

FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Integrated Multimodal Transportation Dashboard

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Mestrado Integrado em Engenharia Informática e Computação

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Abstract

2 There are numerous sophisticated Information Systems (IS) that exist in the modern world which
are dedicated to management and supervision problems within the transportation sector. However,
4 individual solutions for different means of transport do not favor multimodal transport manage-
ment, while combined solutions are still rare and immature. Therefore, a need for a multimodal
6 supervision dashboard arose.

In terms of the scope of monitoring within transport management, the Level of Service (LOS)
8 is one of the most essential aspects requiring constant supervision. Therefore the dashboard will
provide a comprehensive view in order to observe whether or not all systems are functional and
10 operating at an acceptable LOS.

This creates a number of challenges, such as (1) the heterogeneity of the information sources,
12 which supply services and data of different scope, detail and quality levels, (2) the metrics for
LOS evaluation which should be identified, adapted or created for each transportation system;
14 these should then be applied based on the data that is available from the communication proto-
cols existing in the transportation area and (3) the visualization approach for the dashboard, which
16 should deliver the information on the multimodal transport LOS in an efficient and easily perceiv-
able way.

18 We hereby addressed this problem, aiming to create a functional prototype of a system for
the monitoring of multimodal transports. Such a system could become an essential tool in trans-
20 port systems supervision and management, supplying the necessary information for strategic and
emergency planning to the authorities and other active participants in the sector.

22 For the purpose of concept validation, a prototype was developed for the transportation net-
work of the city of Porto, Portugal. With historical data as input, it was possible to observe the
24 mutual dependencies between different transport modes. This verification manifests the impor-
tance of this tool in monitoring and evaluation of the level of service of multimodal transportation
26 systems at various levels of abstraction, since it permits an analysis based on a global vision of
different transport modes.

28 **Keywords:** multimodal transport, intelligent transportation systems, levels of service, trans-
portation dashboard, multimodal dashboard, performance measures

Resumo

2 **Titulo:** Painel Integrado de Monitorização de Transportes Multimodais

Atualmente, existem vários sistemas de informação sofisticados focados na resolução de prob-
4 lemas de gestão e supervisão na área de sistemas de transportes. No entanto, a maioria destas
soluções aborda individualmente cada um dos diferentes meios de transporte, o que não favorece
6 a geração de políticas e mecanismos integrados de gestão de transporte multimodal. Para além
disto, apesar de existirem algumas soluções combinadas, estas são raras e ainda bastante imaturas.
8 Surge, assim, a necessidade de um painel de monitorização multimodal.

Em relação aos parâmetros de monitorização no âmbito de gestão de transportes, o nível de
10 serviço é um dos aspectos essenciais, que necessita de supervisão permanente. Portanto, o painel
de monitorização deve fornecer uma visão geral de modo a se poder observar se todos os sistemas
12 estão funcionais e a operar a um nível de serviço aceitável.

Isso inclui uma série de desafios, tais como (1) a heterogeneidade das fontes de informação,
14 que fornecem serviços e dados de alcance diferente e com níveis de qualidade e detalhes variáveis,
(2) as métricas para a avaliação do nível de serviço, que devem ser identificadas, adaptadas ou
16 criadas para cada sistema de transportes, devendo ser aplicadas com base nos dados que estão
disponíveis a partir dos protocolos de comunicação existentes na area de transportes. Por último,
18 (3) a abordagem a utilizar para o painel de visualização, que deve fornecer a informação sobre os
níveis de serviço de transportes multimodais de forma eficiente e facilmente compreensível.

20 Deste modo, o problema foi abordado tendo como objetivo a elaboração dum protótipo fun-
cional de um sistema para monitorização de transportes multimodais. Tal sistema pode servir
22 como uma ferramenta essencial na supervisão e gestão de sistemas de transportes, fornecendo as
informações necessárias para o planeamento estratégico e de emergência para as autoridades e
24 outros participantes ativos no setor.

Para a validação de conceito, um protótipo foi desenvolvido para a rede de transportes da
26 cidade do Porto, Portugal. Com os dados históricos como dados de entrada, foi possível observar
as dependências mútuas entre os diferentes modos de transporte. Esta verificação demonstrou a
28 importância desta ferramenta na monitorização e avaliação do nível de serviço dos sistemas de
transportes multimodais em vários níveis de abstração, visto que permite uma análise a partir de
30 uma visão global dos diferentes modos de transporte.

Palavras-chave: transportes multimodais, sistemas inteligentes de transportes, níveis de serviço,
32 painel de monitorização de transportes, painel de monitorização multimodal, medidas de desem-
penho

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Ana Zaiat

2

*“The limits of the possible
can only be defined
by going beyond them into the impossible.”*

4

Arthur C. Clarke

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Abbreviations

API	Application programming interface
ATIS	Alliance for Telecommunications Industry Solutions
ATS	Artificial Transportation Systems
BFS	Breadth-first search
CEN	European Committee for Standardization (Comité Européen de Normalisation)
DAO	Data Access Object
DB	Data Base
DFS	Depth-first search
EC	European Commission
EJB	Enterprise JavaBeans
EMS	Event Management System
ETC	Electronic toll collection
EVP	Emergency Vehicle Preemption
EU	European Union
FDOT	Florida Department of Transportation
FIPA	Foundation for Intelligent Physical Agents
GIS	Geographic Information Systems
GTFS	General Transit Feed Specification
GUI	Graphical User Interface
HCM	Highway Capacity Manual
HDC	Highway Data Collection
HGV	Heavy goods vehicle
IATA	International Air Transport Association
ICT	Information and communications technology
IFOPT	Identification of Fixed Objects in Public Transport
IDE	Integrated development environment
IS	Information System
ISO	International Organization for Standardization
IT	Information Technology
ITS	Intelligent Transportation System
JP	Journey Planner
LOS	Level Of Service
MDOT	Maryland Department of Transportation
MIELE	Multimodal Interoperability E-services for Logistics and Environment sustainability
MM	Multimodal
MVC	Model–view–controller
NMEA	National Marine Electronics Association

ABBREVIATIONS

ORM	Object-Relational Mapping
POJO	Plain Old Java Object
PPM	Public Performance Measure
PT	Public Transport
RCMP	Regional Congestion Management Program
REST	Representational state transfer
RSQI	Rail Service Quality Index
RTMMIS	real-time multimodal information systems
SIRI	Service Interface for Real Time Information
SOA	Service-oriented Architecture
SOAP	Simple Object Access Protocol
STCP	Sociedade de Transportes Colectivos do Porto
SWOT	Strengths, Weaknesses, Opportunities, and Threats analysis
TC	Transport Canada
TCS	Traffic Control System
TIS	Traveler Information System
TEM	Trans-European North-South Motorway
TMS	Traffic Management Systems
TPEG	Transport Protocol Experts Group
TRB	Transportation Research Board
TS	Transport system
TSP	Transit Signal Priority
UK	United Kingdom
URI	Uniform resource identifier
US	United States
US	User Stories
V2I	Vehicle-to-infrastructure
V2V	Vehicle-to-vehicle
VCS	Video Control System
VDC	Vehicle Data Collection
VDOT	Virginia Department of Transportation
WCF	Windows Communication Foundation
XML	Extensible Markup Language
WWW	<i>World Wide Web</i>

Chapter 1

20 Introduction

22 With the growth of Information Systems (IS) and their expansion in various fields of our life, they
have occupied an important place in the Transportation area. The term ITS (Intelligent Transporta-
24 tion System) has been spread during recent decades and is defined as follows:

26 “Intelligent Transport Systems (ITS) are advanced applications which without em-
bodying intelligence as such aim to provide innovative services relating to different
modes of transport and traffic management and enable various users to be better in-
formed and make safer, more coordinated and ‘smarter’ use of transport networks.” 2
[PotE10, p. 1]

At the present time, various intelligent systems exist in the Transportation area, which permit 4
monitoring, control and other relevant functionalities for a given transport mode. However, the
individual solutions for different transport modes don’t favor multimodal transport management; 6
there are a very few solutions that combine different transport types in one application. Therefore,
a need for a multimodal supervision dashboard arouse – a dashboard that would permit to combine 8
transportation systems of different types and that would provide a comprehensive view in order
to observe whether all the systems are functional and operating at an acceptable Level of Service 10
(LOS). This work will address the above issue specifically for the Transportation Network of the
city of Porto, Portugal, as a case study. 12

1.1 Context

This project is carried out under the supervision and with the help of Armis, an IT company 14
based in Porto, Portugal, with a considerable experience in development of IT solutions for the
transportation area and other fields. 16

The paper refers to the area of Transport and IS existing within this area, mainly Intelligent
Transportation Systems (ITS) and Information and communications technology (ICT) Systems. It 18

provides a review of some studies and existing dashboards that address the issue of multimodal transport systems and their performance monitoring.

Another domain, which is in fact the central subject of this paper, is Level of Service (LOS) which measures the level of performance of a transportation system and its operational state. The methods and approaches to the measurement of LOS are considered and analyzed for different transport modes including road transport, railway, aviation and waterborne transport. The paper proposes an extensive hierarchy-based model that integrates all modes and sub-modes of transportation network for the evaluation of LOS of each component at all levels of abstraction.

Since no measurements may be made without information, it is necessary to analyze the possible sources of the input data for the dashboard, as well as the types of data supplied by these sources, its formats and channels. In the world of transport, thanks to the advanced state-of-the-art of ITS and ICT systems and the existing trends towards information sharing and standardization of communication between distributed applications, be it within one organization or between different entities, a certain number of recognized standards already exist in the transport area. The paper suggests an overview of the most important data communication protocols relevant to the study and their brief comparison.

