a safe drive around the accident area. Some of these techniques may also be used to address operations during planned special events, like it was referred on the Freeway Management section (section 2.3.1.1.2).

2.3.1.3.3 Emergency Management

In countries with tendencies to have emergency situations ITS may be used to give a better response to the needs of drivers in adverse situations. For example, in the United States "*there are over 400 tropical storms, hurricanes, tornadoes and hazardous materials incidents that require evacuation each year*" (U.S. DOT, 2008, p. 113) and, on these situations, the minimization of losses of life and the improvement of safety is a priority to travel agencies. It is necessary that responders reach the scene as fast as possible, victims must be evacuated and traffic congestions on evacuation exits must be diluted. "*ITS applications for emergency management aim to improve public safety by giving agencies the tools and equipment they need to plan for and implement response actions quickly and efficiently*" (U.S. DOT, 2008, p. 113).

For the transportation of hazardous materials ITS systems are applied to vehicle tracking, roadside detection, driver authentication and route planning, allowing management centers to know when a shipment deviates from its original route and detect accidents faster. Driver authentication technology confirms that only authorized drivers take control of the HAZMAT vehicle and report to safety entities if unexpected drivers try to steal or drive the vehicle.

On the Freeway Management section (2.3.1.1.2) some lane management techniques were mentioned, namely reversible flow lanes, which can also be used on emergency situations to help reducing congestion.

In large-scale emergency situations, ITS applications can help the response management with the tracking of emergency vehicles fleets using automatic vehicle location (AVL) technology to better manage the whole fleet and direct each of the vehicles to the nearest spot where help is needed. "*Studies of ITS deployed to enhance emergency response have shown the potential of these technologies to assist organizations in improving emergency response actions*" (U.S. DOT, 2008, p. 114).

2.3.1.3.4 Electronic Payment and Pricing

Systems of electronic payment use different types of communication and electronic components to make transactions between travelers and transportation agencies easier.

Electronic toll collection (ETC) systems are used at toll plaza transactions as an automatic payment without requiring the vehicle to stop and pay manually (or when required to stop, minimizing the stop time), which increases operational efficiency and convenience to tollway drivers. Besides this, ETC also helps on the reduction of fuel consumptions and emissions at toll plazas and minimizes delays and queuing.

These systems are also used for public transportation and have various benefits on this area too. The efficiency of cash-handling processes is increased and that leads to an improvement on administrative controls. It has also benefits for the users because they do not have to pay for every single trip and they can select from a variety of fare products such as electronic rechargeable cards, smart cards or payment with credit card. Sometimes there is also the possibility of using the same card for different modes of transportation and on different operators. The detection of stolen cards is also improved with these systems as the management center can track the cards and detect where and when a stolen card is being used.

Electronic payment is often used on parking lots too, presenting similar benefits on the management of parking facilities and simplifying payment for users, along with the reduction of queues and consequent improvement on the operation.

Figures 2.4 and 2.5 – Electronic payment cards

As for pricing systems, on the U.S. DOT 2008 Report it can be read that "*congestion pricing, also known as road pricing or value pricing, refers to charging motorists a fee that varies with the level of congestion*" (U.S. DOT, 2008, p. 127). If a road is congested, the price to pay for using an alternative road will increase and that will reduce the number or cars entering that road, helping to eliminate congestion faster and providing drivers the decision to pay more for a better road. According to the U.S. DOT (U.S. DOT, 2006), there are four main types of congestion pricing strategies: a) variable priced lanes including express toll lanes and high-occupancy toll (HOT) lanes; b) variable tolls on entire roadways or roadway segments, i.e., changing flat toll rates on existing toll roads to variable rates based on congestion levels; c) cordon charge, i.e., charging a fee to enter or drive in a congested area; d) area-wide charge including distance-based charging or mileage fees.

Recent studies demonstrate that ETC is one of the most successful applications of ITS because of its numerous benefits related to delay reductions, improved throughput and fuel economy. It has also been demonstrated that variable pricing strategies are effective at influencing drivers' behavior and, although the first impact is a negative one, research indicates that road users value the time savings achieved with it and are willing to pay to avoid congestion and delay.

2.3.1.3.5 Traveler Information

Traveler information is important because it allows travelers to make more aware decisions regarding a better service in terms of departure times, route choice and mode of travel. At the same time, these systems help the reduction of congestions because if a driver chooses a less congested road there will be fewer cars entering the congested one and the traffic will be more uniformly distributed.

Information may be provided to the driver before or during the travel. Pre-trip information may be obtained through internet, television, radio or telephone and includes information about traffic conditions, road weather, public transport, and work zone information. During the trip, the driver may obtain information via roadside message signals, various in-vehicle devices, or mobile phones (smartphones, mainly, which nowadays have a wide range of applications for traffic information).

2.3.1.3.6 Information Management

The amount of information collected by ITS systems about operational status of the transportation system is enormous and with a proper archiving and analysis can provide significant benefits to travel agencies.

The collecting of ITS data is done by Archived Data Management Systems (ADMS), which also assists in transportation administration, policy evaluation, safety, planning, program assessment, operations research and other applications. These systems may belong to only one agency (small-scale data archiving systems) or belong to all the agencies of a region (large-scale data archiving systems), acting like the warehouse of ITS data of that region. Transportation Management Centers (TMCs), which were referred on 2.3.1.3.1, provide an excellent opportunity to collect ITS data in a centralized way so the collection of data often occurs at TMCs.

On the U.S. DOT 2008 Report (U.S. DOT, 2008), some examples of uses of archived ITS data are given:

- Incident management programs may review incident locations to schedule staging and patrol routes and frequencies for service patrol vehicles;
- Historical traffic information can be used to develop predictive travel times;
- Public transport agencies may review schedule performance data archived from automatic vehicle location, computer-aided dispatch systems and/or automatic passenger counting systems to design more effective schedules and route designs or to manage operations more efficiently.

2.3.1.4 Freight

2.3.1.4.1 Commercial Vehicle Operation

Commercial Vehicles Operation (CVO) systems use a variety of ITS technologies to enhance communication and improve the efficiency of commercial vehicles companies and fleets, also increasing their safety. These systems are particularly important to big commercial vehicles companies because they allow the company to control each vehicle position, travel itinerary, travel speed or stopping places. It is also possible to predict the time of the arrival of goods to their destination, improving the quality of the information given to the buyer.

Systems similar to CVO systems may be used for emergency vehicles too, for example, to manage a fleet of ambulances. Using CVO systems, the manager of the ambulance fleet may know the exact position of an ambulance and if it is transporting a patient or not, which can improve the whole system’s efficiency and better serve the population.

CVO systems include a whole different type of technologies for traveler's information, traffic management, vehicle control and management. Some examples are Automatic Vehicle Identification, Automatic Vehicle Classification, Automatic Vehicle Location, Pedestrian Movement Direction, Board Computers, and Real Time Traffic Transmissions (Figueiredo et al., 2001).

The way the system works is simple: in each vehicle is adapted a device that identifies the exact location and conditions of the vehicle and transmits that information to the central, where the information about all vehicles is gathered. The central, using this information, transmits to each vehicle orders and directions in order to provide a better service on the whole system. With these systems we assist to an increase on the speed of goods delivery (and patient transport, in the case of the example with the ambulance fleet), with a reduction of operation costs. The impact on the operation costs is obvious, because if a truck gets off its route or is delayed it can be redirected to a better route on real-time, allowing the company to provide a premium service at only a slightly higher cost.

2.3.1.4.2 Intermodal Freight

ITS systems applied to freights include freight tracking applications to monitor, detect and communicate status information to ensure that the containers remain sealed during the whole transportation route. To monitor the location and identification of containers in real time, systems of asset tracking technologies are used. On the terminal side, ITS freight terminal processes may be applied to improve operations at freight transfer stations, "*using information technology to expedite procedures often carried out using paper records*" (U.S. DOT, 2008, p. 171). The use of all these technologies combined reduces shipment process times and increase the productivity of the system.

Intelligent Transportation Systems applied to drayage operations "*promote the efficient transfer of cargo by truck around major port facilities, using information technology to provide dispatchers and truck drivers with information on vessel traffic, container/cargo availability, on and off-port traffic conditions and delay times at terminal entrances*" (U.S. DOT, 2008, p. 171). The crossing of international borders is also facilitated with these systems, being faster, more efficient and causing less delay associated with customs and the tax collection process. CVO systems are also related to intermodal freight technologies, facilitating a safe and efficient motor carrier operation.

2.3.2 Intelligent Vehicles

"*In-vehicle applications of ITS use vehicle-mounted sensors and communication devices to assist with the safe operation of vehicles, prevent crashes and mitigate the consequences of crashes that occur*" (U.S. DOT, 2008, p. 179). There are 3 main types of in-vehicles systems that will be discussed on this section: collision avoidance, driver assistance and collision notification.

2.3.2.1 Collision Avoidance

Collision avoidance systems use a variety of technologies such as sensors and telecommunication networks to communicate with other vehicles and at the same time with the infrastructure. Some in-vehicle warning systems were also developed to alert drivers in possible cases of accident, when they are too close to a nearby vehicle or close to the infrastructure limits.

On the U.S. DOT 2008 Report (U.S. DOT, 2008), some collision avoidance systems are mentioned as being in development, tested and deployed. Those systems are synthesized on Table 2.2.

Table 2.2 – Collision avoidance systems

System	Function
Intersection collision warning systems	Detect and warn drivers of approaching traffic and potential right-of-way violations at intersections.
Obstacle detection systems	Detect obstructions - such as other vehicles, road debris, or animals - in a vehicle's path or projected path and alert the driver.
Lane change warning systems	Alert bus and truck drivers of vehicles (or other obstructions) in adjacent lanes when the driver prepares to change lanes.
Lane departure warning systems	Warn drivers if their vehicle is unintentionally drifting out of the lane.
Rollover warning systems	Notify drivers when they are traveling too fast for an approaching curve, given their vehicles operating characteristics.
Road departure warning systems	Warn drivers when their vehicle is about to leave the roadway, whether they are approaching a curve too fast, or about to drift off the road on a straight roadway segment.
Forward collision warning systems	Warn drivers if they are in a conflict situation with a lead vehicle.
Rear-impact warning systems	Warn the lead vehicle driver if he is in conflict with a following vehicle.

2.3.2.2 Driver Assistance

Driver assistance systems are used to help the driver in multiple tasks while on the road such as driving tasks, navigation, speed control or parking. Technologies like these have strong acceptance in the marketplace. A table like the one presented on the collision avoidance section is presented below for driver assistance systems, also based on information from the U.S. DOT 2008 Report (U.S. DOT, 2008).

Table 2.3 – Driver assistance systems (based on U.S. Department of Transportation, 2008)

System	Function
In-vehicle navigation and route guidance systems with GPS technology	Reduce driver error, increase safety, and save time by improving driver decisions in unfamiliar areas.
Integrated communication systems	Enable drivers and dispatchers to coordinate rerouting decisions on-the-fly can also save time and money, and improve productivity.
In-vehicle vision enhancement	Improve visibility for driving conditions involving reduced sight distance due to night driving, inadequate lighting, fog, drifting snow, or other inclement weather conditions.
Object detection systems	Warn the driver of an object (front, side, or back) that is in the path of or adjacent to the path of the vehicle.
Adaptive cruise control (ACC), intelligent speed control, and lane-keeping assistance	Assist drivers with safe vehicle operation.
Roll stability control systems	Take corrective action, such as throttle control or braking, when sensors detect that a vehicle is in a potential rollover situation.
Drowsy driver warning systems	Alert the driver that he or she is fatigued which may lead to lane departure or road departure.
Precision docking systems	Automate precise positioning of vehicles at loading/unloading areas.
Coupling/decoupling systems	Help vehicle operators link multiple vehicles, such as buses or trucks, into platoons.

On-board monitoring systems	Track and report cargo condition, safety and security status, and the mechanical condition of vehicles equipped with in-vehicle diagnostics. This information can be presented to the driver immediately, transmitted off-board, or stored. In the event of a crash or near-crash, in-vehicle event data recorders can record vehicle performance data and other input from video cameras or radar sensors to improve the post-processing of crash data.

2.3.2.3 Collision Notification

Collision notification systems are used to detect collisions and report their location and severity to services responsible for emergency response actions. The systems may be activated manually or automatically (Automated Collision Notification Systems) and can establish wireless data and voice communications with call centers which transmit the information to emergency response services.

"*More advanced ACN systems use in-vehicle crash sensors, global positioning system (GPS) technology and wireless communications systems to automatically determine the severity, location, condition and orientation of vehicles in a crash and communicate this information to emergency responders*" (U.S. DOT, 2008, p. 197). The systems may also inform emergency responders which equipment will be necessary for the operation, which is the best mode of transport to reach the crash scene and which is the nearest available hospital to take possible injured people. Lots of these products are already available to public as factory-installed options on luxury cars or installed as after-market products.

2.4 PURPOSE OF INTELLIGENT TRANSPORTATION SYSTEMS

Building enough new roads or new lanes to meet increasing transport demand is becoming impossible, especially in urban areas where more capacity is needed. By applying the latest technological advances to transport systems, ITS can address increasing demand for road transport by improving quality, safety, and effective capacity of the existing infrastructure (Garcia, 2004).

The main objectives of ITS may be summarized on 3 items: increase safety, reduce congestion, and contribute to energy saving and environment protection. The association between these three is obvious, if there's no congestion on roads the traffic will flow smoothly, without problems of security and without a waste of energy like the one that occurs in congestion situations.

Hamed Benouar says it with a simple sentence, "*The goal of ITS is to improve mobility, create better accessibility and enhance safety while meeting stringent environmental requirements*" (Benouar, 2001, p. 1012). On the same paper he also writes about the benefits of deploying ITS systems, which can be associated with their objectives too. He says that there are many different ITS benefits and that these can be classified in four different terms: reduction in crashes and their severity, reduction in delay and travel time, throughput increase, and reduction in maintenance and operation costs.

Mitretek Systems go for a more extended definition of the objectives of ITS, but focused on the same 3 items mentioned above. They say that the implementation of ITS have 6 main objectives (or benefits) that can be well defined:

- Improving safety on the roads, by reducing the risk of having traffic accidents (reduction of potential crashes);
- Improving mobility on the whole network with the reduction of delays and travel times;
- Optimize the use of the existing infrastructures, improving their efficiency;
- Increase productivity by saving on the costs;
- Energy saving and environment protection;
- Achieving customer's satisfaction. (Mitretek Systems, 2001)

This definition of objectives by Mitretek Systems seems to be more appropriated than the ones referred before because of the wide scope of areas where Intelligent Transportation Systems may be applied. In fact, both definitions presented before are a bit limitative for the variety of ITS available, limitation that is not verified on the definition of objectives by Mitretek Systems. Therefore, for the development of this dissertation when the objectives of ITS are mention one should remember this definition.

2.5 RESUME OF THE CHAPTER

Resuming what was said in this chapter, the definition of Intelligent Transportation Systems to be used on this work is the one presented by Jana Gurínovà, which says that "*ITS refers to a variety of tools, such as traffic engineering concepts, software, hardware and communications technologies, that can be applied in an integrated fashion to the transportation system to improve its efficiency and safety*" (Gurínová, -, p. 1).

A proper division of ITS proposed by the U.S. DOT is presented, along with complements from other bibliography found and giving a greater importance to the Intelligent Transportation Systems that have more to do with the scope of this dissertation. Some examples of application areas for IST that were referred are Arterial and Freeway Management, Crash Prevention and Safety, Public Transport Management, Information, Electronic Payment, or Intelligent Vehicles.

Finally, the main purposes of ITS were presented according to the opinions of three authors, being the most correctly defined the one by Mitretek Systems, which divides the objectives of ITS in six main themes, from the increase of productivity to the improvement of road safety.

3 CREW MANAGEMENT OF PUBLIC TRANSPORT WITH ITS

3.1 MANAGEMENT OF PUBLIC TRANSPORT WITH ITS

Advanced Traffic Management Systems (ATMS) have the potential to improve public transport system productivity, through increased ridership in response to improved information dissemination and better quality of service. On the other hand, these also meliorate productivity through improved operational efficiency in both day-to-day system and responding to special situations (Sullivan and Gerfen, 2004).

As it was said on section 2.3.1.2, there are three different application areas for ITS on the management of public transport systems:

- Improving the operation of vehicles and facilities;
- Improving planning and scheduling;
- Personnel management (or Crew Management);

The most important of these three areas for the scope of this dissertation is the last one, so it will be the one with a more detailed description, while both the first and the second will be just briefly referred.

3.2 SCHEDULLING OF VEHICLES (AND DRIVERS)

The scheduling of vehicles and crew (or drivers, in the case of bus companies) is one of the more important issues when it comes to management, because it can be determinant on the costs for the company, while optimizing the service provided. These problems are frequent in the real world, mainly in the airline and mass public transport industries, typically bus (Beasley and Cao, 1996).

An effective scheduling of vehicles considering the different demands along the day (or week, or month) combined with an appropriate crew roster minimizes the costs for the company and provides a better service for users. This is supported by the Brazilian authors Rodrigues, de Souza, and Moura, who say that "*these schedules must meet the passenger demand and satisfy technical and contractual restrictions stemming from the daily operation of the lines, while optimizing some measure of operational cost*" (Rodrigues, de Souza and Moura, 2006, p. 844).

Scheduling problems are often composed of an objective function, operational constraints, and specific restrictions that vary depending on the scenario being studied. On the specific case of bus scheduling problems, "*one should consider the problem size, the structure of the trips, the assignment of trips to depots, and perhaps some additional factors including local operational* *constraints in choosing the appropriate method of solution*" (Haghani, Banihashemi and Chiang, 2003, p. 321).

According to these last mentioned authors, public transport scheduling usually consists of four main interrelated components: design of routes, creation of time tables, scheduling of vehicles to trips, and assignment of drivers, being the last two the most important ones (see Haghani, Banihashemi and Chiang, 2003). The objective is to go through these four steps maximizing the benefits for the company and for society in general, while minimizing the costs associated (mainly, operational costs). In other words, the main objective of a scheduling problem is to construct vehicle and crew schedules, satisfying a given set of problem restrictions, while optimizing some operational criteria such as the number of vehicles, size of crews (or number of drivers), or extra duty minutes (Rodrigues, de Souza and Moura, 2006).

On a paper about a case study on a limousine rental company, Laurent and Hao defined the objectives of the scheduling problem as the efficient use of both type of resources, crews and vehicles, which has been a subject of continuous research since the 1950's (Laurent and Hao, 2007). However, one must not forget that a set of conditions and restrictions must be met while working on scheduling problems, which are obviously different from case to case. Some of them may be similar in all cases, like for example the set of conditions presented below, that should be satisfied in any scheduling problem (Haghani, Banihashemi and Chiang, 2003):

- An objective function given in advance is optimized;
- Each trip is run by exactly one vehicle;
- Each block of trips starts and ends at the same spot;
- Each depot has a given maximum number of vehicles (capacity);

All operational constraints, including restrictions on the total time a vehicle spends away from the depot, usually must be satisfied. However, some restrictions are more flexible than others and on specific occasions they may not be fully satisfied and exceptions may occur.

3.3 CREW MANAGEMENT

Staff scheduling and rostering is an area that has become increasingly important as business becomes more service oriented and cost conscious. The origins of staff scheduling and rostering go back to works on traffic delays at toll booths, in the 50's. Since then, staff scheduling and rostering methods have been applied to numerous transportation systems, like for example airlines and railways, health care systems, emergency services such as police, ambulance and fire brigade, call centers, and many other service organizations such as hotels, restaurants, and retail stores (Ernst et al., 2004a). Advanced mathematical models to optimize crew utilization were introduced in the beginning of the 1990s and have evolved continuously since then. The key for the long-term success of such models is their adaptability to changes in planning conditions and their ability to assimilate advancements in technology.

In 2004, Ernst et al. compiled a comprehensive collection of some 700 references in the area of personnel scheduling and rostering. Table 3.1 groups the applications found according to their application and it is interesting to identify which are the main application areas for these problems.

Table 3.1 – Applications for crew scheduling models (Ernst et al., 2004b, p. 34)

Application	Papers	Application	Papers
Buses	129	Civic Services and Utilities	22
Nurse Scheduling	103	Venue Management	19
Airlines	99	Protection and Emergency Services	16
Railways	37	Other Applications	14
Call Centres	37	Transportation Systems	12
General	33	Hospitality and Tourism	7
Manufacturing	29	Financial Services	6
Mass Transit	28	Sales	3
Health Care Systems	23		

Adopting optimized staff schedules can lead to enormous benefits, but these have to be done with carefully implemented decision support systems in order to meet customer demands in a cost effective way, while satisfying requirements such as flexible workplace agreements, shift equity, staff preferences, and part-time work. Good solutions are extremely hard to find and optimal solutions are even more difficult due to the high number of constraints and variables that these problems present (Ernst et al. 2004a).

When referring to public transport, staff management often takes the name Crew Management, which is divided in two sub-problems that will be described next: Crew Scheduling and Crew Rostering. The high complexity of Crew Management is emphasized by Sussman in a soft approach and with a good point of view:

"*How do you take crews – like airline crews, train crews, or bus drivers – and assign them to elements of work? I would suspect, if you asked the typical business operator, 'Is that hard or is that easy?' the answer would be, 'Well, it is easy in my business. I go to my factory, and I tell people to be there at eight, and I tell them to go home at four, and everything seems to work. Sometimes somebody is sick, so I have to get a temp or someone works an extra shift. It's not a big problem.' Their factory, of course, does not move around like vehicles in a transportation system. Crew assignments in the transportation system turn out to be hard to construct.*" (Sussman, 2000, p. 22)

The same author points out an important particularity of the public transport sector, which is the bimodal demand associated with it. People want to go to work in the morning and want to go home in the evening, which leaves the hours in between with a significant decrease in demand (Sussman, 2000). A problem that was already complicated turns out to be even more complicated with this kind of demand. One way to solve this problem are the called split-shifts, which consist of two spells of work usually centered on the peak periods, separated by a gap of several hours. The break in between the spells of work is not paid, which make these shifts a less wanted job for drivers (Wren and Rousseau, 1993).

3.3.1 Crew Scheduling and Crew Rostering

The Crew Management problem is usually divided in two sub-problems: the Crew Scheduling and the Crew Rostering problems. The former deals with the daily planning of work schedules for the crew. The latter takes the solution of the Crew Scheduling problem to build another work schedule for a longer period, a month for example. Due to the impacts it can economically have, airline crew scheduling and rostering is probably the biggest application of staff scheduling and rostering, although it has also received a considerable attention on other public transport systems (Ernst et al., 2004a). According to Souza et al., in what comes to public transport by bus, most of the existing applications refer to the Crew Scheduling Problem, leaving the Crew Rostering Problem to be solved manually (Souza et al., 2005).

The Crew Scheduling problem uses as input the set of trips that have to be daily covered by the company. Each trip has a duration, a start time, and a start and end point associated (which are often called control points, where changing of drivers may occur). The duration of trips is statistically calculated from field collected data and depends on a variety of factors, including the day of the week and the start time of the trip along the day. The outputs of the Crew Scheduling problem are called duties (in this case, feasible duties), which consist on sequences of trips that are assigned to crews for the day. A feasible duty is a duty that satisfies all the Crew Scheduling problem constraints. The objective of this problem is to minimize the costs associated with the allocation of drivers to trips and therefore minimizing the number of crews to cover all trips, respecting the operational and labor rules. "*The cost of a schedule is the sum of the costs of all its duties. Hence, minimizing the cost of a schedule is the same as minimizing the number of crews involved in the solution or, equivalently, the number of duties it constraints*" (Yunes et al., 1999, p. 39).

Due to fluctuations on passenger demand, the set of duties to be performed varies according to the day of the week. So, the Crew Scheduling problem generates a series of different sets of duties, one for each type of day considered (weekdays, Saturdays, Sunday and holidays). The solutions obtained from the Crew Scheduling problem are used as an input to the Crew Rostering problem.

The objective of the Crew Rostering problem is to construct the work schedule of crews for a longer period of time, usually one month, using the minimum number of crews that covers the given set of duties respecting considered constraints. The problem is that, contrarily from the Crew Scheduling problem, the restrictions are dynamic. Some constraints behave differently for each crew, depending for example on the hours of work performed in the previous month. Moreover, there are different needs for days off among different crews, imposed by personal requirements (Yunes, 2000). Because of what was stated before, to construct a schedule for a determined month some particularities must be introduced: the number of days in the month, the number of holidays in the month, and the day of the week corresponding to the first day of the month (to determine the number of Saturdays and Sundays in the month).

An optimal solution for the Crew Rostering problem is one that performs all journeys required for all the days of the month, using the less number of crews and respecting all the restrictions imposed. Additionally, it is desirable to balance the workloads among crews to promote equity inside the company, since each trip has different adversities associated. Usually, crews are paid equal salaries, so it is necessary to assure that all work duties for each month are similar. This includes the equal distribution of extra work time periods, when these occur (Souza et al., 2005).

The number of used crews may vary from month to month. For example, a month with more workdays than other will have a higher number of trips to perform and will consequently needs a higher number of crews to perform them. Therefore, some rules must be set to determine which crews are left out when months with less demand occur. These rules take in account the number of hours worked in previous months, seniority, drivers' skills, among others, creating a list of all crews according to a certain ranking function.

3.3.2 Benefits of Crew Management applications

The main benefits of using Crew Management applications are economic benefits and are proportional to the size of the company, the bigger the company is the more evident the benefits are. Also, these applications increase both the quality of the work of the drivers as well as the punctuality and efficiency of the system (Abbink et al., 2004).

When using Crew Management applications, the number or crews will be optimized, which is the same as saying it will be minimized. In bigger companies, employees' wages may represent more than 50% of company's total expenses, so even a small percentage of savings can be quite significant to the company's economic sector (Yunes, 2000). Also the number of backend staff is minimized because it is obviously easier to work with the help of appropriate scheduling and rostering software than doing all the work without it.

Other benefits are an easier calculation of the amounts to pay to each worker, which can be done with the help of the software mentioned before (according to the duration of shift assigned to each driver) and an optimized and fair distribution of work among all drivers (that can be complemented with hierarchies of seniority, for example).

3.3.3 Restrictions

Both the Crew Scheduling and Crew Rostering are restricted by a set of conditions, some of them defined by general labor rules and others defined by company specific policies. The restrictions for these problems are different from one to another, being the Crew Rostering problem the more constrained of the two.

The Crew Scheduling problem is constrained by a set of restrictions, based on national and local rules, like the maximum hours of work per day, minimum rest time in between shifts, or the minimum rest time per day (Wren and Rousseau, 1993). Other restrictions regard operational issues. For example, being (i,j) a consecutive set of trips, with i<j, we may have:

$$(start\ time)_i + (duration)_i \leq (start\ time)_j$$

$$(final\ depot)_i = (initial\ depot)_j$$

(Yunes et al., 1999)

The Crew Rostering problem is much more constrained than the Crew Scheduling problem. As it was said before, it has to take in account which days of the month are holidays, and which workers are on personal holidays or unable to work. The main set of restrictions may be found in Yunes' master's degree thesis:

- Minimum rest time between consecutive workdays;
- Every employee must have at least one day off per week;
- For every time window spanning 7 weeks, at least one of the days off must be on a Sunday;
- When an employee performs one or more split-shift duties during a week, his day off of that week must be Sunday;
- In every 24-hour period starting at midnight, within the whole planning horizon, each crew can start to work on at most one duty. (Yunes, 2000)

Most of these restrictions were also referred by Souza et al., on their article presented on the Panorama Nacional da Pesquisa em Transportes Conference (Souza et al., 2005). One should take in account that these are the restrictions for a specific case study. Some restrictions vary according to the company, the country, and other factors, so they are here presented as an example of what the restrictions may be.

3.3.4 Methods and Models

The development of methods and models for solving the crew scheduling and rostering problems is nothing new. Back in 1974, Baker presented a simple algorithm (requiring only hand calculations) to help on the scheduling of a full-time workforce meeting cyclic seven-day demand staffing requirements. The model assumed that each of the employees was entitled to two consecutive days off per week and had the objective of find the minimum staff size capable of meeting the problem objectives (Baker, 1974). The problem with this model is that it considers that each trip has the same weight, which usually does not happen. On a public transport system the equity between shifts must be promoted, since each driver normally has the same monthly wage.

On the model presented by Carraresi and Gallo in 1984, a weighting system for the trips is used to promote the equity mentioned on the last paragraph. A weight is assigned to each journey, which represents a cost measure of the journey for the driver. This weight may be determined based on the duration of the journey, its attractiveness, the time spent by the drivers from the depot to the journey starting point, among other factors. The objective of the model is finding a solution that minimizes the sum of the weights referring to the journeys attributed to the worst case scenario crew (Carraresi and Gallo, 1984). The problem of this model is that the days off are fixed to take place on the weekend, not considering Saturdays, Sundays and holidays as working days, which obviously is not the reality of public transport.

Later in 1992, Bianco et al. proposed a model to deal with the problem of planning work schedules in a given time horizon, with consideration of an even distribution of workload among the drivers in a mass public transport system. The formulation of the problem is done with an integer programming model and a heuristic algorithm is described, using a lower bound derived from the mathematical formulation to reduce the dimension of the problem. At each iteration, the algorithm solves a multilevel bottleneck assignment problem for which a new procedure that gives asymptotically optimal solutions is proposed (Bianco et al., 1992).

The crew scheduling and rostering problems were approached by Yunes by using mathematical programming and restrictions programming techniques. For the crew scheduling problem, a hybrid column generation model using both of the techniques was developed. As for the crew rostering problem, two methodologies were used. First, it was modeled as an integer linear programming problem and solved with the branch and bound technique, which can only be applied on small scale problems. The second methodology was based on restrictions programming and proved to be better than the first one (Yunes, 2000).

In 2005, Souza et al. presented an evaluation function to assess previously obtained monthly work schedules (solutions of the crew rostering problem) that can be expressed by the following:

$$FO(s) = F_{RE} + F_{RNE}$$

Both terms of the equation (F_{RE} and F_{RNE}) are also functions, being the first one responsible for evaluating the non-verification of the essential requisites of the crew rostering problem and the second one responsible for evaluating the non-verification of the non-essential requisites of the same problem. Because of the formulation of F_{RE} and F_{RNE}, the lower FO is, the better the monthly working schedule will be.

3.3.5 Examples of application

There is a wide range of situations that are likely to use one of the above mentioned methods for the scheduling of vehicles and crew, from air to road transport and from private to public companies, for the reasons already referred. On this section of the work some examples will be briefly presented, just for a more complete review on this issue's state of the art.

Beasley and Cao approach the crew scheduling problem in a generic way, with an algorithm independent of the particularities of a specific industry. The problem is to assign K crews to N tasks (with K<N). The tasks have fixed start and finish times such that each crew does not work more than the limit total time it can spend working. To solve the problem to optimality, a tree search procedure was used (Beasley and Cao, 1996).