The work was conducted to construct a prototype of a multimodal transportation supervision dashboard, in order to analyze the viability of the idea suggested by this paper and the possibility of providing a comprehensive view on the functioning of the whole transport network in a certain geographic area. For an application of this type it is crucial to possess such features as ease of use and understanding, configurability and quick alerting, in order to enhance the efficient use of the dashboard in real life as a tool for the decision making process. From a technical perspective, the proposed prototype consists of several major components or layers, such as the Communication Layer (retrieval of raw data from multiple sources available online), Data Layer (translation of raw data into useful information, its validation and further storage in a database), Control Layer (Business logic responsible for the calculation of LOS values and providing information to exterior applications through web-services) and Visualization Layer (user interface and graphical representation of transport systems operational state).

1.2 Motivation and Goals

It is a matter of common knowledge that multimodality in transport area has become one of the objectives in modern society. Multiple transport choices and their efficient cooperation are in the first place intended to reduce air pollution and other negative ecological impacts caused by transport. Another benefit brought by multimodality is optimized logistics. The efficient use of multimodal transport however, as well as the growth of urban transport networks in size and complexity, introduces certain challenges. It requires sophisticated management at different scales including a city-scale, which of course cannot be performed without timely and extensive information, including performance measures. The information in turn, especially that referring to performance, needs monitoring.

As it was said in the *Performance Measures for Multimodal Transportation Systems* study:

28 “Information on transportation performance may be used in a variety of policy, plan-
ning, and operational situations. It may be used by public agencies in assessing fa-
30 cility or system adequacy, identifying problems, calibrating models, developing and
assessing improvements, formulating programs and priorities, and setting policies. It
may be used by the private sector in making locational or investment decisions. It may
be used by the general public and media in assessing travelers’ satisfaction.” [PL96,
p. 86]

The institutions and organizations that may need to monitor LOS-related information on trans- 4
port include public authorities, city planning and transportation management entities, in order to
monitor operational state, analyze time behavior, perform a well informed government action, in- 6
vestment, etc. The possible users of the transport LOS information include private sector as well,
namely private transport operators and organizations that use transport service intensively, which 8
benefit from monitoring transport systems to evaluate the impact on their own operations, compar-
ing to competitors within the same sector and alternative modes, planning investment and making
2 optimization decisions. General public is another consumer of multimodal transport performance
information, which plays role in mode selection decisions.

4 The monitoring and control problems in transport area are often solved with the help of In-
formational Systems (IS) that now occupy an important place in transport management. In fact,
6 there exists a great variety of such IS: Intelligent Transportation Systems (ITS), Information and
Communications Technology (ICT) systems. However, the majority of such systems address a
8 single transport mode, and very few solutions combine different modes at the same time. Nev-
ertheless, demand exists for multimodal transport solutions that would provide a comprehensive
10 view of local Transportation Network [SAT⁺13, pp. 1-2]. Such systems could offer a number
of benefits to the public and authorities. One of the important features would be the possibility
12 of monitoring the levels of service (LOS) and performance of local transport networks, thereby
providing support in the decision making process in case of emergency events, etc.

14 The aim of this work consists in studying a possibility of providing a tool for integrated anal-
ysis of LOS of different transport modes existing in a city or another geographical unit. The
16 LOS measures should be combined in a single dashboard in an effective way, in order to permit
monitoring of functioning level of the whole local transportation system. The specific goals to be
18 achieved are as follows:

- Identify the protocols that supply data related to LOS for different transport means (air, land,
20 water, rail);
- Identify or define, when necessary, the metrics and scale for the evaluation of LOS of each
22 transport system and its relevant components, based on literature review;
- Formulate or adapt the methods of LOS degradation detection and localization for the inte-
24 grated transportation systems;

- Implement and test a prototype of a dashboard for an integrated LOS monitoring for multi-modal transport services.

The innovation introduced by this work includes the following aspects:

- **Scientific Contribution:** Synthesis of LOS evaluation methods existing in the World for all urban transport modes; implementation of algorithms that permit automatic inference of LOS of various transport modes, based on the information provided by protocols used for each mode, to be then monitored by means of an integrated dashboard.
- **Technological Contribution:** Proposed architecture of a multimodal dashboard, which would permit an integrated monitoring of the information about perturbations in each transport system operation related to its level of service (accidents, congestion, delays, etc.) by means of integrating varied data sources provided by transport services.
- **Practical Contribution:** Implementation of a functional prototype for an integrated multi-modal monitoring of various transport systems and decision support, to be used by Armis. Such an application would be useful to public authorities providing a comprehensive view on local transport systems operation, their real-time monitoring and decision support in cases of emergency or other situations, when transport is essential. Long-term monitoring with an access to historic data can unveil the weak points of the city transportation network and thus help in strategic transport management. Another advantage would be having such a monitoring facility for all transport modes in one single dashboard instead of the need to use several sources of information.

1.3 Thesis Structure

The Introduction chapter is followed by five other chapters that explicitly describe the problem addressed in this work and its proposed solution. Chapter 2 provides a review of the State-of-the-art in multimodal transportation IS, the studies performed in this field and existing solutions, data communication standards as well as an overview of the existing approaches and methods for transport systems LOS evaluation. Chapter 3 describes the problem in more detail and the proposed approach for its solution. It is followed by the Implementation chapter 4, which explains technical aspects of the dashboard prototype that was built for this project, its architecture and implemented functionalities. The Preliminary Results Chapter, 5, is dedicated to the tests performed on the prototype and tests results discussion. The final Chapter 6 analyzes the results achieved, the strong and weak sides of the project, its perspectives and future work.

Chapter 2

Literature Review

28

2 In case of a multimodal transportation dashboard, two domains are involved in the study: Trans-
4 portation and IS for transport needs. Specifically, due to the nature of the dashboard and its
6 objectives, the study is to be focused on the measurement of transport service levels. In the further
8 sections, starting with a brief analysis of transport modes, a review of the existing LOS metrics is
10 provided, followed by a review of IS existing in transport sector, studies performed on the topic,
as well as the existing multimodal dashboards and the analysis of existing protocols for data ex-
change in the area of ITS. The final part includes conclusions derived from the State-of-the-art in
multimodal transport IS and identifies the existing gaps in the area which result in opportunities
for this project.

2.1 Introduction

12 The importance of LOS-related information was well explained in an article "Performance Mea-
14 sures for Multimodal Transportation Systems" published by Richard H. Pratt and Timothy J. Lo-
max in TRANSPORTATION RESEARCH RECORD Journal in 1996:

"Information on transportation performance may be used in a variety of policy, planning, and
16 operational situations. It may be used by public agencies in assessing facility or system adequacy,
identifying problems, calibrating models, developing and assessing improvements, formulating
18 programs and priorities, and setting policies. It may be used by the private sector in making
locational or investment decisions. It may be used by the general public and media in assessing
20 travelers' satisfaction" [PL96, p. 86].

In order to cover the entire transportation network in a geographic location, it is first necessary
22 to identify and categorize all transport modes existing in an urban area. The main categories are
presented below, including the elements that require an evaluation of their operational state:

- 24 • Road transport

– Road traffic	
– Buses	2
– Bicycles	
● Rail transport	4
– Interurban Rail	
– Urban Rail (Metro and Light Rail)	6
● Aviation	
– Airports	8
– Helicopters	
● Waterborne (Maritime and Inland) transport	10
– Ports	
– Locks and Docks	12

It is also important to understand such concepts as Intermodal and Multimodal transport and the difference between them. Intermodal transport system involves "the movements of passengers or freight from one mode of transport to another, commonly taking place at a terminal specifically designed for such a purpose." [[RCS13](#), ch. 3] While the term multimodal transport system is defined as conjunction of more than one mode of transport (cycling, automobile, public transit, rail, etc.) and connections among modes [[Lit14](#), [EfAtP](#), p. 1].

2.2 Levels of Service

The concept of Level of Service, or LOS, is widely used for measuring traffic flow on roads, however, in recent decades it was also introduced for some other modes of transport, such as pedestrian, bus, public transport terminals [[Kit99a](#)]. In this project the same term will be used to measure the operational state for all transport modes, terminal types, as well as for the entire transportation systems. The metrics that exist for each transport mode are described further in detail.

2.2.1 Road Transport

Road transport includes a good variety of transport types and sub-modes, like private cars, coaches, buses, car-sharing, bike-sharing, pedestrian walking, taxi, rental cars and some other. The most studied and standardized aspect in terms of LOS evaluation is road traffic. Metrics exist as well for public transport, pedestrian walkways and bicycles.

Table 2.1: Average Generalized Passenger Car Equivalents On Motorways.

Vehicle type	Type of terrain		
	Level	Rolling	Mountainous
Trucks and Buses, Eh	1.5	3.0	6.0

2.2.1.1 Road Traffic

In road traffic LOS calculation "Highway Capacity Manual" (HCM), issued by the Transportation Research Board (TRB), US, is a worldwide point of reference. This manual suggests techniques for calculation of LOS for different road types by attributing values from "A" (the best, free vehicle flow) to "F" (the worst, high congestion), based on flow rates [BOA00, Ens12, p. 10-15, p. 32]. The flow rate stands for the number of vehicles counted for a period of time. The value is taken on a per lane basis and is measured in "pc/h/ln" units which stand for passenger cars per hour per lane [BOA00, Ens12, p. 10-24, p. 40]. Passenger car in this case is a generalized unit used for all types of vehicles but with different ratio depending on the terrain type. An example of passenger car equivalents used in HCM [TEM02, p. 11] can be found in the Table 2.1.

The same approach of road traffic LOS evaluation is used in Europe and is based on HCM. The Table 2.2 includes the European recommended standard of level of service criteria as per TEM Standards And Recommended Practice, 2002 [TEM02, p. 9].

2.2.1.2 Public Transport (Buses)

In case of road public transport, such as buses, the TRB in its "Transit Capacity and Quality of Service Manual" suggests a method for measuring the level of service for passenger waiting areas or terminals, such as bus stops, based on passenger density, Table 2.3.