On the air transport side, the airline crew scheduling problem (CSP) is one of the most difficult combinatorial problems known. Guo et al. present a partially integrated airline crew scheduling approach, with time dependent crew capacities and multiple home bases. Due to its complexity, the CSP problem is divided on two sub-problems, the crew pairing problem (CPP) and the crew assignment problem (CAP). The second one takes in account other scheduled activities, training, vacations, and requested off-duty periods. The airline crew scheduling is defined on the paper: "*given an airline's timetable and aircraft rotations, the task of crew scheduling is to assign work schedules to individual crew members during a given planning horizon in such a way that each flight of the timetable is serviced once and total expenses are minimized*" (Guo et al., 2006, p. 1171). The costs considered in this model are overnight expenses of crews, compensation for time that crew spends outside their home domicile, costs for proceeding crews, and pay and credit cost. Computational results with real-life data from a European airline are presented.

Regarding the scheduling of vehicles and crews for a bus company, Rodrigues, de Souza, and Moura presented a computational tool developed to solve the urban transportation problem in the large metropolitan area of São Paulo, Brazil, based on integer programming models coupled with heuristics. This hybrid strategy was able to produce quite adequate solutions, in a fraction of the time that experts take to construct manual solutions. Also, the operational cost of the automatic solution showed considerable gains over the manual ones. Besides the specific operational and labor restrictions for the city of São Paulo, the same ideas may inspire similar approaches for solving the urban transportation problem arising in other metropolitan areas (Rodrigues, de Souza, and Moura, 2006).

4 PERFORMANCE ASSESSMENT

4.1 IMPORTANCE OF ASSESSMENT ON ITS PROJECTS

The introduction of Intelligent Transportation Systems on the surface transportation system raised some concern and confusion among transportation planners, policymakers, and professionals in what comes to their evaluation (Gillen and Levinson, 2004). The problem with ITS evaluation is that it represents a technological change that cannot be assessed solely as a capacity addition. While ITS allows to do old things in a more effective, more secure and faster way, it also allows new things to be done.

As ITS move into deployment, the advantages of carrying out comprehensive impact and performance assessment are significant, since such assessments can validate initial assumptions and provide data to influence future deployment, both locally and within the ITS community more generally (Stevens, 2004).

ITS projects often represent a substancial expenditure of public funds and policymakers should ensure that they are getting the most out of their investment. Evaluation of ITS provides those who have to make the decision about whether to undertake the project or choose between competing projects with valuable information on the differences in their correspondent benefits. On the other hand, besides benefits ITS projects will also have negative consequences. The decision-maker may use the assessment of ITS projects to determine the appropriate design that maximizes the positive impacts and minimizes the negative ones. One of the main advantages of evaluating ITS is that it minimizes the risk of project failure through unmet objectives.

Alan Stevens reinforces this idea that an analysis and evaluation of the whole ITS system is crucial for its better understanding and management. In fact, the need of evaluation is very important for a better application and deployment of these systems, since they deal with substantial investments as referred on the previous paragraph. One can read that "*these projects need sound methods of evaluation and assessment to guide the choice of technology and the allocation of scarce resources*" and also that "*ITS are often the most cost effective method of improving a network and in some cases can bring very quick returns on investment*" (Stevens, 2004, p. 91-92).

According to Chowdhury and Sadek (2003), there are three main types of evaluation, according to when they take place: pre-deployment evaluation (at the planning level), deployment tracking, and impact assessment. The evaluation of an ITS system can start as early as the planning stage, where competing projects are prioritized and selected based on available resources. Once the project is operational, a system assessment or evaluation will be required, which will help on determining whether the system is performing as envisioned during the planning stage or not. On a study that crossed expert and practitioner views on innovation performance measurement (Birchall and Tovstiga, 2006), the conclusions pointed out that both practitioners and academic experts attach moderate importance to this measurement for early warning and less importance to ongoing information to stakeholders. On the other hand, academic experts saw after-the-fact measurement as the primary reason, whereas practitioners attached more importance to ongoing purposes.

When the project is already in operation, two types of evaluation can be conducted. The first one is an inventory of the system that is deployed, which is called "deployment tracking" and assesses the actual deployment level in relation to the plan. The other type of evaluation is an assessment of the changes in impacts, such as travel time and crash rates, of selected attributes in relation to the pre-deployment conditions. In other words, this second type of evaluation is a summary of the main differences between a scenario with and without the ITS. This second analysis is called Performance Assessment.

Performance Assessment refers to a process of monitoring and analyzing how well organizations (or systems) perform with regard to their intended objectives. It must be carefully structured to accurately reflect objectives and it is important because it provides useful guidance for planning and management decisions. Inappropriate or incomplete evaluation can misdiagnose problems and result in bad decisions (Litman, 2009).

4.2 MEASURING PERFORMANCE

"*An effective health maintenance program includes regular checkups to monitor patients' fitness and medical conditions in order to help identify, prevent and manage problems. (…) Similarly, organizations (including businesses, agencies, and governments), need ongoing performance evaluation to identify potential problems and optimize productivity. Just as physicians track factors suck as diet, body weight, blood pressure and lung capacity, good managers track various factors to monitor organizational fitness and health*" (Litman, 2009, p. 1)

While innovating, many challenges are presented to organizations, being one of the hardest its measurement. The saying "If you can't measure it you can't manage it" cited by a handful of authors emphasizes the importance of performance assessment to enable effective management. However, there is not an overall agreement in the literature found about a framework for the measurement of performance. In fact, a variety of approaches have been advocated which have different philosophical stances and organizational purposes and hence different practical impact (Birchall and Tovstiga, 2006).

In order to manage their present and their future, organizations need information on how successfully their different sectors are performing individually and as a whole. When gathered and grouped in well defined groups, in order to reflect certain performance characteristics of each management level of the organization, these informations form a performance assessment system. Sink and Turtle (1993), as well as Kaplan and Norton (2000), compare performance assessment systems to an airplane cockpit, which transmits information on the plane performance so that problems may be detected as early as possible, allowing a more aware decision making to achieve its destination.

For Sink and Turtle (1993), there are seven dimensions of performance for operational systems:

- Effectiveness: indicates if the objective of the activity in analysis is reached;
- Efficiency: indicates if the objectives are reached at a minimal cost;
- Quality: indicates how well the product or service fits the needs and expectations;
- Productivity: the relation between the value generated by the process and the value of work and capital consumed;
- Quality of life on the job: represents the reaction of people in the company to the system in factors like remuneration, conditions of work, culture, leadership and others;
- Innovation: creative process of changing processes and results with success, which is considered necessary to survive, compete, grow and reach the desired results;
- Profitability/Budgeting: profitability is the relation between costs and profits, while the budgeting is the relation between budgets, goals and agreed deadlines with costs, fulfillment and actual deadlines.

The main components of a performance assessment are the performance indicators, or as they are known, key performance indicators (KPI's) (some authors also address them as key success indicators). These are quantifiable measurements that reflect the critical success factors of an organization and help it in defining and measuring progress toward organizational objectives.

KPI's vary according to the kind of organization they characterize; for instance, a business may have a KPI as the annual sales volume, while KPI's of a social service organization may have to do more with the number of people helped out. Moreover, colleges may have number of students graduating per year as one of their KPI's. Whatever key performance indicators are selected, these must reflect the organization's objectives, being the key to its success, and they must be quantifiable (measurable).

Key performance indicators should preferably meet the following essential criteria: be direct (no complex calculations), be objective, be adequate, be quantitative, be practical, and be reliable. When determining the key performance indicators of a project, a meeting during the planning phase of the project should be done for this purpose, involving the following steps:

- Carefull consideration of the results desired;
- Developing a lot of possible indicators during a short brain storming session;
- Assessing each indicator with the above criteria (be direct, be objective, …);
- Selection of the best performance indicators.

Litman (2009) reffered that the Federal Highway Administration (FHWA, 2000) and the Centre for Sustainable Transportation (CST, 2003) pointed out that good performance indicators reflect, among others, the following principles:

- Include various goals and perspectives;
- Effectively indicate how well goals and ojectives are being met;
- Are clearly defined;
- Are simple, understandable, logical, and repeatable;
- Are suitable for trend and comparative analysis;
- Are accessible, understandable and useful to decision-makers and other stakeholders.

Litman also indicated that there are three general types of performance indicators, namely *Service Quality* (which reflect the quality of service experienced by users), *Outcomes* (which reflect outcomes and outputs), and *Cost Efficiency* (that reflect the ratio of inputs, or costs, to outputs, or desired benefits).

Usually, KPI's are long term considerations and the definition of what they are and how they are measured do not change often. However, the goals for a particular KPI may change as the organization's objectives change, or as it gets closer to achieving a goal. Considerations regarding how a KPI is to be measured should be established in advance. Definitions as to exactly how the indicator is to be calculated and wheter it is to be measured in monetary amounts or units should also be specified. Also, it is imperative that the organization sticks to these definitions from year to year so that annual comparisons are possible.

Different sections of an organization must have different KPI's that converge to the overall KPI's of the organization. It is needless to say that to achieve a particular target level of Key Performance Indicator for a company, every department has to work in synergy towards it. For this purpose, the definition of respective KPI's for each section that work towards the overall KPI's of the organization is crucial.

However, one shall not drown managers with indicators. Sometimes, when the number of indicators is too high contradictions may happen, so managers end up with a zero sum game and measurement is useless. The establishment of the relationship between performance and measures is also problematic, since choosing the right set of measures is also a small part of boosting innovation performance (Birchall and Tovstiga, 2006).

Resuming, performance indicators must be carefully selected to accurately reflect objectives and identify problems. Inappropriate or incomplete indicators can misdiagnose problems and misdirect decision-makers. For example, an index that only considers quantity will encourage organizations to produce abundant but inferior output, while an index that only considers quality can result in high quality but inadequate production quantity (Litman, 2009).

4.2.1 Benefits of measuring performance

The measurement of performance has benefits for various entities, from the company to the potential user. Some benefits of measuring performance were named by Pezerico (2002) on his master thesis:

- User satisfaction, through the identification of which user requirements are being satisfied;
- Monitoring of processes, identifying existing problems and allowing the improvement of processes in the organization;
- Assuring that decisions are based on facts and not on emotions;
- Determine if improvements are taking place, encouraging processes of improvement and change;
- Communicates to the organization members if customer and processes requirements are being satisfied.

4.2.2 Some approaches to the performance measurement problem

Over the years, there have been no proper system and procedures to address the question of overall efficiency within an organization unit or between organizations or sectors. A number of performance measures were used in the public sector, with the most prominent being the centrally evaluated set of cost-weighted activity indices. Birchall and Tovstiga (2006) support this idea, saying that there is no overall agreement in the literature about a framework for measurement. While searching for literature regarding the performance measurement problem, some different approaches were found.

According to Sink and Turtle (1993), the performance measurement process consists on defining what to measure, collect, process and evaluate the data collected in order to know and characterize the results of an organization. According to the model proposed by these authors, the performance of a system is function of a complex inter-relation between the seven dimensions of performance referred by Sink and Turtle (1993): effectiveness, efficiency, quality, productivity, quality of life on the job, innovation, and profitability/budgeting.

For Moreira (1996), the definition of a performance measuring system starts at understanding the mission of the organization, followed by the identification of strategies and critical factors to reach this mission. The last step is the creation of measures of quantification for these factors. For the author, the basic objective of performance measuring is telling the organization if they are heading the right way to achieve the objectives pretended. The performance measurement should supply a reliable support basis for the strategy of the organization, allowing work classification on six different groups of indicators:

- Resource utilization;
- Quality, emphasizing the processes;
- Time, divided on delivering time and development time;
- Flexibility, focused on reaction capacity and adaption to changes;
- Productivity;
- Inovation capacity (Adapted from Pezerico, 2002, based on Moreira, 1996).

Kaplan and Norton (2000) developed the Balanced Scorecard (BSC), which is a performance measuring system that tries to balance financial factors putting strategy and vision on the center of the system, translating them into objectives and tangible measures contemplating four perspectives:

- The financial perspective;
- The client perspective;
- The processes perspective;
- The learning and growth perspective.

Another widely used technique to address performance assessment is the well known Data Envelopment Analysis (DEA). This is a non-parametric approach to efficiency measurement that allows the comparison of diverse factors (that can be or not KPIs) and provides a summary measure of performance for an organization. Taking in account the special circumstances faced by public agencies, this mathematical programming technique is particularly suited for the assessment of public sector performance. The technique is able to compare the efficiency of multiple service units that provide similar services by only considering their use of multiple inputs (i.e. resources) to produce multiple outputs (i.e. services). Also, DEA does not require the conversion of these inputs and outputs to a common monetary unit, which enables the introduction of factors that are harder to put against a price. The programming model attempts to maximize a service unit’s efficiency by comparing it to the performance of a group of similar service units that are delivering the same service (Husain, Abdullah and Kuman, 2000).

Nakanishi and Falcocchio (2004) pointed out five advantages of using DEA, namely:

- *Provision of a summary measure of performance* – there is no need for analysts and decision-makers to review numerous and possibly conflicting indicators;
- *Elimination of Peer Grouping* – DEA can take into account “background conditions” such as demographic characteristics;
- *Use of dimensionless variables* – there is no need to convert the various units for input and output variables into a common unit, since DEA is a non-parametric approach. Also, it is not necessary to know the form of the production function;
- *Comparison of individual agencies to best-practice agencies* – unlike regression analysis which compares each agency to the average agency, DEA compares each agency to the best-practice agency;
- *Time-series analysis is possible* – a technique that incorporates all time periods into the analysis allows comparisons of performance in year x against agency’s performance in year y.

Along with these advantages, the same authors also presented some of the shortcomings of DEA. Due to the non-parametric nature of this technique, statistical analysis and hypothesis testing are not possible and, consequently, confidence levels and error rates are impossible to determine. Also, there is the need for researchers to be experts in their study area or have information that will assist them in selecting the appropriate weights for input variables, because these weights are selected based on the best judgemet of researchers. Finally, the scores generated by this technique are based on comparisons with best practice agencies on the same area of study. If all of these agencies happen to be weak performers, then the comparison will not be close to the optimal performance for that area (Nakanishi and Falcocchio, 2004).

There are four basic DEA models, presented below on Table 4.1. The model choice depends on a variety of factors, being the more important the type of envelopment surface (which can be either constant or variable returns-to-scale) and the projection path leading to the envelopment surface (which is analogous to the orientation type).

Table 4.1 – Basic DEA Models (adapted from Nakanishi and Falcocchio, 2004)

Model	Year	Description
Charnes, Cooper and Rhodes model	**1978**	Established DEA as a mathematical programming process, useful for measuring the efficiency of decision-making units. Constrains returns-to-scale alternatives to constant returns-to-scale, which may not be realistic in many industries.
Banker, Charnes and Cooper model	**1984**	Adjusted the dual program to allow for variable returns-to-scale. Optimization is done through a two-stage process: (1) maximal reduction of inputs, and (2) movement toward the efficient frontier using slack variables.
Multiplicative model (Charnes et al.)	**1982**	Incorporates the logarithmic values of output and input data (log(X), log(Y)). Constructs an envelopment that is either piecewise log-linear (called the variant multiplicative model, which has constant returns-to-scale) or piecewise Cobb-Douglas (called the invariant multiplicative model, which has variable returns-to-scale), unlike the other DEA models which are piecewise linear.
Additive model (Charnes et al.)	**1985**	The primal program's convexity constraint causes the model to have variable returns-to-scale

4.3 MEASURING PERFORMANCE ON PUBLIC TRANSPORT SYSTEMS

In recent years the paradigm for public transport agencies around the world has changed from the provision of service to the improvement of the quality of service, profit making and competition. This happened because governments privatized transportation services in urban areas in order to control costs and reduce the need for public assistance. Therefore, as public agencies are pushed to offer their services under severe operating conditions, characterized by the decrease in financial assistance from the government and reduced ridership, it is necessary that these agencies use their resources in the most efficient way (Sheth et al., 2007).

When it comes to the aspects of performance of road transport, the bottom line indicator for both freight and passenger transport is the operating cost per tonne or tonne-km or per passenger or passenger-km, respectively. However, not only the costs are important. Level of service aspects such as travel time, reliability, safety, comfort and security are also important, as well as environmental impacts. When trying to assess the performance of road transport the challenge is to find reliable ways to measure costs and level of service indicators described above (*MRPT*, 2011).

Performance improvement on public transport systems has always been one of the major objectives, if not the principal one, of the industry. The measurement of performance on a public transport system has different areas of application, both on the point of view of the efficient use of resources as well as in terms of providing effective services. However, the literature available for performance assessment for public transport companies is mainly focused on efficiency and effectiveness measures, or Fielding's (1987) three dimensions of public transport performance, namely, cost/production efficiency, service effectiveness, and cost/operation effectiveness. The lack of published research combining these three dimensions into a single model places a limit on the understanding of multi-activity production and consumption processes (Yu and Fan, 2009).

To assess public transport systems performance and productivity, many authors used indicators separated in three categories: efficiency, effectiveness, and overall indicators. Other authors examined the effects of subsidies on the performance and productivity of public transport systems through the use of performance indicators. The problem is that some of these authors used such a large variety of performance indicators that in the end did not yield consistent results and a generalization of the findings could not be made. This leads to the conclusion that a single indicator, or a smaller group of reliable and well chosen indicators, is needed to describe public transport systems performance, contrarily to what Stokes (1979) stated when he said that no single indicator of performance can reveal the relative performance of a public transport system (Karlaftis, 2004).

For the performance assessment of a public transport system to be done, one needs to define inputs and outputs of the system. As for inputs, public transport systems usually use three input quantities, namely labor, fuel, and capital to produce output. Labor can be measured as the total number of employees (operators, maintenance, and administrative personnel); Fuel is measured as the total amount of fuel used by the system on a determined period of evaluation; and Capital may be the total number of vehicles operated by the system (Karlaftis, 2004).

The outputs are a little bit more difficult to define. As opposed to other industries where outputs are clearly identifiable entities, the output of a public transport company can be quantified in different ways. The main reason for this difference is the fact that the output of a public transport system is not able to be stored for future use. If a bus runs at half capacity, the remaining seats can not be stored for a future scenario where the bus is at full capacity; once they are lost they are lost forever. This lead to two separate measures of public transport output: vehicle-miles (often referred to as "produced output type") and passenger-miles or passenger boardings (often referred to as "consumed output type"). The first is usually related to service efficiency, while the second one often is related to effectiveness (Karlaftis, 2004).

Sheth et al. (2007) referred an important issue when they said that while measuring the service performance along a public transport network it is necessary to include both the provider's and the consumer's points of view. The reason is that both of these entities define "efficient" service along a route in a different, if not contrasting manner. For the provider an efficient service is the one where the public transport agency will provide adequate service at the least cost, while for the consumer is the one where most quality attributes such as the shortest travel time, highest frequency, or the highest level of seating comfort are verified.

Bus utilization is one of the stronger aspects that influence the balance between fixed and variable costs of a bus public transport company and gives an important indication of overall efficiency. The three main factors that may affect the performance of bus utilization are referred in *Measuring Road Transport Performance* (*MRPT*, 2011):

- Poor roads which may limit speeds;
- Unreliable buses which break down often;
- Lack of efficient scheduling using more than one driver when justified.

It is important to refer that the utilization depends of the scheduling technique: if the bus operates a timetabled service it is likely to achieve a higher distance operated than if it is dispatched only when full after waiting in a queue of buses. This latter form of operation is usually applied on developing countries and can lead to very low utilization, even though average loads can be higher, nearly 100% in many cases compared to about 60%-70% for timetabled services (*MRPT*, 2011).

One of the main areas of performance assessment of public transport agencies is the study of bus lines. According to Brochado et al. (2009), the continuous and rigorous performance assessment of bus lines allows the implementation of supply adjustments according to variations on the demand side, as well as the estimation of the motivations that led to the observed variations.

When measuring the overall performance of a bus system, level of service features should also be included on the evaluation, both qualitative and quantitative measures. As for the quantitative measures, one can refer the following:

- Passenger travel times, including walking and waiting times;
- Predictability of departure and arrival times;
- The rate of bus breakdowns;
- Availability of special features such as comfortable chairs, air conditioning, toilets, videos/music, etc.;
- Passenger facilities at bus stations (MRPT, 2011).

Besides these, there are qualitative aspects of level of service which are more difficult to quantify or to include in the acessment framework. From the passenger's point of view, cleanliness or availability of timetable information are important factors and should be included on the overall performance assessment. According to *Measuring Road Transport Performance* (*MRPT*, 2011), these aspects can be assessed using survey techiniques designed to reveal how passengers make choices, or rank in importance one aspect of service from another.

The two main approaches for assessing the performance of public transport systems (and other transportation systems) are using existing information, and/or carrying out surveys. In developing countries, using existing information may be a problem because the data available to measure performance is unreliable or inexistent. In many of these countries the number of vehicles is not known accurately, there are errors in recording vehicle characteristics, and there are poor database systems. When the approach to consider is the second one (surveys), the following types can be considered: a) roadside counts and interviews; b) interviews of hauliers, consignors and freight forwarders; c) analysis of operating records; d) interviews of informal drivers/operators in operational centers; and e) analysis of past records of transport data (*MRPT*, 2011).

4.3.1 Measuring performance of crew management systems

Performance assessment of the public transport is divided into efficiency (do things right) and effectiveness (do the right things) components (Yu and Fan, 2009). When measuring the performance of crew management systems (and in particular measuring performance of the crew rostering problem application, which is the scope of this dissertation), we are focusing on the first part of what was said before – do things right. Assuming that the right things are being done (covering all the demand with the right amount of buses, at the right time of the day, etc.), the efficiency will be measured in terms of resource management (in this case, drivers). The main criteria in the scheduling process of drivers are feasibility, efficiency and acceptability (Kroon, et. al., 2004), so it is adjusted if a performance assessment of schedules is also focused on these terms.

Feasibility means that it should be possible to carry out the schedules in practice, and that they are sufficiently robust for outside disruptions and for delays of buses. Key parameters here are the minimum connection time when changing from one bus to another, and the minimum number of bus changes per duty, if that happens. Of course, if a driver stays at the same bus and on the same line through the whole duty, these parameters are not meaningful.

Efficiency means that the percentage of productive time in the duties is high. In other words, an efficient schedule is one that minimizes non-productive times, which include the meal-break (but giving it enough time to happen), the required pre-time and post-time at the start and the end of a duty, and also the gaps between trips.

Acceptability is related with the qualitative aspect of the schedule, referring to the probability that the obtained schedule is accepted by the drivers. Acceptability may be related with the level of variation of the duties, with the balance of work times, or with respect of minimum rest times in between work shifts.

The crew management core business areas may be divided in three categories, namely Crew Operations, Crew Administration, and Crew Planning, as it is shown on Table 4.2.

Table 4.2 – Crew Management Core Business Areas (adapted from m2p Consulting, 2009)

Crew Operations	Crew Administration	Crew Planning
- Check bus status	- Crew Recruitment	- Manpower planning
- Prepare bus for operation	- Crew Training	- Crew Scheduling
- Deliver service	- Crew Record	- Crew Rostering
- …	- Payroll	- Roster Maintenance
	- …	- …

The constant struggle to make every journey optimal forces Crew Management to balance successfully various drivers and constraints. Some of them are listed on the diagram presented on Figure 4.1.

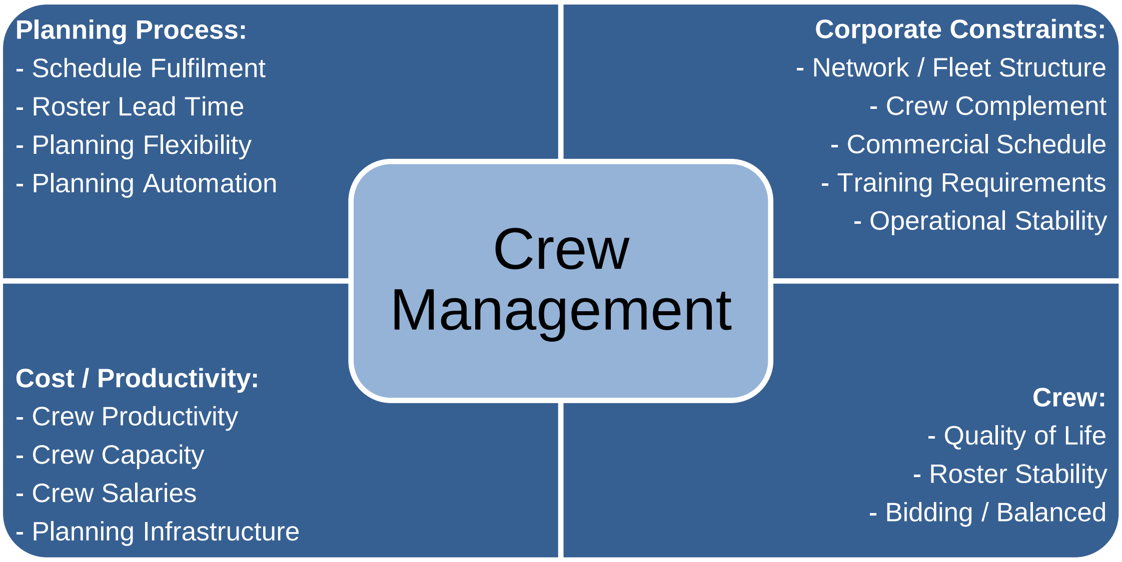

Figure 4.1 – Crew Management drivers and constraints (adapted m2p Consulting, 2009)

From the research made, no results were found for performance assessment methodologies for crew rostering or crew scheduling systems. Performance assessment is usually made to assess the performance of the whole public transport system and not only the assessment of a section of it, as the crew scheduling and rostering. However, since the scope of this dissertation is the assessment of the ITS used to perform the crew rostering of a bus network, a methodology to assess only the crew rostering is needed.

5 CASE STUDY CHARACTERISTICS AND METHODOLOGY

5.1 CARRIS

Carris is a large scale public transport company that operates buses, trams, and elevators in the area of Lisbon, the capital of Portugal. In this section it will be presented first a brief history of the company, followed by a description of ITS systems used in their network (with special attention to the crew rostering system). Finally, the performance assessment of the crew rostering system will be done, comparing the schedules before and after the introduction of OPT software.

5.1.1 History

Carris is a centenary public transport company that was founded in September 1872, in Lisbon, being associated with the whole development of the city transportation system. At first the company was called “Carris de Ferro de Lisboa”, which means “Railways of Lisbon”, because as it will be explained next the company worked only modes of transport by rail back then.

The first mode of transport operated by the company was the “Americanos” in 1873, which were small cars on rail pulled by horses, as it can be seen on Figure 5.1. The initial impact was extremely positive and Carris had to increase the fleet (and also the number of horses needed to work the “Americanos”), which lead to a need for acquiring new properties for installations.

Figure 5.1 – Carris “Americanos” in operation at Lisbon

Although Carris has started its activity with animal powered vehicles, the replacement for a more efficient and reliable system was soon considered. A search for information on steam locomotives used for urban public transport system started in 1877, which some years later lead to the implementation of temporary lines using this mode of transport. However, steam powered locomotives were not the only new systems found and other studies and experiences were made on the following years. In 1900, the process of implementation of the new system started with the new rails settlement and the construction of an electricity factory capable of providing the energy needed to its normal functioning. The first power-driven line was inaugurated in August 1901 and in four years the whole network was electrified and the “Americanos” ran out of business.

Later in 1944 the bus network was inaugurated, but only a few years later (in the 60s) it brought major changes to the overall picture of Lisbon mass public transport system. Carris started replacing trams for buses because of two principal factors, the increasing use of private transport and the opening of the underground network, not needing to continue working with trams on some areas of the city.

The adoption of buses was fast and in 1974 Carris already had to buy 200 new vehicles. Also the station that existed (Amoreiras) was not capable of meeting the capacity needs, so the three stations that are still opened today, Pontinha, Musgueira and Miraflores were inaugurated in 1975, 1981 and 1983, respectively.

More recently, in the 90s there were new types of buses brought into service (standard, articulated and mini-buses) and also a renewed interest in the tram network, which led to the acquisition of new ones. They still run on the original lines, but combine up to date electro-mechanical equipment with higher levels of comfort and passenger-carrying capacity (Figure 5.2).

Figure 5.2 – New trams that started operating in the 90s

Between 2004 and 2005 a new renovation on the bus fleet took place, being acquired a total of more than 300 vehicles, which allowed a reduction of the average age of the fleet to 7.4 years.

This also meant a significant fall in pollutant emissions and also a great impact on safety and comfort for users, on operational procedures and on maintenance costs, since the new buses were equipped with a series of innovations on these fields.

In 2006, Carris got a quality certification given by APCER, the Portuguese association for certifications, which means that since then the company has the commitment of respecting the norm requirements and improving continuously its system's efficiency. The attribution of this certificate was the result of a strategic decision that elected the "continuous improvement of quality offer" as one of Carris main purposes. Table 5.1 shows the objectives defined on the strategic plan and the commitments to customers that were adopted when the quality certification took place.

Also in 2006, Carris signed the Charter on Sustainable Development, which was in the line of its sustainable policy, and published its Code of Ethics and Conduct, which is a fundamental reference to enterprise performance, professional practice of employees and social, institutional and environmental relationship.

Until the present date, Carris continues its effort on fleet renovation, acquiring new and more environment friendly vehicles frequently, signing and taking part on initiatives that promote safety (signing of the European Road Safety Charter in 2007) and sustainable development (joining the Business Council for Sustainable Development also in 2007). Recently, in 2008, the company got 64,6% on a customer satisfaction study, which shows that the majority of the passengers is satisfied with the service provided (CARRIS, 2011).

5.1.2 ITS at Carris

As it can be understood from the last section, Carris is constantly seeking for improvements and ways to work in a better, more efficient and safer environment. The pursuit for these goals is usually complemented and achieved with the use of new technologies, which include the use of ITS.

From practical use of the company's network and from a meeting with Carris members, Mr. Carlos Figueiredo (Logistics Director) and Mr. José Maia (Co-Ordinator of the Planning and Operation Control Unit), some ITS systems used by the company were identified.

On the user side, there are a series of information providing systems to allow a better use of the network. For example, some bus stops are equipped with dynamic message signals that show the time until the next bus arrival, allowing a better management of users' waiting time. This service is also available by SMS and the user receives information regarding the bus he wants to catch on his cell phone, not requiring presence at the bus stop. Both these systems take advantage of GPS devices that are installed on every Carris bus, that provide their exact location and allow an estimative of the expected arrival time at each bus stop of their journey. This is also used to inform the driver if he is ahead or delayed in order to comply with predicted timetables.

Table 5.1 – Carris quality certification in 2006

Quality Certification	
Objectives Defined	• To contribute for Transport System improvement in Metropolitan Area of Lisbon, ensuring customers mobility, according to their needs and expectations; • To increase the efficiency of the Mass Public Transport Service, adjusting supply to demand and rationalizing resources and methods; • To accomplish their requirements and commitments assumed in Carta do Cliente, in order to gain customer trust on the service; • To gradually increase the customer satisfaction level, measured by regular evaluation enquiries; • To improve the service quality, based on major regularity, reliability, comfort and safety of the transport, investing in new information technologies, renewing and modernizing the fleet and giving formation to Human Resources.
Commitments to Customers	• To develop its network, so that on every point of the city there is a bus stop at an acceptable distance; • To define schedules adapted to the demand, undertaking corrective measures whenever necessary; • To make available correct and simple information; • To promote actions that ensure customers safety; • To adopt measures that ensure a regular service, in coordination with other entities; • To expand the Sales Network to make it easier for the customer to get transport titles; • To keep the vehicles clean and safe; • To ensure the quality of company human resources; • To accomplish legal requirements about pollutant emissions, in order to protect the environment; • To evaluate regularly, by query, the customer satisfaction level; • To pay attention to customers complaints and suggestions as an information source to improve the service.