This approach suggests clear metrics, however is intended for terminal planning purposes rather than real-time LOS monitoring. Still, such real-time information on some major urban terminals might be useful for transport network LOS monitoring.

Another metrics that exists for scheduled urban transit, measure service availability based on headway and number of vehicles per hour. The metrics was defined in "Transit Capacity and Quality of Service Manual. PART 5 QUALITY OF SERVICE", also by TRB [Kit99b, p. 5-16], and is available in Table 2.4.

The same metrics is used by the Florida Department of Transportation (FDOT) and explained in their "QUALITY/ LEVEL OF SERVICE HANDBOOK", 2013 [oT13, p. 32].

2.2.1.3 Bicycles

Bicycle LOS has been studied thoroughly during recent decades and various metrics have been created. The LOS value calculation is more complex than that of traffic LOS, since the level of service perceived by bicycle riders depends of multiple factors. In 2000, Highway Capacity Manual offered a reference table for measuring Bicycle LOS based on hindrance, "the fraction

Table 2.2: Levels Of Service Criteria For Basic Motorway Sections. [TEM02, p. 9]

LEVELS OF SERVICE CRITERIA FOR BASIC MOTORWAY SECTIONS				
LOS	MAXIMUM DENSITY (pc/km/ln)	MINIMUM SPEED (km/h)	MAXIMUM SERVICE FLOW RATE (pc/h/ln)	MAXIMUM v/c RATIO
FREE-FLOW SPEED = 120 km/h				
A	6	120	720	0.29
B	10	120	1,200	0.47
C	15	115	1,725	0.68
D	20	104	2,080	0.85
E	28	85.7	2,400	1.00
F	>28	<85.7	>2,400	>1.00
FREE-FLOW SPEED = 110 km/h				
A	6	110	660	0.28
B	10	110	1,100	0.44
C	15	109	1,635	0.66
D	20	101	2,020	0.84
E	28	84.0	2,350	1.00
F	>28	<84.0	>2,350	>1.00
FREE-FLOW SPEED = 100 km/h				
A	6	100	600	0.26
B	10	100	1,000	0.42
C	15	100	1,500	0.63
D	20	96	1,920	0.81
E	28	82.0	2,300	1.00
F	>28	<82.0	>2,300	>1.00
FREE-FLOW SPEED = 90 km/h				
A	6	90	540	0.24
B	10	90	900	0.39
C	15	90	1,350	0.59
D	20	90	1,800	0.78
E	28	80.4	2,250	1.00
F	>28	<80.4	>2,250	>1.00

of users over 1.0 km of a path experiencing hindrance from passing and meeting maneuvers" [BOA00, p. 11-15], as shown in the Table 2.5.

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Later, in 2009, the FDOT suggested a more sophisticated method for Bicycle LOS calculation, which considers such factors as average effective width of the outside through lane, motorized vehicle volumes, motorized vehicle speeds, heavy vehicle (truck) volumes and pavement condition [oT09, p. 26]. A relative importance is then attributed to each of these variables. After the application of an equation explained in the FDOT QUALITY/LEVEL OF SERVICE HANDBOOK, a numerical LOS score is calculated. The final value usually ranges from 0.5 to 6.5 and is stratified to a LOS letter grade, based on a reference table, Table 2.6.

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Table 2.3: Levels of Service for Queuing Areas [Kit99a, Ch. 2, p. 4-4]

Level of Service	Average Pedestrian Area (m ² per person)	Average Inter-Person Spacing (m)
A	≥ 1.2	≥ 1.2
B	0.9-1.2	1.1-1.2
C	0.7-0.9	0.9-1.1
D	0.3-0.7	0.6-0.9
E	0.2-0.3	≤ 0.6
F	≤ 0.2	Close contact

The National Transport Authority, Ireland, suggests a different bicycle LOS chart in its National Cycle Manual. The term used in the manual is "Quality of Service", which depends on such characteristics as Pavement Condition Index, Number of adjacent cyclists (the capacity for cycling abreast and overtaking), Number of conflict (potential interruptions to a cyclist per 100m), Junction time delay (the percentage of the actual time delay at junctions from the total journey time) and Heavy goods vehicle (HGV) influence (the percentage of HGVs and buses adjacent to cyclist against the total traffic volume). The metrics is presented in Table 2.7.

The difference between the metrics presented above consists not only in the LOS calculation method, but also in their purpose and possible application. The criteria suggested by HCM can be used in real-time bicycle LOS monitoring, while the National Cycle Manual of Ireland is rather focused on bicycle facility planning and improvement.

Though, overall, bicycles usually may have little significance as compared to other transport modes for the whole transportation network in a city or another geographical unit, there are countries where the share of bicycle trips is quite high. In the Netherlands, in 2007, 26% of all trips were made by bicycle [FdMV09, pp. 10,11]. Therefore, for some countries or cities measuring bicycle LOS might be as important as other transport modes LOS.

2.2.2 Rail Transport

Rail transport service levels and requirements are also well standardized and specified by the Transit Capacity and Quality of Service Manual, TRB US. The manual offers metrics for such elements of rail stations as platforms, stairways, escalators, elevators and even ticket machines among others [Kit99a, Ch. 3]. For this work, the most important element in terms of rail stations LOS measurement is platforms, which are measured equally to passenger terminals, based on passenger density, as shown in Table 2.3, "Levels of Service for Queuing Areas".

A similar, but wider and more complex concept exists in Europe and China for the rail transport, which is Rail Service Quality Index (RSQI). The purpose of such index consists in measurement and evaluation of quality of the railway passenger service. It includes such parameters as ticketing service quality, waiting service quality, train punctuality, comfort, security and exit service degree [LG09, p. 266]. This metrics however doesn't properly fit the objectives of the dashboard, due to its non-viability in the real-time environment and the focus on the quality of

Table 2.4: Service Frequency LOS: Urban Scheduled Transit Service. [Kit99b, p. 5-16]

LOS	Headway (min)	Veh/h	Comments
A	<10	>6	Passengers don't need schedules
B	10-14	5-6	Frequent service, passengers consult schedules
C	15-20	3-4	Maximum desirable time to wait if bus/train missed
D	21-30	2	Service unattractive to choice riders
E	31-60	1	Service available during hour
F	>60	<1	Service unattractive to all riders

service perceived by the passengers. Most of the parameters are hard to acquire citywide. Some of them don't change frequently and may be considered as static rather than dynamic, such as for instance "connections with other forms of public transport" [Ltd10, p. 13].

As for the rail lines on-time performance, a term Public Performance Measure (PPM) is used in United Kingdom. This indicator measures percentage of trains that arrive at destination on time [Rai, Kee13, p. 2].

2.2.3 Aviation

In aviation, airports are the core component for the evaluation of the operational state of the whole infrastructure. Although there exists a good variety of parameters that affect the airports functioning level, such as weather conditions, flight delays and others, it is a common worldwide practice to measure airport terminal LOS based on passenger density, similarly to public transport terminals LOS.

Airport terminal LOS, as a concept, appeared in 1970s and was developed by Transport Canada (TC). [MBBI10, p. 146]. The metrics used by TC to measure it are illustrated in Figure 2.1.

These metrics have been adopted by The International Air Transport Association (IATA), the trade association for the world's airlines, and have become an internationally recognized standard. The IATA terminal LOS standards are shown in the Table 2.8.

Criticism exists on these criteria suggesting that terminal LOS is a more complex concept that may depend on other factors, such as passenger perception, amount of time spent in a facility and some others [JP07, p. 525]. But despite that, IATA LOS standard is still used in airport planning and management.

Another important aspect in airports functioning is flights on-time performance. In this respect, Eurocontrol in its monthly reports [Dir13, p. 5] presents detailed analysis of such figures as:

- Average daily airport and en-route delays (minutes)
- Monthly airport and en-route delay trends (percentage)
- Proportion of airport and en-route delay by reason (percentage)
- Delays per location (minutes and percentage)

Table 2.5: LOS Criteria For Uninterrupted Bicycle Facilities [BOA00, p. 11-15]

LOS	Hindrance %
A	<=10
B	10-20
C	20-40
D	40-70
E	70-100
F	>100

- Average daily flights with ≥ 15 min en-route delay (minutes)
- 18 • En-route delays per flight (minutes)
- Reasons for Airport delays (minutes)
- 20 • Average Airport delays per flight (minutes)
- Average departure delay per flight (minutes)
- 22 • Monthly departure delays (percentage)

As for the threshold values for distinguishing normal operation from severe delays, the same
 24 report suggests analysis of delays within the following categories: over 15 minutes and over 30 minutes. [Dir13, p. 12]

2.2.4 Maritime and Inland Transport

In the area of Sea and Inland transportation, the LOS isn't a widely used concept. The only
 2 standard for LOS measurement that was found during the research is applied to river systems in
 the United States, specifically to locks and is presented in the Table 2.9. 4

The "Waterway Guidelines 2011", Netherlands, defines operating regimes for commercial nav-
 6 igation based on the type of schedule, listed in the Table 2.10.

The metrics presented above may be applied for identifying the type of facility or schedule in
 use. However, in the scope of this work, they are of a little help, since they don't permit measuring
 8 current state of an infrastructure or a facility that varies in time in terms of normal/abnormal
 behavior. 10

2.3 Information Systems in Transportation

ITS systems are being widely introduced in our everyday life due to the benefits that they bring,
 12 such as safety, comfort of use, wide range of services, higher efficiency on all levels from private
 car driving to road network management and reduction of pollution. 14

Based on their scope and functions, ITS systems may be classified into the following categories
 [Eze10, p. 8]: 16

Table 2.6: Bicycle and Pedestrian LOS Categories. [oT09, p. 27]

LOS	Score
A	≤ 1.5
B	> 1.5 and ≤ 2.5
C	> 2.5 and ≤ 3.5
D	> 3.5 and ≤ 4.5
E	> 4.5 and ≤ 5.5
F	> 5.5

- Advanced Traveler Information Systems – are systems that provide useful real-time information to drivers.