Carris website also has a variety of information to display, including a user friendly trip planning application. By simply introducing the origin and destination points on the network, the application shows all the buses performing the required journey, along with their timetables. Prices of tickets, a map of the network, information regarding waiting times, points of ticket selling and other information are also provided at the company's website (CARRIS, 2011).

The ticketing system used by Carris also takes advantage of ITS systems. Pre-paid tickets are available on form of electronic payment rechargeable cards, which can be charged either with an amount of single trips or with money that is debited as the user travels. If the user chooses to buy the ticket on board, the driver also sells tickets with the help of an electronic ticketing machine that calculates the value of the trip according to the entry and exit points. This system also records all ticket sales done and transmits it to the central, allowing a better management of the ticketing system.

On the operations side, the company uses ITS systems for a better management of vehicles and crew, which includes a Crew Rostering system that will be better explained on the next section, since it is in fact the main topic of this dissertation.

Besides the mentioned systems some more were identified, like for example the security system. Most of the company's buses are equipped with video cameras that are used to identify possible situations where help is needed in a faster way, providing a top quality security system. Another ITS system used by Carris is a system that registers each driver driving skills, which can be used to assign more skilled drivers to more difficult journeys.

5.2 CREW MANAGEMENT AT CARRIS

The whole process of schedule generation at Carris starts with the creation of a series of necessary journeys to cover the demand for the area of Lisbon. Then, with the schedule of journeys already determined, vehicles are allocated to the journeys and only after that the crew scheduling and rostering takes place.

Part of the crew management in Carris is done with the help of a system called GIST (Gestão Integrada de Sistemas de Transportes, which can be translated to English as Transport Systems Integrated Management) developed by the company OPT – Optimização e Planeamento de Transportes, S.A. This company was created in 1992 and is a pioneer Portuguese company in what comes to I&D projects development applied to public transport, developing informatic solutions to the optimization and management of transport systems. OPT is responsible for the installation, implementation, maintenance and actualization of all modules of the GIST system (OPT, 2011).

According to the company's website, "*The GIST system is an integrated decision support system for operational planning, addressing the following processes: network information management, route information management, timetabling management, vehicle scheduling, crew scheduling and crew rostering*" (OPT, 2011).

One of the more important parts of the GIST system is the Crew Scheduling module, which assigns drivers or crews to vehicles for each type of day (workdays, Saturdays and Sundays/Holidays). This module integrates the vehicle schedules previously defined and takes in account a large set of rules and constraints to define daily drivers' duties using optimization algorithms and heuristics, all in user oriented interface design.

The Crew Rostering module helps on the construction of long-period schedules using the set of tasks provided by the Crew Scheduling module. The daily assignment of drivers takes in consideration historical information and crew availability, enabling real time changes required by operation. This module is divided in three main sections: i) Management of Drivers' Availability, ii) Pre-Scaling, and iii) Scale Generation, which are followed by a Pos-Scaling phase.

On the first section, information about drivers' availability is introduced, including situations that may occur without any prediction (illness, for example). It is possible to check drivers' status along time, allowing the determination of the number of drivers available on a specific moment, the number of worked hours for each driver, etc. This provides effective decision tools for the manager regarding for example information on when each driver may have holiday periods.

The Pre-Scaling module is the section where the long term scales are made. The process is done regarding a homogeneous amount of work amongst all drivers, either in terms of work time equity or in terms of difficulty of the work.

On the Scale Generation phase, some last minute changes may be applied to the scales generated for specific situations, for example, information included on the first module (illness of drivers).

The Pos-Scaling phase creates a record of changes on the scale made along the day, which allows a comparison between the work that was predicted and the work that was really done. This information is also exported to other applications that are not part of the GIST system, for example to a wage calculation application that calculates the wage of each driver according to the work load he had that month.

At Carris, the crew scheduling is divided in two distinct parts: the scheduling of effective drivers (Effectives) and the scheduling of extra drivers (Supras). The process is presented on Figure 5.3.

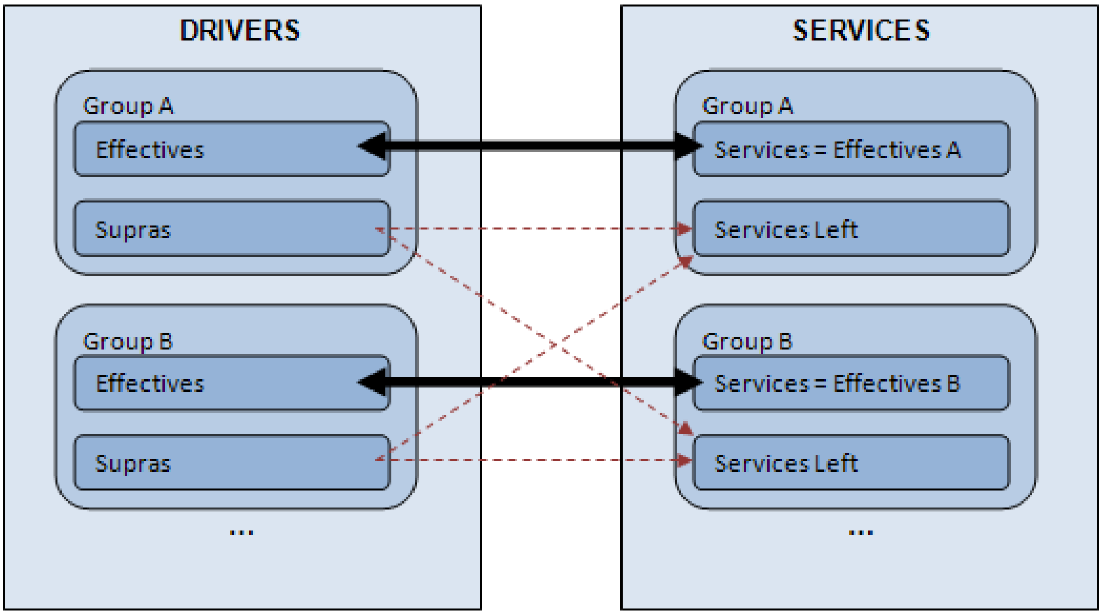

Figure 5.3 – Crew Management at Carris

The drivers are divided in groups, as well as the services that must be performed. When the month schedule is done, effectives from group A and services from group A are grouped together, so these drivers always have similar work schedules along the months, if not always the same working schedule. For some reason, the services on a determinate group may not be sufficient to all the drivers of that group, resulting on drivers without a service for that month (Supras). On the other hand, the contrary may happen as well, a determinate group not having sufficient drivers to perform all the services of the correspondent group, resulting on services without an assigned driver.

It is to this particular group of drivers left without service and services left without driver that the OPT Crew Rostering system is applied, assigning drivers to services according to a defined sequential set of conditions and restrictions, rules and preferences of drivers, for example for a determinate route, for work shifts, among others.

The main rules in terms of scheduling and rostering of crews at Carris that have a connection to this work, and consequently will be used on the case study, are the following:

- The minimum rest time in between consecutive days of work is 11 hours;
- A driver cannot work more than 6 consecutive days without a day off;
- The maximum number of work hours per day is 9 hours;
- All drivers must have at least one Sunday off from 5 to 5 weeks.

There should be uniformity on the crew rostering construction so that there is a low deviation between the monthly hours of work for a specific driver and the average monthly hours worked by all drivers. For that reason, the software tries to balance the mean working times by ordering the drivers by mean working hours on the last 120 days when assigning them to monthly schedules.

Besides taking in account the restrictions above mentioned, the crew rostering application also tries to attend the preferences of Supras in terms of working periods, even though this is not an objective of the crew rostering. However, when possible, it is better that drivers are working at their favourite period of time because it improves their motivation to work better. These preferences regarding working periods must be standardized and so, there are four different groups of schedules, which englobe six different working periods, classified according to start and ending times. As it was said on Chapter 4, drivers may choose to provide their preferences or not, but if they choose to do so, they must determine a sequential order of 3 of the 4 available groups shown on Table 5.2. So, the preferences of drivers are given on the form PFxyz, where x is the first preference of the driver, y is the second, and z is the third. For example, a driver that defines his preferences as PF123 will be preferring to be allocated to journeys of the Group 1 first, journeys of the Group 2 second, and journeys of the Group 3 third.

Table 5.2 – Groups of working periods for the determination of drivers' preferences

Group	Working Period	Start Time	End Time
Group 1	"Madrugada"	Before 5:00	-
	"Cedo"	Between 5:00 and 8:00	-
Group 2	"Média"	After 8:00	Before 22:00
Group 3	"Semi-Serão"	-	Between 22:00 and 24:00
	"Serão"	-	Between 24:00 and 27:00
Group 4	"Rede"	-	After 27:00

One should understand that the use of 24:00 and 27:00, instead of 0:00 and 3:00 respectively, is to ease the determination of hours worked by each driver.

5.3 FORMULATION OF THE METHODOLOGY

For the reasons presented in the end of section 4.3.1, a methodology for the performance assessment of the crew rostering problem had to be created. The methodology that will be used on this work is based on part of the methodology presented by Souza et al. (2005), namely the process for the classification of quality of schedules generated, which was briefly described on Chapter 3. It was decided to use this methodology for the static classification of schedules because it is hard to find more methodologies that do this and this seemed to be applicable for the case study of this dissertation, with some modifications as it will be explained.

Although it is not a pure performance assessment function (its original purpose was the classification of work schedules for the crew rostering system, with the objective of comparing them and reach a better work schedule), it is acceptable that it is used to classify the schedules generated with and without the ITS. After that, a comparison between schedules will be able to return results on the performance of the ITS, by studying the changes observed on both scenarios. By applying the function to work schedules obtained before and after the ITS deployment and comparing their results, one will be able to conclude about the ITS performance.

On this section, a description of the methodology proposed by Souza et al. will be given, followed by modifications that were made for applying it to the Carris case study. After that, the structure of the methodology to be used on this work will be presented.

5.3.1 Description of methodology by Souza et al.

In 2005, Souza et al. presented an evaluation function to assess previously obtained monthly work schedules (solutions of the crew rostering problem) that can be expressed by the following:

$$FO(s) = F_{RE} + F_{RNE}$$

Both terms of the equation (F_{RE} and F_{RNE}) are also functions, being the first one responsible for evaluating the non-verification of the essential requisites of the crew rostering problem and the second one responsible for evaluating the non-verification of the non-essential requisites of the same problem. Because of the formulation of F_{RE} and F_{RNE}, the lower FO is, the better the monthly working schedule will be.

The essential requisites for the crew rostering problem are, according to the authors, three: i) the verification of the minimum rest time in between consecutive working days; ii) the verification of the minimum number of days off per week; and iii) the verification of at least a day off on a Sunday. So, F_{RE} may be determined by the following equation:

$$F_{RE} = p_1 I_1 + p_2 I_2 + p_3 I_3$$

where:

I_1 – time left to complete the minimum rest time in between working days (measured in minutes);
I_2 – number of days beyond the maximum number of days without a day off allowed;

I_3 – number of drivers that do not have a Sunday day off during the whole month, for that working schedule;

p_1, **p_2**, **p_3** – weights respectively corresponding to I_1, I_2 and I_3.

As for the second part of the equation, this has the objective of minimizing operational costs and get the most of each crew working time. Besides that, there is also the objective of balance the different journeys in terms of duration. F_{RNE} may be expressed by the following equation:

$$F_{RNE} = q_1 R_1 + q_2 R_2 + q_3 R_3 + \cdots + q_{11} R_{11} = \sum_{i=1}^{11} p_i R_i$$

where:

R_1 – sum of the number of days off missing or in excess in relation to the minimum and maximum numbers of days off imposed, for each driver. This is used to promote a more balanced distribution of days off among the crew;

R_2 – number of times that each driver changes line;

R_3 – number of different lines contained in the monthly work schedule of each driver;

R_4 – number of changes in working shifts, for each driver, during the month. This has the objective of standardize working shifts for all crews;

R_5 – sum of the number of times that each driver changes journeys on working days (Monday to Friday);

R_6 – sum of the number of times that each driver changes journeys considering only Saturdays;

R_7 – sum of the number of times that each driver changes journeys considering only Sundays and holidays;

R_8 – number of different journeys for each driver considering only working days (Monday to Friday);

R_9 – number of different journeys for each driver considering only Saturdays;

R_{10} – number of different journeys for each driver considering only Sundays and holidays;

R_{11} – sum of the difference between the working time of each driver and the mean working time of all drivers;

q_1, **q_2**, …, **q_{11}** are the different weights respectively corresponding to R_1, R_2, …, R_{11}.

Based on this function and using both Simulated Annealing (SA) and Iterated Local Search (ILS) and Random Drom (RD), Souza et al. created a method of finding better solutions for the crew rostering problem through the changing of journeys in between crews. Both algorithms for SA and ILS are presented in the Annexes 1 and 2 (Souza et al., 2005).

5.3.2 Adaptations of the methodology to the Carris case

An interview with Mr.José Maia (Co-Ordinator of Carris' Planning and Operation Control Unit), and Ms. Maria José (responsible for Carris' Crew Rostering), was conducted in order to better understand how the crew rostering works and if the methodology presented suited or not the operations at the company. The conclusions from that interview pointed out that some modifications on the methodology had to be done, since some of the inputs were not adjusted according to Carris' operation reality. Those modifications are described next and the reasons for their introduction are explained according to what was discussed on the interview.

On the first part of the equation (F_{RE}), only the first indicator "I_1 - time left to complete the minimum rest time in between working days" was considered by Carris responsibles as important to measure. As for the other two essential indicators (I_2 and I_3), these were considered redundant, since the company itself assures that these factors are always strictly fulfilled. However, their measurement is not a hard task to do with the data provided by Carris for the developing of this work, and so, I_2 will be measured anyway. As for I_3, it will not be measured because it refers to the rule of scheduling that says that each driver is entitled to a Sunday day off at least 5 to 5 weeks. The schedule in analysis is for one month only, which may not have five complete weeks, so the measuring of this indicator would not lead to consistant results.

The second part of the methodology is the one that will suffer a higher amount of modifications, since the only indicator that was agreed to stay as in the original methodology was R_{11}, "sum of the difference between the working time of each driver and the mean working time of all drivers".

First, some of the requisites presented by the authors of the methodology were not adjusted in the eyes of Carris responsibles and will be eliminated from the methodology to apply on this work. Namelly, the following indicators will not be measured:

- R_1 , "sum of the number of days off missing or in excess in relation to the minimum and maximum numbers of days off imposed, for each driver". Since not all drivers work on a regular basis (remember the Supras mentioned on section 5.2), there is no such thing as minimum days of work. As for the maximum number of days worked in a row, Carris guaranteed that this is always verified and they never work more days in a row than the ones allowed. So, R_1 was decided to be left out of the methodology;

- R_2 and R_3, which are the "number of times that each driver changes line" and the "number of different lines contained in the monthly work schedule of each driver", were considered not important by Carris responsibles. On their point of view, these two indicators have no influence on the quality of schedules or on the quality of the final service provided to users, so it was decided that they would not be used on the final methodology;

- Simmilarly to the previous mentioned, R_5, R_6, R_7, R_8, R_9 and R_{10} will not be used as well. R_5, R_6 and R_7 refer to the sum of the number of times that each driver changes journey on weekdays (R_5), on Saturdays (R_6), and on Sundays and holidays (R_7), which according to Carris do not matter for the performance of the crew management process. As for R_8, R_9, and R_{10}, these refer to the number of different journeys for each driver along the month considering weekdays (R_8), Saturdays (R_9), and Sundays and holidays (R_{10}), which according to Carris are not important as well.

Second, the indicator R_4 presented by the authors of the original methodology was considered useful, but only if some modifications were made:

- R_4, "number of changes in working shifts, for each driver, during the month", according to the authors has the objective of standardize working shifts for all crews. Carris considers that this will not have an impact on the quality of the schedule so it will not be measured this way. However, this could be modified to verify if the preferences of the drivers are attended or not. Each driver at Carris defines his preferences in a sequential order for three of the four daily shifts available. So, R_4 will be divided on three indicators: i) R_{41}, "number of drivers not allocated on the first preference", ii) R_{42}, "number of drivers not allocated neither on the first nor on the second preference", and iii) R_{43}, "number of drivers not allocated on any of the preferences declared". The reason for this definition is that the lower the objective function is, the better the schedule will be and so, imagining all drivers are allocated on the first preference (ideal situation, with $R_{41} + R_{42} + R_{43} = 0$), the objective function will be minimized. Some of the drivers may not indicate a set of preferences and on those cases these indicators will not be taken in account.

Finally, to complete the methodology there was one indicator that Carris considered essential to be on the framework and had to be incorporated, related to how the overtime periods (extra hours) were affected by this new methodology. Overtimes are paid at a higher value, so it is important to Carris to understand if the implementation of this new system had or not a significant impact on the amount of extra hours to be paid. Regarding extra hours, it is Carris intention to minimize them and to spread them as equally as possible among all the drivers. So, the following indicator was added to the methodology:

- R_{12}, "extra hours to be performed", which will be determined by summing the durations of complete services left without driver after the application of the ITS. There is no way to determine the impact of the ITS on the extra hours, since according to Carris these suffer a high amount of manual changes after the ITS application. However, since there is no other alternative, Carris suggested that the analysis of this indicator could be based on the complete services left without driver, or in other words the extra work left to perform after the ITS application. Unfortunatly, there is no way to know which drivers perform the extra work at this stage, so quantity will be the only factor to analyse regarding extra hours.

Another modification on the methodology was made in order to make each indicator represented by a dimensionless value, always considering the universe of hypothesis of failure for each indicator (one should remember that the methodology is always done negatively, or in other words, the higher the values the worse the results). This is not done on the original methodology and values represented in different units are used, which is not entirely correct. This quest for a dimensionless value for each indicator will at the same time strive for a fairer comparison between the two months, since the number of drivers might be different and that has a strong influence on the final results. However, this issue will be covered on a more detailed form in Chapter 6, related to the Case Study, on each indicator's section.

5.3.3 Final formulation of the methodology

As a complement for a better understanding of the methodology to be applied in this disseratation, a structure of it is presented on Figure 5.4.

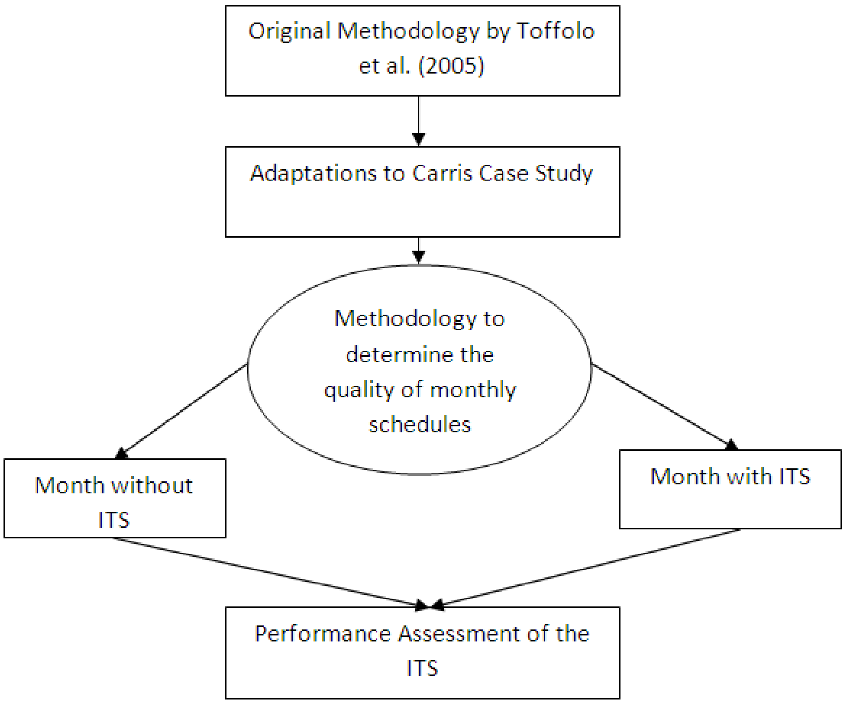

Figure 5.4 – Structure of the methodology used

After all the modifications described on 5.3.2, the methodology to determine the quality of monthly schedules is finally determined. The quality of a schedule may be traduced by the objective function:

$$FO(s) = F_{RE} + F_{RNE}$$

$$F_{RE} = p_1 I_{1f} + p_2 I_{2f}$$

$$F_{RNE} = q_{41} R_{41f} + q_{42} R_{42f} + q_{43} R_{43f} + q_{11} R_{11f} + q_{12} R_{12f}$$

The indice "f" on each indicator stands for "*formula*", which means this value is the dimensionless factor described on the last paragraph of section 5.3.2. The calculation of each of these dimensionless values is different for each of the different indicators and tries to relate the values calculated for each indicator with the optimal values that could be obtained for each indicator. In other words, the dimensionless factors will measure the deviation from the optimal values. This will be more clearly described on each indicator's section on Chapter 6.

Finally, it was decided not to use the objective function because efforts to reach a common classification of indications to transform it in a value function were not successful. This said, the comparison between the different schedules will be done by comparing the dimensionless factors of each indicator in both months. Table 5.3 explains what each indicator is intended to classify and how is it measured, which was already mentioned on sections 5.3.1 and 5.3.2, but is here presented to be easily connected with the formulation described above.

Table 5.3 – Indicators to use on the case study

Indicator	Object of analysis	Description
I_1	Respect for minimum rest periods	Time left to complete the minimum rest time between consecutive shifts
I_2	Respect for number of days worked in a row	Number of days beyond the maximum number of days without a day off allowed
R_{41}	Attendance to Drivers' Preferences	Number of drivers not allocated on the first preference
R_{42}		Number of drivers not allocated neither on the first nor on the second preference
R_{43}		Number of drivers not allocated on any of the preferences
R_{11}	Equilibrium in terms of working times	Sum of the difference between the working time of each driver and the mean working time of all drivers
R_{12}	Extra hours	Number of extra hours to be performed

In order to understand what are the most important indicators from the list of the ones used in this work, a meeting with Carris was conducted. In this meeting Carris responsibles ordered the indicators by importance and attributed a value to them. However, this will be better explained on Chapter 6 when the application to the case study takes place.

The methodology of this work consists on applying the adapted formulation referred to two different month schedules of Carris' crew of drivers defined as Supras, one of them before the ITS deployment and the other one after the introduction of the ITS application. Comparing the results obtained on the indicators for both months, one will be able to conclude about the performance of the ITS being analysed. A comparison indicator by indicator will be the object of analysis to conclude about the deployment of the Crew Rostering application.

6 CASE STUDY APPLICATION

6.1 DATA FOR THE CASE STUDY

For the case study to be developed it was needed input data, namely the schedules of drivers (Supras) for two months of activity, being one of them referent to a month without the Crew Rostering application in use, and the other for a month where the ITS was already used. After a meeting with Carris responsibles, where it was mentioned that the OPT system was introduced in the year of 2009, the schedules choosen to be used on this work were the ones relative to February 2008 and February 2010, for mainly two reasons.

First, it was mandatory that both schedules were referent to the same month in order to be as uniform as possible in terms of number of days, amount of work, demand, holidays, etc. Second, the schedule of the month with the OPT system already in use had to be referent to a month that should allow some learning time after implementing the system, in order to avoid some mistakes that usually are made when one is using new technologies for the first times. It was considered that a schedule for a month in 2010 was the best option, since the system was put in use in 2009.

From the schedules provided by Carris (see Annex 4 for an excerpt from the tables provided by Carris) the determination of all the indicators to use in the modified methodology described on Chapter 5 was possible, as it will be seen on the next section. The data that figures on the schedules provided by Carris have the following relevant information:

- Date of the service;
- Plate number (one different per driver);
- Start and End times of each service;
- Duration of each service.

Besides the schedules, another table with driver's preferences was supplied, which was essential to determine how this was being taken in account (see Annex 3 for an excerpt from the preferences table provided by Carris). Also, for the determination of extra work to be performed, a list of services left without driver after the application of the ITS was provided for both months (for February 2008, it is a list of services left without driver after all Supras have attributed schedules), which an excerpt is presented on Annex 5.

6.2 APPLICATION OF THE METHODOLOGY

On this section, the methodology presented in Chapter 5 will be applied to the data supplied by Carris. Each of the following sections will refer to one of the different indicators determined when defining the methodology, both for February 2008 and February 2010. When all the indicators are determined, the comparison between the two monthly schedules will be made.

6.2.1 Determination of I_1

This indicator has the objective verifying how the requisite of the minimum 11 hours of rest between shifts changed with the introduction of the crew rostering software. According to the Portuguese law, a driver should rest a minimum of 11 hours between the end time of one duty and the start time of the following duty. Yet sometimes for multiple reasons this cannot be attended, and upon agreement of the drivers they rest less than 11 hours.

The indicator I_1 represents, as it was reffered on Chapter 5, the time left to complete the minimum rest time in between working shifts, measured in minutes. So, for a month the value of I_1 will be the sum of all the minutes left to complete the minimum rest time, for all drivers, based on the start and end times of the daily schedules of each driver. For example, a driver that ends his shift at 23:30 and starts working on the next day at 8:00 had a rest time of eight and a half hours, which is two and a half hours less than 11 hours. Consequently, on this day, this driver had a contribution of 150 minutes to the total value of I_1.

The value of I_1 is measured in minutes and therefore there is a need to transform this in a dimentionless value. The methodology to do this was according to the following formulation:

$$I_{1f} = \frac{I_1(\mathrm{m})}{Int.Shifts * 11(h) * 60(m)}$$

The denominator represents the time that should be rested on an ideal scenario, which means the product between the number of intervals between shifts (Int.Shifts, which is equal to the number of shifts of one driver during the whole month subtracted by one) by 11 (number of hours that the driver should rest) and by 60 (so that the final result is in minutes). Figure 6.1 helps on the understanding of how this denominator transforms the result in a dimensionless value.

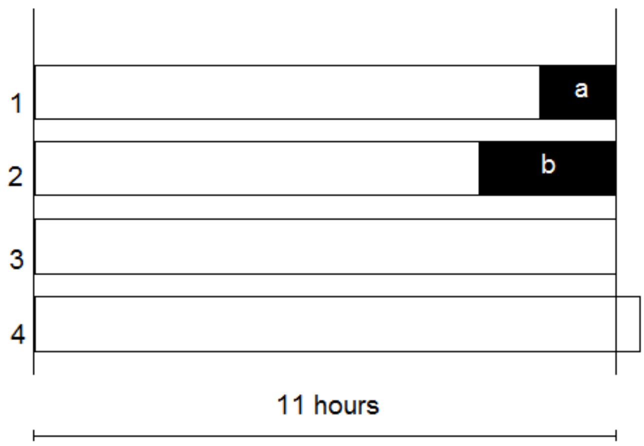

Figure 6.1 – Transformation of I_1 in a dimensionless factor

There are four rest times of four drivers on Figure 6.1 represented by the white bars. As it can be understood, Driver 3 rests exactly 11 hours, Driver 4 rests more than 11 hours, and Drivers 1 and 2 rest less than 11 hours. Since there is no requisite regarding the maximum rest time, the amount of extra time that Driver 4 rests will not enter the calculation. On this case, I_1 would be equal to $a + b$ and the ideal rest time (which will be the denominator) would be verified if all the four drivers rested 11 hours. Therefore, the dimensionless value for this case could be obtained with the following equation.

$$\frac{a+b}{4*11*60}$$

The results obtained for I_1 and I_{1f} for both months of February 2008 and February 2010 are presented on Table 6.1.

Table 6.1 – Results obtained for I_1 in February 2008 and February 2010

	February 2008	February 2010
I_1 (minutes)	7872	6267
Int.Shifts	3345	3194
I_{1f} (dimensionless)	0.00357	0.00297

According to Table 6.1, the quality of the schedule regarding the minimum rest time between shifts has increased with the introduction of the crew rostering application, since Carris drivers' rest time was less respected and more minutes left to complete the minimum hours of rest were counted in February 2008. A decrease of 1600 minutes on the time left to complete the 11 hours of rest between shifts was verified, which is significant even if one takes in account that this is distributed among the whole month and among more than 200 drivers, which results in approximately 7 minutes less per month per driver.

When calculating this indicator, it was noticed that a small group of drivers (two in 2008 and four in 2010) had exceptions on the monthly schedule that would very much affect the final result of I_1. These drivers were working each of them one double shift along the month, which would result on a considerable amount of minutes left to rest. For example, one of these drivers worked a 7 hour shift, then rested for one hour and 30 minutes and worked another 7 hour shift. For the final result, this would have a I_1 contribution of 9 hours and 30 minutes, or 570 minutes, which is a substancial contribution for only one interval between shifts. Because of this, and also because these situations will also be taked in account when analyzing the balance between time worked by each driver, the 2 situations of February 2008 and the 4 situations of February 2010 were left out of the calculation of I_1, which changed the results to the ones presented on Table 6.2.

Table 6.2 – Alternative results obtained for I_1 in February 2008 and February 2010

	February 2008	February 2010
I_1 (minutes)	6825	4366
Int.Shifts	3269	3136
I_{1f} (dimensionless)	0.00316	0.00211

These last results seem to be fairer to use, since they represent the majority of the situations and exclude respectively only 2 and 4 punctual situations that were significantly influencing the results. As it can be seen, excluding this minority of situations, a greater improvement is verified with the introduction of the crew rostering application, since the decrease verified on the number of time left to complete the minimum rest is greater (a decrease of almost 2500 minutes is verified). With that in mind, the factors to be used on the final methodology will be the ones presented on Table 6.2.

6.2.2 Determination of I_2

The use of this indicator has the objective of verifying how the requisite of having a day off at least each 7 days changed with the introduction of the crew rostering software. By law, Carris drivers cannot work more than 6 days in a row, so on the 7^{th} day they must have a day off. Like what happens with the previous indicator, sometimes this may not happen, with a previous agreement with the affected driver.

I_2 is, as referred on Chapter 5, the number of days worked beyond the maximum number of days without a day off allowed. So, for each month I_2 will be the sum of all the days that all drivers worked beyond the maximum of six days in a row, which is a simple value to determine with the data provided by Carris.

I_2 is measured in days, so there is the need to represent it with a dimensionless number, similarly to what happened with I_1. However, the way to do this will be different because each indicator has a different methodology to become dimensionless. On the case of I_2, the task is to determine how many times drivers work more days than the allowed in a universe of a determinate number of blocks. The formulation to calculate it is the following.

$$I_{2f} = \frac{I_2(days)}{Number\ of\ blocks}$$

Figure 6.2 helps on the understanding of how the methodology works. The image refers to the schedule of one driver for one month. On the example shown by the image one can see that the driver worked a total of 22 days, divided by four blocks. Two of the blocks respect the requisite I_2, but the other two do not respect it, since they are composed by 7 days (one day more than the maximum of six days in a row). The value of I_2 for this scenario would be equal to 2 and I_{2f}

would be equal to 0.5, dividing 2 (days that exceed the maximum working days in a row) by 4 (number of blocks), because the driver has four opportunities (blocks) to fail the requisite. In other words, the requisite was fulfilled 50% of the times (0.5).