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- Advanced Transportation Management Systems include traffic control devices, such as traffic signals, ramp meters, variable message signs, and traffic operations centers.

- ITS-Enabled Transportation Pricing Systems, including electronic toll collection (ETC) systems.

- Advanced Public Transportation Systems that permit public transport coordination and information delivery to passengers among their other possible uses.

- Fully integrated intelligent transportation systems, that include vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) cooperative ITS systems, and are based on communication between various types of elements from road sensors to vehicles.

Another classification of ITS systems exists based on their application, according to a survey published in 2013 [QA13, p. 635]:

- Electronic Toll Collection (ETC)
- Highway Data Collection (HDC)
- Traffic Management Systems (TMS), which is quite a broad area that includes system subtypes, such as the following:

- Event Management System (EMS)
- Traffic Control System (TCS)
- Traveler Information System (TIS)
- Video Control System (VCS)

- Vehicle Data Collection (VDC)

- Transit Signal Priority (TSP)

- Emergency Vehicle Preemption (EVP)

Table 2.7: Quality of Service of bicycle facilities. [Nat11, p. 211]

Quality of Service	Pavement condition (PCI range)	Number of adjacent cyclists	Number of conflicts per 100m of route	Journey time delay (% of total travel time)	HGV influence (% of total traffic volume)
Level A+	86 – 100	2 + 1	0 – 1	0 – 5	0-1
Level A	66 – 85	1 + 1	0 – 1	6 - 10	0-1
Level B	51 – 65	1 + 1	1 – 3	11 - 25	2-5
Level C	41 – 50	1 + 0	4 - 10	26 - 50	6-10
Level D	20 – 40	1 + 0	>10	>50	>10

Another type of IS that exists in Transportation sector and that ITS cannot be separated from is Information and Communication Technology (ICT) systems. The term may be explained as "unified (tele)communications, the integration of telecommunications with computers, as along with the necessary software, middleware, storage and audio-visual systems that enable users to create, access, store, transmit and manipulate information. In other words, ICT consists of IT as well as telecommunications, broadcast media, all types of audio and video processing and transmission, and network based control and monitoring functions" [Sal12, pp. 9-10]. In the transport sector ICT systems are responsible for data collection, data communication and data quality [ET]. One of the examples of multimodal ICT systems is the MIELE (Multimodal Interoperability E-services for Logistics and Environment sustainability) project, conducted under the patronage of TEN-T EU (Trans-European Transport Network Executive Agency), which had as an objective the design and development of a "pre-deployment pilot for an interoperable ICT platform (the "MIELE Middleware") able to interface ICT systems (i.e. single windows, port community systems) in Italy, Portugal, Spain, Cyprus and Germany (the "National Vertical Pilots")" [Con13, p. 1]. The project addresses the issue of collaboration of different transport modes, such as maritime, railway, road, and air, for the purpose of multimodal freight transport management [OCMA13, p. 1].

Besides the systems described above, most transport related IS are closely connected to Geographic Information Systems (GIS) that "combine computer graphics technology with data base structures and techniques of spatial analysis" [Hux91, p. 1]. GIS tools play an essential role in performance measurements for transportation [Kit12, p. 39].

In addition, it should be mentioned that some other types of IS find their application in the world of transport, such as agent-based simulation systems, which can help in transportation analysis and control [FERO08, RB99, ROB07], and serious games, which help evolving managerial skills [RAKG13].

SYSTEM:	Level of Service Ranges (Square Meters Per Occupant)					
	A	B	C	D*	E*	F
Check-In	17.2FT ² /1.6M ²	15.1FT ² /1.4M ²	12.9FT ² /1.2M ²	10.8FT ² /1.0M ²	8.6FT ² /.8M ²	
Wait/Circulate	29.0FT ² /2.7M ²	24.8FT ² 2.3M ²	20.5FT ² /1.9M ²	16.1FT ² /1.5M ²	10.8FT ² /1.0M ²	Subsystem
Holdroom	15.0FT ² /1.4M ²	12.9FT ² 1.2M ²	10.8FT ² /1.0M ²	8.6FT ² /.8M ²	6.5FT ² /.6M ²	
Bag Claim Area (Without Device)	17.2FT ² /1.6M ²	15.1FT ² 1.4M ²	12.9FT ² /1.2M ²	10.8FT ² /1.0M ²	8.6FT ² /.8M ²	Breakdown
Pre-PIL 1.4	15.1FT ² /1.4M ²	12.9FT ² 1.2M ²	10.8FT ² /1.0M ²	8.6FT ² /.8M ²	6.5FT ² /.6M ²	

* For the periods up to 15 minutes within the design hour.

Figure 2.1: Transport Canada LOS standards for Airport Terminals. [MBBI10, p. 148]

2.4 Studies Overview

2.4.1 Current Trends of Real-Time Multimodal Urban Mobility Information Services (RTMMIS)

The work describes a study performed in 2011, that identifies the trends in real-time multimodal information systems (RTMMIS), within a research project aimed at "improving real-time public transport information of commuters of the Sophia- Antipolis agglomeration in France" [GST11, p. 1]. Analyzing the existing multimodal traveler information systems in and outside Europe, the study comes to the following conclusion on the availability of a multimodal view on five major types of information:

- Advice / tips ('User Manual' of the transport network, practical advising) – variable;
- Reference (available reference information sources) – Public Transport plus car;
- Recurring or planned events – rare;
- Delays, including car park availability, road travel times – no;
- Perturbations – partial.

The results of the analysis clearly show current weak points in traveler information systems that need attention. Two important issues that the study describes are local coordination and open data which are crucial for multimodal IS of any kind, due to the involvement of numerous infrastructures and organizations usually with a high share of private sector. The key success factors identified by the study are [GST11, p. 9]:

- Sharing data
- Common tools for coordinated mobility management and user information (data provision platform, off-line observatory, traffic management tools, web portals)

Table 2.8: IATA LOS standards for Airport Terminals (figures in square meters). [MBBI10, p. 149]

TERMINAL AREA	A	B	C	D	E
Check-in Queue Area	1.8	1.6	1.4	1.2	1.0
Wait/Circulate	2.7	2.3	1.9	1.5	1.0
Hold Room	1.4	1.2	1.0	0.8	0.6
Baggage Claim	2.0	1.8	1.6	1.4	1.2
Government Inspection Services	1.4	1.2	1.0	0.8	0.6

- User participation.

Despite that the study considers multimodal solutions existing for traveler's needs, rather than for situation monitoring by public authorities, it provides a useful overview of multimodal solutions existing at the moment as well as identifies major problems, weak points and key factors in this area.

2.4.2 ITS Action Plan. Study "Towards a European Multi-Modal Journey Planner"

The study has been carried out within the ITS Action Plan policy framework, promoting the development of multimodal travel information services. The objective of the study is "to support the EC's work towards a European multi-modal journey planner, and to prepare the elaboration of functional, technical, organizational and service provision specifications as required by the ITS Directive" [TR11, p. 3]. The study provides a detailed analysis of some of the existing journey planners on regional, national and international scale, pointing out their strong and weak sides:

- Regional scale: transport-idf.com, vialsace.eu, jv-malin.fr
- National scale: Rejseplanen.dk, Transport Direct, IDOS
- International scale: EU-Spirit, Google Transit.

The study also suggests a detailed review of technical aspects of journey planners, taking into account transport multimodality and multiple information sources. It describes three main types of architecture:

- Centralized
- Decentralized with a central DB and application
- Fully decentralized

Decentralized architectures collate data from multiple local sites into a centralized database. Different parts of the itinerary are collected from the different sites and then assembled into the full journey by the application. Whereas, in case of a centralized architecture, the main site aggregates data from multiple sources in a central database and performs all calculations.

The data flow is divided into a number of consecutive steps:

Table 2.9: Definition of Levels of Service for Inland Locks. [Mck13, p. 6]

Level	Title	Description	Guideline for Range of Lock Operation Data
1	Full Service 24/7/365	24 hours/day, 7 days/week, 365 days/year	More than 1,000 commercial lockages per year
2	Reduced Service - Two Shifts Per Day	16-20 hours/day, 7 days/week, 365 days/year (two shifts of either 8 or 10 hrs)	Between 500 to 1,000 commercial lockages per year.
3	Limited Service - Single Shift	8-12 hours per day, 7 days/week, 365 days/year	Less than 500 commercial lockages per year or greater than 1,000 recreational lockages per year
4	Scheduled Service - Set times per day	Lockages (including recreation craft) at set times per day. For example 8 am and 4 pm.	Limited commercial and/or substantial recreational traffic, with a more consistent pattern of lockage
5	Weekends & Holidays	Lockages on weekends and holidays only	Little to no commercial lockages with significant recreational lockages (500 or more per year) with no consistent pattern.
6	Service by Appointment	Commercial lockages by appointment	Limited commercial traffic with no consistent pattern of lockage.

- Raw data (basic data acquisition)
- Data validation and integration 14
- Information production (processing phase)
- Service generation (insertion of data in a service system) 16
- Service delivery (dissemination)
- Consumption (by users) 18

The study makes a review of the existing standards on data models and data exchange interfaces, as shown in the Table 2.11. 20

In general, the study contains some useful information in the scope of this work, such as architecture and standards overview, however is focused on journey planning needs, rather than transport network performance monitoring. 22

2.4.3 Designing A Multi-Modal Traveler Information Platform For Urban Transportation 24

This thesis project was performed in 2008 - 2010, at Georgia Institute of Technology, the United States, and was aimed at creation of a multimodal travel information platform for urban area 26

Table 2.10: Operating Regimes for Commercial Navigation, The Netherlands [aN11, p. 144]

regime	Monday	Tuesday – Friday	Saturday	Sunday	total weekly hours
1	0 - 24	0 - 24	0 - 24	0 - 24	168
2	6 - 24	0 - 24	0 - 20	8 – 20	146
3	6 - 22	6 - 22	8 - 20	9 – 17	100
4	6 - 22	6 - 22	8 - 18	–	90
5	7 - 19	7 - 19	–	–	60

transport [Dos10, p. xii]. The work reviews the standards, frameworks and specifications, existing in the United States and worldwide, which are listed in the Table 2.11, as well as some examples of journey planning solutions existing in the world.