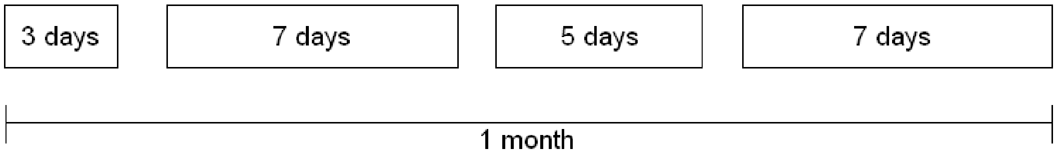

Figure 6.2 – Transformation of I_2 in a dimensionless factor

One can say that this does not make the factor dimensionless, since days are being divided by blocks, so the unit is days/blocks. However, we can face the results in a different way, saying that I_2 is the number of blocks that do not respect the requisite. I_2 is measured in days so that it can be easier to understand, but for calculation effects it is measured in blocks.

The results of I_2 and I_{2f}, for both the months of February 2008 and February 2010 are presented on Table 6.3.

Table 6.3 – Results obtained for I_2 in February 2008 and February 2010

	February 2008	February 2010
I_2 (days)	5	5
Number of Blocks	972	881
I_{2f} (dimensionless)	0.00514	0.00568

From the analysis of the table one can verify that the number of days beyond the maximum number of days without a day off allowed remained constant for the months analysed. However, an increase on the dimensionless factor was noticed, since the number of blocks is lower in February 2010. However, this increase is not that significant and these situations occur mainly due to changes in the schedule suggested by drivers for personal reasons.

6.2.3 Determination of R_{41}, R_{42} and R_{43}

The introduction of R_4 in the methodology happened to evaluate how the drivers' preferences were being met before and after the introduction of the crew rostering software. Drivers at Carris may present their preferences by working shifts, like it was mentioned and explained on Chapter 5, and Carris tries to attended these if possible. This is not an essential requisite for the schedule to work, but it is easily understood that the working conditions are better when employees' satisfaction is guaranteed, so it is one of Carris' efforts to attend these preferences.

As it was described on Chapter 5, R_4 is divided in three different indicators (R_{41}, R_{42}, and R_{43}) because when drivers present their preferences they provide a sequence of three shifts where they prefer to work, by preference order. Therefore:

- R_{41} is the number of times that drivers were not allocated on the first preference;
- R_{42} the number of times that drivers were allocated neither on the first nor on the second preference;
- R_{43} the number of times that drivers were not allocated on any of the preferences declared.

Besides the Excel table with the crew schedules for both months of February 2008 and February 2010 (Annex 4), Carris supplied another Excel sheet with the preferences indicated by each driver (Annex 3). To calculate R_{41}, R_{42} and R_{43} it was necessary to cross the information provided by the Preferences Excel and the schedules provided, verifying how many times the drivers that indicated preferences were placed at chosen schedules, according to start and end times of the duties performed along the month and aided by Microsoft Excel formulations.

R_{41}, R_{42}, and R_{43} are measured in preferences not attended. If it is his will, each driver presents his set of preferences for the whole month. For this work, this was considered equal to say that for each day of work on that month the driver will have the same preferences' set. This means a number of preferences per driver equal to the number of days that driver worked.

This was probably the most intuitive indicator when trying to make it dimensionless, since it was only needed to divide it by the days worked by all the drivers that declared preferences. In other words, the results that will be used on the methodology are the percentages of R_{41}, R_{42}, and R_{43} according to the total of preferences declared on that month. The following formulation is the one used to calculate R_{41f}, R_{42f}, and R_{43f}, but the equation presented is only referent to the first one.

$$R_{41f} = \frac{R_{41}}{\sum_{x=1}^{n} d(x)}$$

where x is a driver that declared preferences, n is the number of drivers that declared preferences, and $d(x)$ is the number of days worked by driver x.

The results obtained for these factors in the months in analysis are presented on Table 6.4.

Table 6.4 – Results obtained for R_{41}, R_{42}, and R_{43} in February 2008 and February 2010

	February 2008	February 2010
R_{41} (pref.)	850	815
R_{42} (pref.)	729	358
R_{43} (pref.)	194	79
Number of preferences	3124	3402
R_{41f} (dimensionless)	0.27209	0.23957
R_{42f} (dimensionless)	0.23336	0.10523
R_{43f} (dimensionless)	0.0621	0.02322

From the analysis of Table 6.4 an increase on the attention given to drivers' preferences may be observed as 2008 and 2010 are compared. The quality of all indicators has significantly increased, even with the higher amount of preferences declared by drivers, which reflects a better adjustment of the schedules generated to drivers' preferences.

Because the methodology is formulated according to the non verification of the requisites, this indicator also had to be formulated similarly. The results are in this case more complicated to understand and even incomplete, since none of the three indicators measures how many drivers were allocated on the first preference. With that in mind, it seemed necessary to present the percentages of preference allocations for both months in analysis in order to understand how it evolved. Table 6.5 shows the absolute values and percentages of attendance of drivers' preferences for the months analysed.

Table 6.5 – Attendance of drivers' preferences for February 2008 and February 2010

	February 2008		February 2010	
1st Preference	1351	43.24%	2150	63.20%
2nd Preference	850	27.21%	815	23.96%
3rd Preference	729	23.34%	358	10.52%
None	194	6.21%	79	2.32%
Total	3124	100%	3402	100%

The quality improvements in terms of attendance of drivers' preferences are notorious and the values presented on Table 6.5 speak for themselves. The placement of drivers on the first preference has raised almost 20%, reaching a value of 63.2%, which means that more than half of the drivers who declared preferences were placed on the first preference presented. In 2010, only a few times drivers were not placed in any of the preferences declared (2.32%), which is almost three times less than the value presented in 2008 (6.21%). Even though the percentages for the 2nd and 3rd preferences decreased, and since their decrease is accompanied by a significant increase on the 1st preference, it still means the schedule quality in terms of preferences attendance is significantly better. The graphics below offer a more visually attractive approach to the results presented, where the referred improvement is clearly seen.

As it can be seen on Table 6.5 and on Figure 6.3, in 2010 almost 90% of the drivers were placed either on the 1st or in the 2nd preference, which is a good indicator of how the preferences are being taken in account.

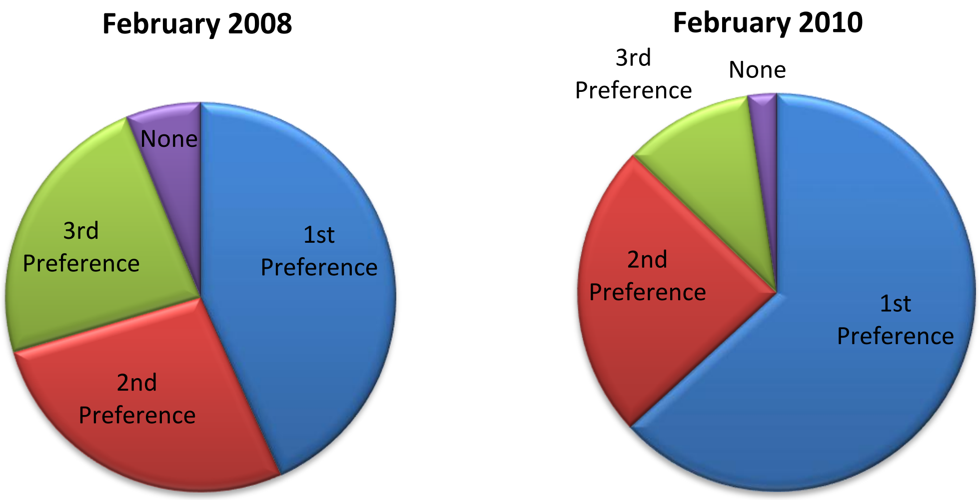

Figure 6.3 – Graphic representation of drivers' preferences for both months analysed

6.2.4 Determination of R_{11}

The indicator R_{11} intends to measure how the working time is distributed among the different drivers through a comparison with the mean working time of all drivers. This is an important issue since drivers have a fixed salary independent of actual driving hours and therefore should work an amount of time as equal as possible. The nature of the problem sometimes makes it harder to balance these working periods since bus schedules are fixed schedules and one cannot add or remove minutes as it fits. The struggle for a fair distribution of working hours must be a factor to always take in account when constructing the schedules because an unfair schedule might generate dissatisfaction among the drivers.

As it was referred on Chapter 5, R_{11} is the only indicator of the second part of the original methodology that remained without any modification, where it is described as the sum of the difference between the working time of each driver and the mean working time of all drivers. The differences to the mean working time shall be measured in absolute values and the summed, since it is considered with the same weight working more or less hours than the mean working time.

In order to transform this indicator in a non-dimensional factor, R_{11f}, the following formulation was used:

$$R_{11f} = \frac{R_{11}}{MWT * Shifts}$$

where MWT is the mean working time per shift and Shifts is the number of shifts considered in the calculation of that mean value. R_{11} is measured in hours, MWT is measured in hours/shift and Shifts in measured in shift, so the final result is a dimensionless value. The denominator is an ideal scenario where all the shifts had the same duration equal to the mean working time per shift calculated.

Figure 6.4 illustrates how this process works for an example with 3 schedules, one of them with a duration equal to the average duration minus a, other with a duration equal to the average duration, and other with a duration equal to the average duration plus b.

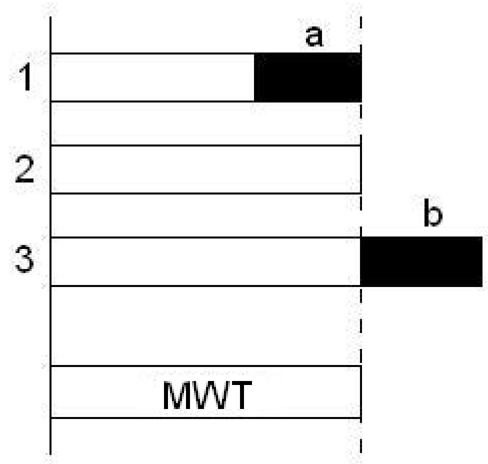

Figure 6.4 – Transformation of R_{11} in a dimensionless factor

On this scenario, the dimensionless value of R_{11}, which is given by $a + b$, would be give by the equation

$$\frac{a + b}{3 * MED}$$

which is consistent with the formulation previously presented.

The results obtained for the months in analysis are the ones presented on Table 6.6, where the values of MWT, number of Shifts, R_{11}, and R_{11f} are shown.

Table 6.6 – Results obtained for R_{11} in February 2008 and February 2010

	February 2008	February 2010
MWT (hours/shift)	7.86	7.90
Shifts (shift)	3562	3394
R_{11} (hours)	1252.33	1161.18
R_{11f} (dimensionless)	0.04471	0.04331

The sum of the differences between the duration of all the shifts worked and the mean working time per shift decreased in 2010 and even though the number of shifts also decreased, the dimensionless value R_{11f} is still lower in 2010 when comparing it to the 2008 value. This means that the balance among the working hours per shift was fairer in 2010, which means that the ITS brought some advantages on this issue.

The values to be used in the final methodology are the ones presented on Table 6.6, but the fact that in 2010 a few shifts were considerably shorter than others (there were shifts with a duration of 3 hours, for example), and since this could be giving a strong contribution to the final result, another scenario was calculated where only shifts with more than 6 hours were considered. The results of that scenario are presented on Table 6.7.

Table 6.7 – Alternative results obtained for R_{11} in February 2008 and February 2010

	February 2008	February 2010
MWT (hours/shift)	7.95	7.98
Shifts (shift)	3490	3320
R_{11} (hours)	804.35	752.71
R_{11f} (dimensionless)	0.02900	0.02841

The dimensionless value is still lower in 2010, but the variation is not so high as in the scenario considered before, which means that these shifts with less than 6 hours were having a considerable contribution on the final result, but not as significant as expected. The 2010 schedule is still better comparing to the 2008 schedule in what comes to the balance of the duration of working shifts.

6.2.5 Determination of R_{12}

R_{12} was added to the methodology because the original one did not included any indicator measuring extra hours. This indicator is the one responsible for determining how did the extra hours evolved from the month before to the month after the application of the software. Extra hours mean costs to the company, so they are an important issue to be covered when analyzing the quality of schedules; thus a good schedule will minimize the number of extra hours to be paid. Besides the minimization of extra hours used, Carris' responsibles reffered as well the importance of distributing extra hours among the drivers entitled to them. Most drivers do not mind working a few extra hours since it means a more robust salary in the end of the month, so for reasons of equity these should be distributed as equally as possible. However, like it was said on Chapter 5, there is no way to know which drivers performed the extra work at the stage where the analysis takes place, so the quantity of extra work will be the only factor to analyse regarding this issue.

R_{12} will be obtained by summing the durations of complete services left without driver after the application of the ITS. There is no way to determine the impact of the ITS on the extra hours, since according to Carris these suffer a high amount of manual changes after the ITS application. However, since there is no other alternative, Carris suggested that the analysis of this indicator could be based on the complete services left without driver, or in other words the extra work left to perform after the ITS application.

The methodology that Carris uses to calculate how much extra time a driver worked is based on a rounding to 15 minute periods, so each of the parcels that compose R_{12} had to suffer this modification. For example, if a driver worked 8 hours and 34 minutes, the amount of extra time to be paid is 30 minutes (or 0.5 hour). On the other hand, if a driver worked 9 hours and 23 minutes, the amount of extra time to be paid is 90 minutes (or 1.5 hour).

R_{12} is measured in hours, which means that it will have to suffer a process to become dimensionless. The process adopted was to determine the ratio between the extra work time and the total amount of time worked along the month, measured in hours. One should note that extra hours are performed not only by Supras but also by Effective drivers. So, the total amount of time worked to consider will be not only the time worked by Supras. According to this, R_{12f} may be calculated with the formulation

$$R_{12f} = \frac{R_{12}}{\sum_{x=1}^{n} dur(x)}$$

Where n is the total number of daily services along the month and $dur(x)$ is the duration of shift x. The values of both R_{12} and R_{12f} are presented on Table 6.8.

Table 6.8 – Results obtained for R_{12} and R_{12f} in February 2008 and February 2010

	February 2008	February 2010
R_{12} (hours)	333.25	232.00
Total hours worked (hours)	66251.23	68907.05
R_{12f} (dimensionless)	0.00503	0.00337

As it can be seen, there is a significant improvement with the introduction of the crew rostering software, which is traduced by the decrease of R_{12} in February 2010. The number of hours left without a driver (and that consequently will be performed as extra work) in February 2010 were moreless 100 hours less than in February 2008, which is a significant reduction.

6.2.6 Relative importance of the indicators

In order to understand the relative importance of the indicators used, some weights were obtained from a meeting with Mr. José Maia and Ms. Maria José conducted in May 2011. The intention of that meeting was to look at the five different indicators used on the calculation and try to classify them on a scale of 0 to 100 points.

Carris' members decided that I_1 and I_2 had maximum importance since they are imperative and according to the legislation, therefore a weight of 100 was attributed to these indicators. For the remaining three indicators, 100 points were distributed as it can be seen on Table 6.9. The quotations were then converted to a scale from 0 to 100.

The values presented on the last column of Table 6.9 are the final weights transformed on a percentual value. As it can be seen on the table, R_{41}, R_{42} and R_{43} share the 10 points given by Carris to the drivers' preferences indicator. This happens because these three indicators were presented to Carris as one global indicator that would analyse the attendance to drivers' preferences and not as three different ones.

Table 6.9 – Weights attributed by Carris to all indicators

Indicator	Carris Quotation	Weight	Value
I_1	100	p_1	33.33
I_2	100	p_2	33.33
R_{41}		q_{41}	1.11
R_{42}	10	q_{42}	1.11
R_{43}		q_{43}	1.11
R_{11}	30	q_{11}	10
R_{12}	60	q_{12}	20

6.2.7 Resume of the results obtained for the indicators

In summary, the results obtained for all the indicators are presented on the graphic presented on Figure 6.5. Some of the values are too short to be seen on the graphic, so a table resuming the values obtained is provided along with the graphic.

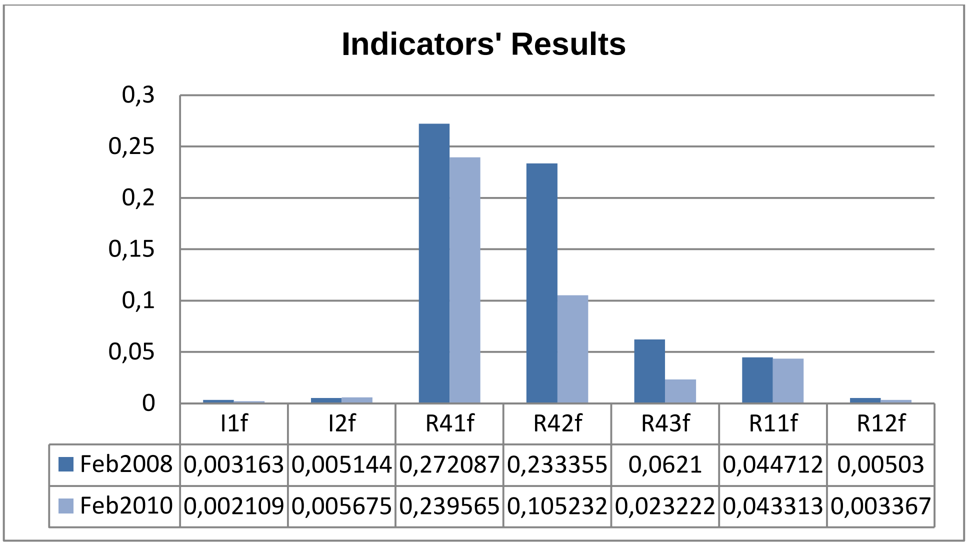

Figure 6.5 – Graphic representation of indicators' results

Table 6.10 presents the percentual variation on the quality of each indicator verified with the introduction of the ITS. The negative values indicate a decrease on the quality of the respective indicator and the positive ones indicate that an improvement was verified.

Table 6.10 – Quality variation for the indicators considered

	Feb2008	Feb2010	Quality Variation	Weight
I_{1f}	0.00316	0.00211	33%	33.33
I_{2f}	0.00514	0.00568	-10%	33.33
R_{41f}	0.27209	0.23957	12%	1.11
R_{42f}	0.23336	0.10523	55%	1.11
R_{43f}	0.06210	0.02322	63%	1.11
R_{11f}	0.04471	0.04331	3%	10
R_{12f}	0.00503	0.00337	33%	20

6.3 GENERAL CONCLUSIONS OF THE CASE STUDY

The results of the methodology adopted indicate a significant improvement on the quality of monthly schedules for Supras. The comparison per indicator allows a better understanding of improvements verified on each one.

As it can be observed, all the indicators saw its performance improved by the introduction of the ITS except I_2, which is the indicator related to the respect for the maximum consecutive days of work without a day off. However, if one remembers the results obtained on this indicator they remained constant and the contribution of the indicator only raises because the amount of blocks is lower in 2010. Although this is one of the more important indicators, the decrease observed is not significative.

It was observed that the most important indicators had shorter contributions to the final value of the objective function, being the less important indicators the major responsibles for the improvements introduced by the ITS. This may indicate that the ITS is doing its best to improve the important indicators, which results on higher contributions of the less important indicators due to non possibility of respecting them by imposition of higher rated indicators. In other words, to improve the more important indicators the other ones may be left behind, resulting on higher contributions of the latest.

7 CONCLUSIONS AND FUTURE

7.1 CONCLUSIONS

The introduction of ITS for the improvement of public transport envolves a large expenditure of funds and therefore needs to have its positive impacts maximized. Performance Assessment is a powerful instrument for concluding whether the IST is performing according to intended objectives or not, allowing corrections to the deployment is the results obtained are not the expected. An appropriate construction of the Performance Assessment methodology is essential for the results to be relevant; otherwise the conclusions may not be consistent with the reality.

This study carried out a Performance Assessment of one ITS, the Crew Rostering application used on the public transport company Carris, based on the capital of Portugal, Lisbon. The methodology developed was based on a methodology for the quality classification of monthly schedules of drivers, presented by Souza et al. (2005). An adaptation of that original methodology was made for the Carris case and was later applied to two different month schedules, one for February 2008 and other for February 2010 (the former referent to a month without the application of ITS and the latter with the ITS already being deployed).

Due to the lack of data for a correct attribution of value to each indicator, the objective function could not be used. However, through the quality classification of both schedules, comparing the key indicators of each month, one was able to conclude about the performance of the ITS used. The final results obtained indicate that the ITS brought significant improvements to the scheduling of Supras.

The variation of each indicator between February 2008 and February 2010 was analysed in order to understand how each indicator changed in the period of analysis. The indicators that had higher positive variation were the ones related to drivers preferences (R_{41}, R_{42}, and R_{43}, with improvements of quality equal to 12%, 55%, and 63%, respectively), the indicator related with the respect for the minimum rest time between consecutive shifts (I_1, with a quality improvement of 33%), and the indicator related with extra hours (R_{12}, also with an improvement of 33%). A smaller improvement, but yet an improvement, was verified for the factor related with the equilibrium between the working hours of all drivers (R_{11}), which had its quality meliorated in 3%. The only indicator that had its performance affected negatively with the introduction of the ITS was the indicator related with the respect for number of consecutive work days without a day off (I_2 saw a decrease of 10% in its quality).

According to the results presented, the conclusion is that the ITS analysed is presenting good improvement results, with almost all indicators considered presenting improvements in their quality.

7.2 APPLICABILITY AND CONTRIBUTIONS OF THIS WORK

This work provided Carris with information regarding the changes of each indicator considered with the introduction of the ITS analysed. Carris' responsibles can now understand which indicators improved with the ITS introduction and which ones did not. Moreover, it provides Carris with quantitative results for all indicators considered, determining how better or how worst each indicator was.

At another level, it proved that even with an adimensionalization of each indicator, it is more secure to analyse them one by one than put all the resposability of performance assessment in a global result. However, if the global result is able to adimensionalize all the indicators relating them with each other, it might be a good solution. However, analyzing the changes in each indicator independently proved to be more adequate in this case.

Regarding the applicability of this work, the formulation developed may be applied to other public transport companies (or even to companies not related to public transport that have to deal with the task of assigning work to a number of employees high enough to justify a crew rostering application). With specific modifications, the methodology is prepared to be applied to a variety of situations, returning a performance assessment indicator by indicator. One should note that all the indicators used are not specific for public transport, they evaluate the respect for work rules, for the preferences of workers (in the case study, drivers), and they evaluate the amount of extra hours to be paid, which are common indicators for other problems and facilitate the application of these formulation to other scenarios.

7.3 DIRECTIONS TO FUTURE INVESTIGATIONS

If one intends to improve this methodology in order to provide more reliable final results, a way to relate all the indicators together may be studied. If a way to adimensionalize all indicators taking in account the relative importance between them is found, the results of the objective function will be more accurate and conclusion may be taken with them.

On the other hand, we have to look at the limitations of this work. Only two months are being analysed, which is a short period of time for the magnitude of the problem. Maybe a wider analysis, for example for a whole year of application of the software versus one year of schedules without the software, will return more reliable and trustable results. The introduction of other indicators that are important for public transport companies may also be considered, since the ones considered were the ones considered important for Carris but other companies may not think alike.

Another limitation of the presented work is that the methodology only takes in account the changes regarding the schedules of drivers and number of drivers. Some other dimentions should be included in a wider analysis, like for example changes in the backend staff (the introduction of a software may sometimes imply the dismissal of some staff), changes of the company structure, and so on. An important change that happens with the introduction of this ITS was discussed with Carris, which is the time spent on developing the month schedules. There are obvious benefits with the introduction of the ITS but they are too difficult to estimate and analyse.

Finally, if one is able to put prices against each indicator (or if the importance of each indicator can be traduced by a monetary value) the result will be an economic analysis, which will have a common denominator and therefore results will be easier to classify. This is what was tried in the beginning of this work, but putting prices against each indicator proved to be a very hard task to perform, as well as classify monetarily the changes in the company with the introduction of the software. The application to other case studies may find this an easier task and, when possible, it is recommended.

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9 ANNEXES

9.1 ANNEX 1 – Simulated Annealing (SA) Proceding

Procedimento Simulated Annealing (SA)

1. Seja s_0 uma solução inicial, T_0 a temperatura inicial, α a taxa de resfriamento e SA_{max} o número máximo para atingir o equilíbrio térmico;
2. s <- s_0; {Solução corrente}
3. s* <- s; {Melhor solução obtida até então}
4. T <- T_0; {Temperatura corrente}
5. $iter_T$ <- 0; {Número de iterações na temperatura T}
6. enquanto (Critério de parada não satisfeito) faça
7. enquanto ($iter_T$<SA_{max}) faça
8. $iter_T$ <- $iter_T$+1;
9. Gere um vizinho qualquer s' Є N(s);
10. Δ = f(s') – f(s*);
11. se (Δ<0)
12. então s* <- s';
13. senão
14. Tome x Є [0,1];
15. se x < $e^{-\Delta/T}$ então s <- s';
16. fim-se;
17. fim-enquanto;
18. T <- α × T;
19. $iter_T$ <- 0;
20. fim-enquanto;
21. retorne s*;

Fim SA

9.2 ANNEX 2 – Iterated Local Search Proceding

Procedimento Iterated Local Search – Random Drom (ILS-RD)

1. Seja s_0 uma solução inicial, kp_{max} o nível máximo de perturbação e kp_0 a perturbação inicial, $iter_{max}$ o número máximo de iterações consecutivas sem melhora que são permitidas para um nível de perturbação kp e Δ o intervalo entre os níveis de perturbação;
2. s <- BuscaLocal (s_0); {Solução corrente}
3. enquanto (Critério de Parada não satisfeito) faça
4. kp <- kp_0; {Perturbação corrente}
5. enquanto (kp ≤ kp_{max}) faça

```
        iter <- 0; {Número de iterações}
        enquanto (iter < iter_max) faça
            iter <- iter + 1;
            s' <- Perturbação (s,kp);
            s'' <- Busca local (s');
            se (f(s'') < f(s)) então
                s <- s'';
                kp <- kp_0;
                iter <- 0;
            fim-se;
        fim-enquanto;
        kp <- kp + Δ;
    fim-enquanto;
fim-enquanto;
retorne s;
```

Fim ILS-DR

9.3 ANNEX 3 – Excerpt of the drivers' preferences table provided by Carris

ORDEM	CHAPAFEV	OBS
171395	0006573	PF123
178462	0006574	PF123
173177	0006575	PF321
171760	0006576	PF123
174211	0006577	PF123
172731	0006578	PF132
171921	0006579	PF123
177776	0006580	PF321
178586	0006581	PF432
175072	0006582	PF123
171611	0006583	PF123
178331	0006584	PF432
177539	0006585	PF123
176354	0006586	PF312
177644	0006587	PF321
178667	0006588	PF432
173134	0006589	PF312

9.4 ANNEX 4 – Excerpt of the schedules provided by Carris

Date	Service	Order no.	Plate no.	Bus lines	Start node	End node	Start time	End time	Duration
01-02-2008	0018	088293	0006021	709/02	Miraflores (Est.)	Pç. Comércio	5:37	13:07	7:30
01-02-2008	0020	150657	0006023	76/03#76/01	Miraflores (Est.)	Algés	6:40	15:40	8:00
01-02-2008	0016	153541	0006024	709/06#709/01	Miraflores (Est.)	Pç. Comércio	6:04	15:34	8:09
01-02-2008	0017	116327	0006025	709/03#709/02	Miraflores (Est.)	Pç. Comércio	7:19	16:10	7:51
01-02-2008	0015	152374	0006022	48/01	Miraflores (Est.)	Marquês Pombal	6:31	14:01	7:30
01-02-2008	0011	144789	0006014	709/05	Miraflores (Est.)	Campo Ourique	5:15	12:29	7:14
01-02-2008	0012	162272	0006016	709/01	Miraflores (Est.)	Pç. Comércio	5:26	12:56	7:30
01-02-2008	0013	093424	0006019	60/11	Miraflores (Est.)	Alcântara Terra	5:25	12:55	7:30
01-02-2008	0014	158968	0006020	709/04#709/05	Miraflores (Est.)	Pç. Comércio	5:48	15:19	8:16
01-02-2008	0563	154733	0006411	28/11	Miraflores (Est.)	Miraflores (Est.)	4:33	12:03	7:30
01-02-2008	0561	138606	0006408	76/02	Miraflores (Est.)	Algés	4:05	11:35	7:30
01-02-2008	0562	096385	0006412	28/10	Miraflores (Est.)	Belém-Jerónimos	4:20	11:50	7:30
01-02-2008	0045	152129	0006056	723/08#723/05	Miraflores (Est.)	Algés	6:11	15:55	8:30
01-02-2008	0041	150193	0006057	723/05	Miraflores (Est.)	Algés	5:45	13:15	7:30
01-02-2008	0042	171310	0006747	723/03#723/08	Miraflores (Est.)	Algés	6:32	15:02	7:30
01-02-2008	0043	157325	0006061	723/07	Miraflores (Est.)	Algés	5:58	13:28	7:30
01-02-2008	0044	161268	0006062	723/01	Miraflores (Est.)	Algés	6:04	13:34	7:30
01-02-2008	0048	148954	0006063	76/01#76/03	Miraflores (Est.)	Algés	5:52	15:47	8:00
01-02-2008	0049	175722	0006764	723/06#723/07	Miraflores (Est.)	Algés	7:02	16:18	8:00

9.5 ANNEX 5 – Excerpt of the schedules provided by Carris for extra time calculations

Data	Serviço	Linha	Turno	Linha/Turno	Nó Inicio	Nó Fim	Hora Início	Hora Fim	Duração Efectiva	Dur. Global
01-02-2008	0984	709	06	709/06	Miraflores (Est.)	Miraflores (Est.)	15:57	19:44	03:47	03:47
01-02-2008	0986	53	06	53/06	Miraflores (Est.)	Miraflores (Est.)	16:35	21:35	05:00	05:00
01-02-2008	1040	28	12	28/12	Miraflores (Est.)	Belém-Jerónimos	18:28	21:08	02:40	02:40
01-02-2008	1065	750	16	750/16	Algés	Miraflores (Est.)	19:00	21:22	02:22	02:22
01-02-2008	1068	28	18	28/18	Miraflores (Est.)	Belém-Jerónimos	19:06	21:22	02:16	02:16
02-02-2008	0167	751	04,05	751/04#751/05	Belém-Jerónimos	Belém-Jerónimos	09:15	19:31	08:16	10:16
02-02-2008	0183	12	02,05	12/02#12/05	Estação Stª.Apolónia	Miraflores (Est.)	14:04	21:34	07:30	07:30
02-02-2008	0851	28	150S	28/150S	Miraflores (Est.)	Miraflores (Est.)	12:14	18:46	06:32	06:32
02-02-2008	0892	60	03	60/03	Alcântara Terra	Alcântara Terra	09:43	14:18	04:35	04:35
02-02-2008	0897	28	04	28/04	Estação Stª.Apolónia	Estação Stª.Apolónia	09:46	14:18	04:32	04:32
02-02-2008	0903	738	01	738/01	Calvário	Calvário	10:05	12:05	02:00	02:00
02-02-2008	0904	727	05	727/05	Campo Pequeno	Belém-Jerónimos	10:12	14:55	04:43	04:43