The set of requirements defined for the platform’s final version, RideVia:

- Store real-time transit data
- Store data for multiple modes
- Display real-time and static data
- Drive multiple applications
- Multi-modal trip Planning
- Store real-time data history
- Use of uniform data formats
- Scalability and extensibility
- Maintainability
- Loose coupling between layers

The Figure 2.2 shows a general view of a traveler information platform architecture that includes multiple data sources, as suggested by the study.

The work addresses some of the challenges of this project that are introduced by the multi-modality, such as multiple sources of information, information exchange standards, transforming raw data into useful information. The objectives of the work however are different, in the way that it is intended for journey planning purposes, where the final user would be a traveler, and doesn’t address such issues as transport modes performance monitoring.

2.4.4 Measuring Multimodal Transport Level of Service

In the report conducted by Adib Kanafani and Rui Wang, University of California, Berkeley, in 2010, the authors focus on the elaboration of a framework for the evaluation of the level of service of multimodal transport [KW10, p. 1]. The authors speak in their work of the lack of an

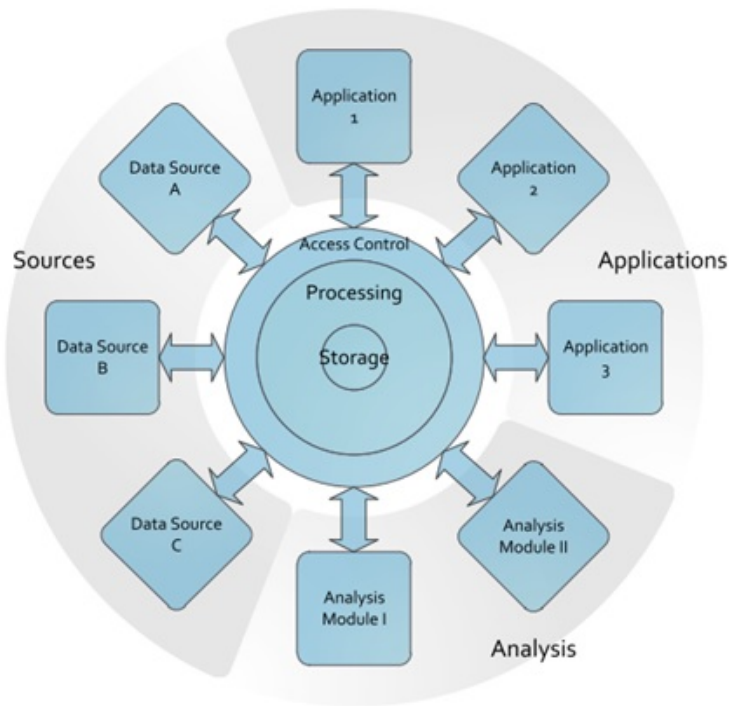


Figure 2.2: Traveller information platform architecture. [Dos10, p. 59]

established approach to the multimodal transport LOS measurement. They analyze performance measurement applicable to different points of view and define two major perspectives: the user's perspective and the provider's perspective. In the context of the work, the user represents the consumers of the transportation services while the term provider stands for the government and private service providers. The perspective defines the attributes that should be considered during LOS evaluation. For instance, in case of user perspective, the authors consider such characteristics as time, cost, safety reliability and flexibility. While government and public agency's perspective includes the following attributes: equity or utility, energy consumption, emissions, utility for users and monetary cost. In general, the work suggests an interesting point of view on the measurement of multimodal transport LOS for the purposes of decision-making process, such as planning and investments.

In relation to this project, the "Measuring Multimodal Transport Level of Service" has some similarity in the proposed approach to LOS measurement by means of aggregation of a certain set of attributes with weights. Though the purpose of measuring LOS is different to that of the project. The framework proposed in the work requires prior studies that would produce the input values for a certain location in order to help decision-makers in long-term strategic planning. This project, however, addresses the issue of service availability and operational state in real-time mode first of all.

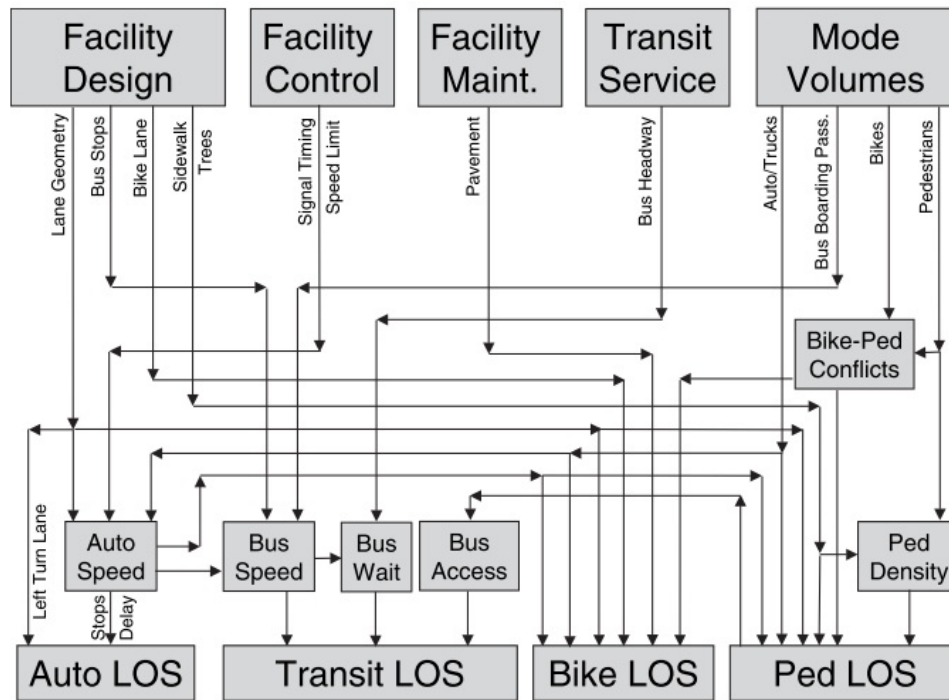


Figure 2.3: LOS Model Interactions [DRF⁺08, p. 95]

2.4.5 Multimodal Level of Service Analysis for Urban Streets

The report issued by TRB within a NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM is another example of a framework for measuring multimodal transport LOS. It describes an extensive study that had been carried out, including a comprehensive analysis of existing LOS evaluation metrics and frameworks and a survey of LOS perceived by different participants of road flow (car drivers, transit passengers, bicycle riders, and pedestrians). The objective of the work was to "develop and test a framework and enhanced methods for determining levels of service for automobile, transit, bicycle, and pedestrian modes on urban streets, paying particular respect to the interaction among the modes" [DRF⁺08, p. 3]. Though the report does not aggregate LOS values of different modes in one single value, it provides a profound analysis of modes interactions, as it is seen in Figure 2.3.

The report is dedicated solely to road transport and is intended to help in urban street planning and decision making.

2.4.6 Standards in Related Works

The Table "Standards, frameworks and specifications analysis in related works", 2.11, lists communication standards and frameworks that were reviewed by the related works described above.

Table 2.11: Standards, frameworks and specifications analysis in related works. (Tempier and Rapp 2011; Doshi 2010)

Standards, frame-works, specifica-tions	Geography of origin and/or application	Description	Study 2.4.2	Study 2.4.3
National ITS Architecture	US	A framework for planning, defining, and integrating ITS		Y
SAE J2354	US	Message Sets for ATIS		Y
GTFS	US and In-ternationally	General Transit Feed Specification, a format for public transportation schedules and associated geographic information, developed by Google, Inc.		Y
Transmodel	Europe	The European Reference Data Model for Public Transport	Y	Y
TransXChange	UK	A UK nationwide standard for exchanging bus schedules and other related data, which is based on Trans-model		Y
SIRI	UK and Eu-rope	The Service Interface for Real Time Information, about public transport, based on Transmodel	Y	Y
NETEX	Europe	A Standard currently in development for exchanging PT reference data	Y	
TPEG-PTI	UK and Eu-rope	An ISO standard for the description of real-time information on Public Transport	Y	
IFOPT	Europe	A data model for the Identification of Fixed Objects in Public Transport	Y	
NMEA 0183	Internationally	Interface Standard for electrical signal requirements, data transmission protocol, and specific sentence formats for a serial data bus		Y

2.5 Dashboard and Traveler Information System Examples

²⁶ This section presents some of the dashboard and Traveler Information System examples found during the research phase. The criteria used whilst researching, included transport infrastructures related information, transport performance indicators, real-time information, multimodality as well as different options of graphic solutions for dashboard.

2

2.5.1 CityDashboard

The CityDashboard [Lon] by University College London, is an example best fitting the goals of this work, being a properly multimodal dashboard, displaying real-time information, configurable

4



Figure 2.4: The FAST Dashboard [(RT)]

to a certain extent, allowing layout changes by moving information blocks. It isn't focused on transport, but it does offer some transport related information, such as:

- Tube line status
- Bike sharing (bikes available, stations empty, etc.)
- Buses and underground trains in service
- Street cameras snapshots

This dashboard however is missing information on other modes of transport, such as airport functioning, waterborne transport (only river level is available) and doesn't suggest proper transport networks LOS related data, that might include road congestion levels, buses on-time performance, etc.

2.5.2 The FAST Dashboard

This dashboard [(RT)] is not multimodal, it is focused solely on road traffic information in Las Vegas, Nevada, US. But it offers an interesting combination of charts, map and camera views that allow monitoring current situation with roads LOS, daily and weekly historical data, monthly average speeds and some other useful information, Figure 2.4.

2.5.3 RCMP Roadway Performance Dashboard

Regional Congestion Management Program (RCMP) Performance Dashboard [oG] displays charts with historical data on roads performance indicators such as lane miles by LOS, Centerline Miles by Pedestrian, Bicycle and Transit LOS. It is LOS-oriented and multimodal in the sense that it

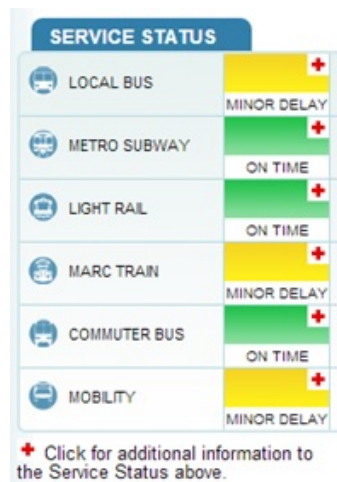


Figure 2.5: Public Transport Service Status, Maryland Department of Transportation. [oTa]

considers different types of road travel modes, such as vehicle, pedestrian, bicycle and transit. However the information is updated only every two years and doesn't include other transport modes. 26

2.5.4 Maryland Department of Transportation

- 2 Maryland Department of Transportation (MDOT), US, on its website [oTa] offers comprehensive information on all transport modes to traveler, including current service status of public transport
4 networks, as shown in the Figure 2.5.

MDOT web portal is properly multimodal and contains real-time information on transport
6 networks service status, including road congestion levels, however it is not aimed at transport network LOS monitoring, but rather at providing information to traveler. Besides, every piece of
8 information needs browsing, since it is spread on separate web-pages.

2.5.5 VDOT Dashboard

- 10 Virginia Department of Transportation (VDOT) dashboard [oTb] is an interesting example of a dashboard in terms of selection of high level performance indicators and their graphical presenta-
12 tion, Figure 2.6.

This dashboard contains historical road transport data, such as congestion levels, safety, road
14 surface condition and some other information.

2.5.6 Trafiken.Nu Journey Planner

- 16 Trafiken.Nu [Tra] is one of European multimodal traveler information portals that displays real-time roads congestion level, public transport service status and information on disruptions. It is a
18 Swedish portal that offers traveler information for three cities: Stockholm, Gothenburg and Skane.

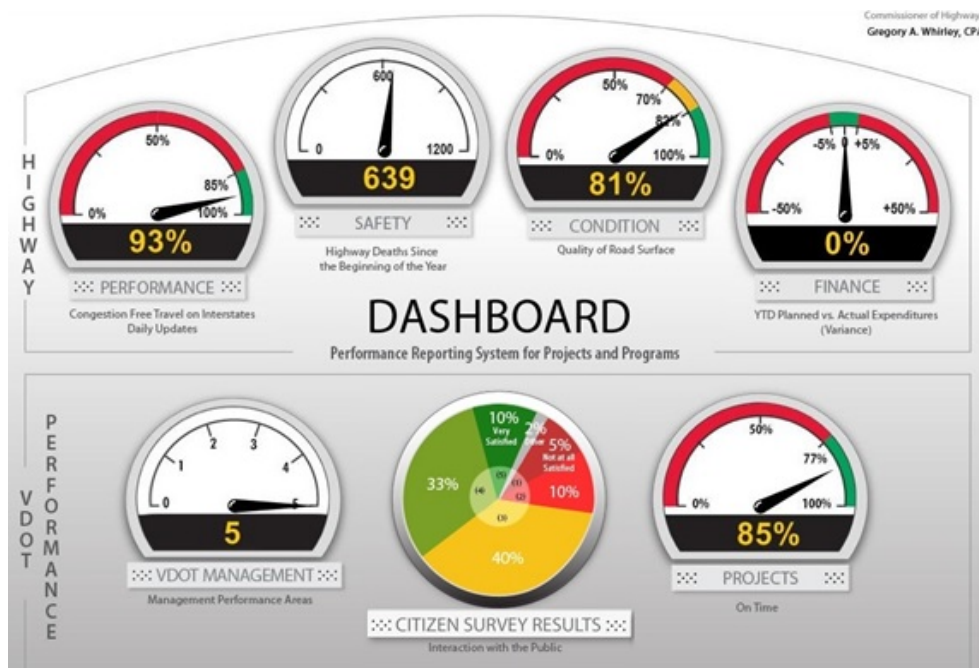


Figure 2.6: VDOT Dashboard [oTb]

It also offers a multimodal trip planning tool. Though this portal provides information on many modes of urban transport it is, however, missing information on airport functioning regime.

2.5.7 TRAVIC

Another interesting example which cannot be omitted in this paper is TRAVIC (Transit Visualization Client), a worldwide transit tracker web-application developed by geOps, Germany, in a collaboration with the University of Freiburg [GeOb, GeOa]. This on-line dashboard provides information on the PT providers worldwide and, on zoom-in, it allows viewing current expected vehicle position on the map and its route details, such as line, direction, route schedule for the vehicle. The dashboard also has an animation feature, which allows viewing vehicle's movement on the map, which is calculated based on a topological network, street information and service line schedules defined per stop. The solution also offers different abstraction levels depending on zoom: from PT operators at a higher scale to vehicles of local-importance PT lines' at the lowest scale. As per the information on the dashboard, for some PT service providers it works in a real-time mode. The data on public transport is acquired for the application through the protocol elaborated by Google - General Transit Feed Specification (GTFS). Despite that at this stage TRAVIC does not contain real-time operational status information for the integrated transport modes, and that the modes observable in the solution are limited by rail and road public transport, it is an interesting example illustrating a map-based approach of PT-related information visualization with data obtained from protocols.

Table 2.12: Data Communication Protocols Comparison (Y = Yes, N = No).

Protocol	Geography	Used in Portugal	Road Traffic	PT	Location Referencing	XML supported
TPEG	EU, Worldwide	Not confirmed	Y	Y	Y	Y
DATEX I, II	EU	Y	Y	N	Y	Y
SIRI	UK, EU		N	Y	Y	Y
NeTEx	EU		N	Y	Y	Y
TransXChange	UK		N	Y		Y
GTFS	Worldwide	Y [ptpL]	N	Y	Y	N

2.6 Data Communication Protocols

6

Data communication protocols are essential for applications comprising multiple exterior data sources, like this project. Many protocols exist today in the world for transport related data exchange. Efforts have been and are being performed for their standardization and increased compatibility. The Table 2.12 suggests a brief comparison based on some most important features for the major protocols used in Europe. The features taken into account are: geography of application, whether a protocol is used in Portugal, supply of information on road traffic and/or public transport (PT), location referencing and support of XML files for data transmission over the Internet.

8

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To date, TPEG is the only protocol family covering data exchange both on road traffic (TPEG-RTM) and public transport (TPEG-PTI) [TIS12, pp. 7-9].

4

DATEX is Europe-wide standard for road traffic information exchange. In Portugal it is used by INIR, Brisa and Estradas Portugal [BLA12, pp. 26-28] [vdVLW13, Annex].

6

SIRI is a European protocol for real-time public transport information exchange, which is widely used in Europe, especially UK. It also served as a base for the development of NeTEx standard [CEN13, CEN09, Mob12, p. 7].

8

NeTEx is a new protocol, which is expected to become a new Europe-wide standard for communication and data exchange on all mass public transport modes, including rail, bus, ferry and airports [CEN09, p. 8]. Some of its parts are still on the development phase. It is based on other protocols and standards, such as SIRI, Transmodel and IFOPT [CEN09, p. 7]. The standard is compatible with TPEG and some country-specific standards, such as VDV 452 and Neptune.

10

12

14

GTFS, defined as The General Transit Feed Specification, is a standard developed by Google for sharing public transport schedules and geographic information [Goob]. The protocol isn't widely used in Portugal yet, but it is gradually gaining popularity.

16

2.7 Conclusions

18

LOS concepts and their measurement methods are well defined and standardized for some transport modes and infrastructure elements, such as road traffic, airport and public transport terminals, waiting areas, flight delays. However, the existing metrics unfortunately do not fully cover all

20

Table 2.13: Dashboard and Traveller Information System Examples Comparison.

Source Name	Scope	LOS Indicators	RT	MM	Dashboard
CityDashboard	Transport and more	Y	Y	Y	Y
FAST Dashboard	Road transport	Y	Y		Y
RCMP Dashboard	Road transport	Y		Within road mode	Y
MDOT	Transport, TIS	Y	Y	Y	
VDOT Dashboard	Road transport	Y			Y
Trafiken.Nu	Transport, TIS, JP	Y	Y	Y	
TRAVIC	PT	N	Y/N	Within PT	Y

modes and components of urban transport networks. Namely, the question of measuring water-
borne transport facilities, like ports, docks and locks, remains open and requires consultations with
professionals working in the area. When metrics are available, they are usually applied to small
facilities or components of a transport system, e.g. a transit terminal or a road segment. However
the goals of this project include providing a judgment on the operational status of entire transport
modes and the whole transportation network in a monitored region. In these cases, a strategy for
evaluating the LOS at different levels of abstraction and granularity needed to be defined for the
dashboard.

Besides the absence of information on certain LOS metrics, there exists a significant diver-
sity of approaches to transport systems performance evaluation which vary between departments,
towns, regions and countries. That presented another challenge and required a thorough planning
of the application and LOS evaluation model to ensure their flexibility and extensibility.

Many US governmental dashboards were found offering transport LOS related information
within a scope of a city, state or countrywide. Most of these examples however contain historical
rather than real-time data and few of them are multimodal. The majority of multimodal transport
portals and applications that exist today are Traveler Information Systems (TIS) and/or Journey
Planners (JP) and are not focused on observing transport systems status. A brief comparison of the
examples described in this chapter is presented in the Table 2.13. Comparison criteria were chosen
based on their relevance to this work and include the scope, presence of LOS related information,
real-time information, multimodality and the form of presentation.

As it was mentioned before, the CityDashboard, UK, corresponds to the goals of this work to
the highest degree, though it doesn't cover all transport modes.

The gaps that were detected in the literature review exhibit the lack of integrated multimodal
transport monitoring solutions and create an opportunity for innovation. As it was stated in one of
the reviewed studies, the data access is one of the key issues in building applications that provide
information on multimodal transport [GST11, p.10]. This may be an obstacle in cases, when
there are numerous stakeholders both from private and public sector, due to restricting data access
policies of the data owners. In this respect, a governmental will and mutual benefits may play
an essential role, which requires a detailed analysis of possible purposes of use of the dashboard

Literature Review

26 or information provided by the system through web-services for the key participants in order to
deliver the vision of possible opportunities for the stakeholders. Another challenge consists in the
28 diversity of data communication channels and formats. However, as the study of the existing pro-
tocols shows, there already exist some common standards as well as Europe-wide trends towards
30 further standardization of data communication for transport area. This will facilitate considerably
the elaboration of the application and its further introduction to the market.

Chapter 3

Problem and Methodology

This chapter provides a closer look at the problem and the necessary steps towards its solution. 2
The methodological approach section includes a description of major phases of the project before the implementation, its proposed architecture and an approach to dashboard presentation. 4

3.1 Problem Definition

The objective of the work consists in studying the possibility of creating a tool for monitoring 6
multimodal transport network performance level in an integrated form in real-time mode. Such a tool should provide support in transport management and decision-making process. 8

This task imposes a certain number of challenges to overcome. First of all it is necessary to build a set of LOS measurement metrics to cover all transport modalities integrated in the solu- 10
tion. These metrics usually measure performance level of small components of a transport system, such as a road segment or a public transport service line, etc. Thus, the next step would be un- 12
derstanding how to evaluate LOS of entire transport systems (rail transport, maritime transport, etc.) and the transport network as a whole, based on the measures obtained for the smaller compo- 14
nents. The diversity of transport modes, infrastructures and performance measure policies presents
2 another challenge, implying heterogeneous data structures and entity relationships, diverse LOS
scales and calculation methods. It is critical in these conditions to identify similar patterns and
4 define ontology that could be applied to all modes and their components. Also, the high number
of stakeholders brought by multimodality results in multiple data sources and thus diverse data
6 formats. Therefore the system's architecture should be tailored to integrate multiple data sources.

The presentation metaphors for the dashboard require a separate analysis. It is necessary to
8 understand how to deliver the information to the user in an efficient and understandable form
and how to integrate different transport domains and levels of abstraction in a single dashboard.
10 Understanding what output information is available for the user is crucial for the accomplishment
of this task.

12 The overview and analysis of the proposed solution and approaches to addressing the challenges derived from the problem are presented in Section 3.3.

14 3.2 Requirements Analysis

The main requirements to the integrated multimodal transportation dashboard consist in the following:

- Real-time monitoring of urban transport systems LOS; 2
- Comprehensive view of the information related to different transport modes;
- Ease of use and understanding; 4
- Quick alerting;
- Configurability and customization. 6

This brings up certain problems that need to be solved, such as:

- LOS measuring methods for different transport modes (when measured, it is usually only done for a single mode); 8
- LOS evaluation based on data supplied by protocols and other available sources; 10
- The design of an integrated view on various transport systems;
- Combination of different modes LOS in one dashboard. 12

The next subsections explain the software quality requirements that were identified for the proposed solution and the involved stakeholders. 14

3.2.1 Software Quality Requirements

The system's quality requirements were defined based on ISO 9126 standard that defines Software Quality Requirements model [PPM10, Fle] and consist in the following: 16

- Functionality 18
 - Suitability - the conformity of the system to its specification;
 - 2 – Accuracy - correctness of functions results;
 - 4 – Interoperability - this is an essential characteristic of the system, taking into account its dependence on diverse information sources (communication protocols, etc.);
- Reliability

- 6 – Fault tolerance - since the concept of a dashboard implies continuous usage of an application, the system should be capable of error handling;
- 8 – Recoverability - the ability of the system to resume working after a failure without data loss;
- 10 • Usability
 - 12 – Understandability - the system's interface should be intuitive to users of different level of computer literacy
 - 14 – Learnability - the system shouldn't present any challenges to its users in learning process, which should take little time;
 - 16 – Operability - users should be able to comprehend the current status of transport systems "at a glance" and reach the necessary information easily;
- Efficiency
 - 18 – Time behavior - for an application working in a real-time mode, response time should be reduced to useful time;
 - 20 – Resource utilization - taking into account the volume of information implied by multimodality, optimal resource use should be one of the major concerns;
- 22 • Maintainability
 - 24 – Changeability - an important feature due to the high number and diversity of stakeholders and possible users of the system, as well as use purposes;
 - 26 – Stability - since the probability of further modifications is expected to be high, the system should be able to continue functioning in an expected way;
- Security - the system is projected to provide public and authorization-based access to its users, therefore, it should be ensured that the protected functionalities and information should be prevented from unauthorized access.

2

3.2.2 Stakeholders

The audience of the information on multimodal transport is very wide and diverse. It includes local authorities, public and private organizations and general public - all providers and users of the transport service. Literally every person and organization is related to or dependent on the transportation to some extent. However it is necessary to identify user groups in order to understand the purposes of their use of the information on transport LOS and use patterns. The typical classification in such case is subdivision into service providers and consumers [KW10, p. 4]. However, within the context of this work a more detailed analysis of stakeholders is essential.

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The dashboard stakeholders list suggested in this paper is based on the transport infrastructure of the city of Porto and is presented in Table 3.1. The table explains possible contributions from each stakeholder and purposes of use. 12

Figure 3.1 reflects interconnections between the stakeholders (public and private service providers), where each connection or arrow represents a benefit delivered by the LOS information on a certain transport mode. Correspondingly, a bi-directional connection stands for a mutual benefit. As it may be seen on the figure, the stakeholders are densely connected, where the highest degree of incoming benefits is attributed to Port, Taxi and Road Traffic Regulation Organization. 14
16
2 The principle stakeholder, which is Local Authorities, is missing in the figure, since it is understood that, as a regulating institution with social responsibility, it has the highest in-degree of
4 benefits being connected to all nodes from the graph.

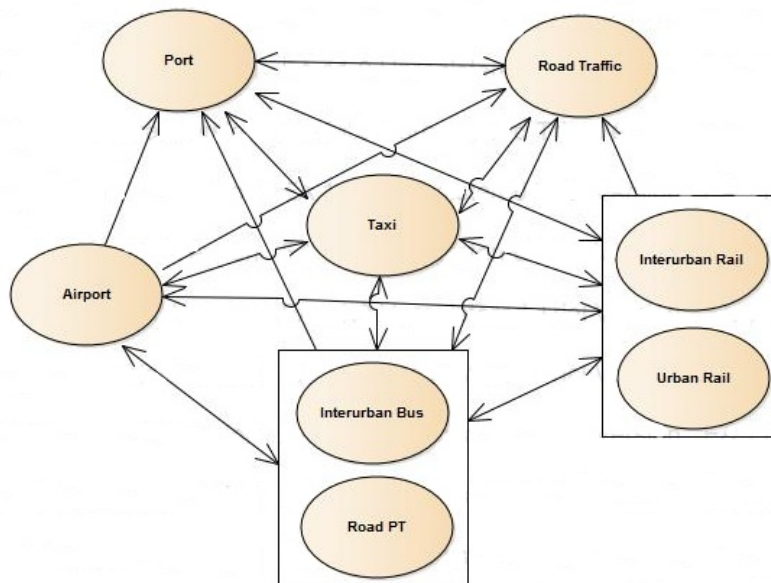


Figure 3.1: Benefits Net.

Table 3.1: Stakeholders

Stakeholder	Contribution	Use
Local Authorities	Access to information	A tool for emergency and capacity planning, strategic planning; Detection of weak sides of transport network; one dashboard with all modes instead of several single mode dashboards; real-time travel information available to the public for increased convenience
Road Traffic Regulation Organizations	Information on roads and road traffic	Nonrecurring congestion and other perturbations forecasts and warnings; Expected traffic growth with location detail; real-time travel information available to the public for increased convenience; traffic flow regulation delegated to travelers
Road PT (urban bus)	Bus schedules; arrival stats; perturbations	Road traffic perturbations for on-road situation monitoring; perturbations / events on interconnected modes (airport, port, rail stops, etc.); estimation of extra passenger flow in case of perturbations with other modes; competitor monitoring and comparison; real-time travel information available to the public for increased convenience
Urban Rail	Train schedules; train arrival stats; train perturbations	Perturbations / events on interconnected modes (airport, port, rail stops, etc.); estimation of extra passenger flow in case of perturbations with other modes; competitor monitoring and comparison; real-time travel information available to the public for increased convenience
Interurban Bus	Bus schedules; arrival stats; perturbations	Road traffic perturbations for on-road situation monitoring and delays forecast; estimation of passenger flow variation in case of perturbations with other modes; competitor monitoring and comparison; real-time travel information available to the public for increased convenience; smart choice of transport mode for arrival/leaving offered to passengers
Interurban Rail	Train schedules; train arrival stats; train perturbations	Estimation of passenger flow variation in case of perturbations with other modes; competitor monitoring and comparison; real-time travel information available to the public for increased convenience; smart choice of transport mode for arrival/leaving offered to passengers
Taxi	service availability; car availability	Estimation of passenger flow with location detail based on perturbations with other modes and arrival times; real-time travel information available to the public for increased convenience
Airport	Flight schedules; delays; airport perturbations	Perturbations / events on interconnected modes (road, PT, rail, taxi); real-time travel information available to the public for increased convenience; smart choice of transport mode for arrival/leaving offered to passengers
Port	Port status, events and perturbations; port schedules and delays; Locks and Docks availability	Perturbations / events on interconnected modes (road, rail, aviation); real-time travel information available to the public for increased convenience; real-time information available to the businesses; advertising of passenger trips/cruises to the public

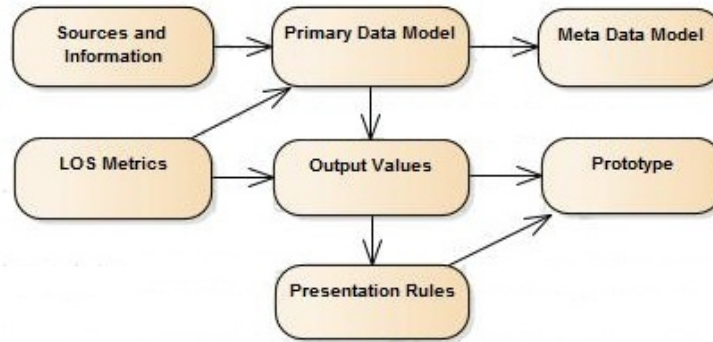


Figure 3.2: Workflow.

3.3 Methodological Approach

This section is dedicated to the methodology used in the project, which was defined based on the software requirements engineering process partially described in the previous section and complemented by the Appendix E. The work-flow may be divided into six phases, as shown in the Figure 3.2.

3.3.1 LOS Metrics

The study of the relevant literature and state-of-the-art on LOS metrics and scales applied to different transport modes served as a background for defining LOS calculation model for the project.

However, the existing metrics unfortunately do not fully cover all modes and components of urban transport networks. For instance, the method for measuring ports operational state was specially defined for this project, as well as some other indicators.

The existing metrics that have been included in the project based on their applicability to the case study are as follows:

- Road Traffic LOS, defined by "Highway Capacity Manual" (HCM), issued by the Transportation Research Board (TRB), US, which is a worldwide point of reference. This manual suggests techniques for calculation of LOS for different road types by attributing values from A (the best, free vehicle flow) to F (the worst, high congestion), based on flow rates [BOA00, p. 10-15] [Ens12, p. 32].
- Terminal LOS for Road and Railway Public Transport, such as bus terminals, subway terminals, etc. The Transportation Research Board (TRB), US, in its "Transit Capacity and Quality of Service Manual" suggests a method for measuring the level of service for passenger waiting areas or terminals based on passenger density [Kit99a, Part 4].
- Public Performance Measure (PPM), which is used in United Kingdom to measure rail lines on-time performance. This indicator measures percentage of trains that arrive at destination on time [Rai, Kee13, p. 2].

- Airport terminal LOS, that is based on passenger density, similarly to public transport terminals LOS. These metrics have been adopted by The International Air Transport Association (IATA) [MBBI10, p. 149] [JP07, p. 525] and have become an internationally recognized standard.
- Average Airport delays per flight (minutes) [Dir13, p. 5] [Net13, p. 1];
- Total Airport delays (minutes) [(EU14);
- Flights with 15 or more minutes delay (the threshold is set to 30 minutes in some sources) [Com05, (EU14, p. III)].

It is understood that new LOS metrics may be introduced in future, therefore it is important that the LOS calculation model is flexible enough to integrate new measures.

3.3.2 Sources and Information

This phase included the study of information sources that exist for different transport modes and their data sets. In general, due to the multimodality of the dashboard, there will exist various sources of information, but what truly presents an interest in this case, is how the information is to be communicated. In transportation area, there exists a number of standards and protocols. Since this case study is performed for Porto, it considers the standards spread in Europe, especially those used in Portugal.

The following protocols and standards have been selected:

- DATEX II. This is a Europe-wide standard for road traffic information exchange with a high coverage in European countries [vdVLW13, p. 28]. In Portugal this standard is used by Brisa and Estradas Portugal [BLA12, pp. 26-28]. It communicates information that may be divided into the following categories [BLA12, p. 11]:

- Road and traffic related events (named "Traffic elements")
- Operator actions
- Impacts
- Non-road event information
- Elaborated data (derived/computed data, e.g. travel times, traffic status)
- Measured data (direct measurement data from equipment or outstations, e.g. traffic and weather measurements)
- Messages displayed on Variable Message Signs (VMS).

- TPEG – a standard with a good coverage in European countries [vdVLW13, p. 96, Annex] [Kop03, pp. 3-4,14]. It has several versions including:

- TPEG-PTI – multimodal public transport information

Problem and Methodology

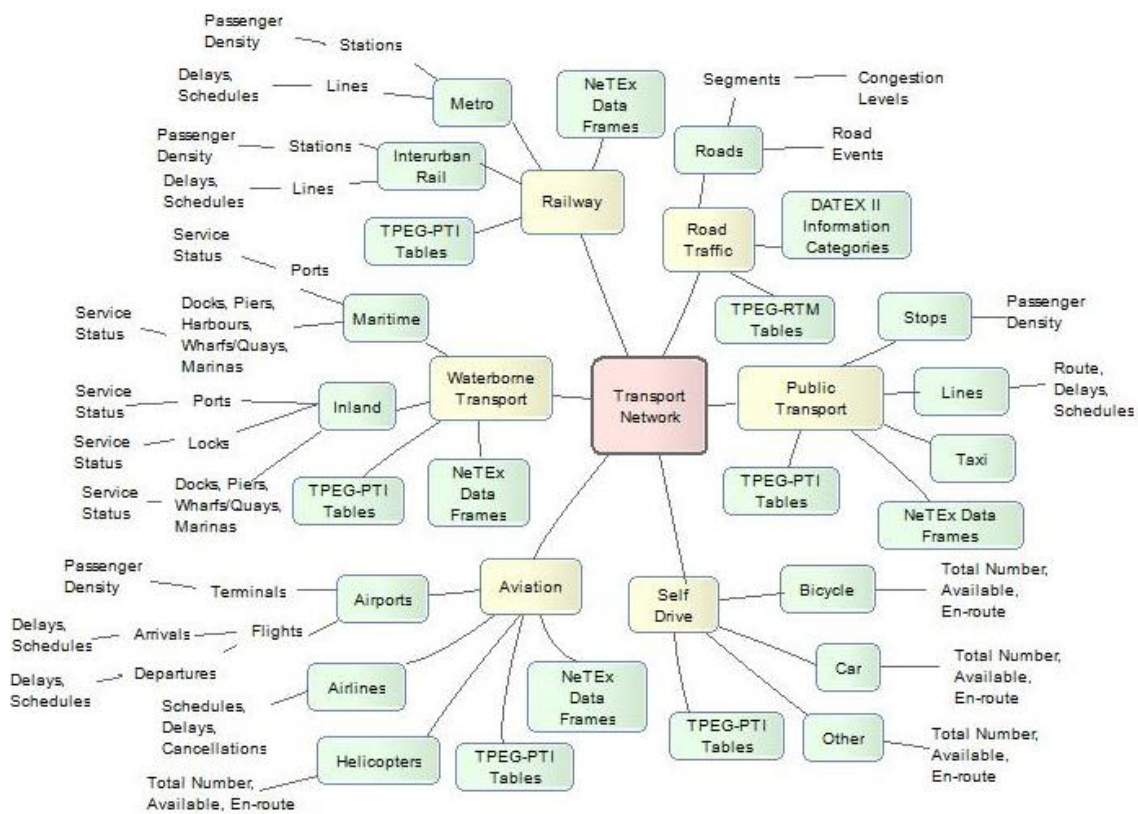


Figure 3.3: Primary Data Model.

- TPEG-RTM – road traffic messages

This protocol supports transmission of data in a form of data stream messages or XML through various channels: RDS-TMC, teletext and Internet. The messages are language independent and constructed based on TPEG tables. Each TPEG table has its own Id and contains a set of attributes, their codes and translations to several languages [BBC, TIS12, p.8].

3.3.3 Primary Data Model

This phase includes the analysis of relevant raw data, its categorization and structuring, data sets provided by the sources identified on the previous phase and elaboration of a primitive data structure diagram.

The general view of the diagram is presented in the Figure 3.3, where there are listed the main travel mode categories, such as Rail, Water, Air, Road Traffic, Public Transport and Self-Drive, and their subcategories.

Each data category includes one or more subcategories representing the protocols applicable to the corresponding categories. Each such subcategory includes data sets delivered by the protocol.

Table 3.2: TPEG-PTI Tables Applicable to Air Transport [BBC].

TPEG-PTI Table Code	TPEG-PTI Table Name
01	mode_of_transport
08	air_service_type
13	service_information_type
14	transport_vehicle_information_type
15	route_point_type
16	scheduled-predicted
17	service_delivery_point_type
18	event_reason_type
19	miscellaneous_event_type
20	personnel_problem_type
21	equipment_event_type
22	environment_event_type
23	service_facility_type
24	service_facility_type
25	ticket_restriction_type
26	severity_type
27	message_report_type
28	time_type
30	additional_information_type

For instance, TPEG-PTI tables that may be relevant in air transportation are listed in the Table 3.2.

3.3.4 Metamodel

Based on the Primary Data Model, a metamodel diagram was elaborated, Figure 3.4. This includes first of all the identification of basic entities, which share common features of those identified on previous phase, their most important attributes and relationships.

Five major types of entities were identified on this stage:

- Infrastructures – transport networks existing in an urban area (Ex: Subway Network);
- Organizations – private or public sector entities involved in an infrastructure (Ex: a bus line operator);
- Links (Ex: road segment, metro line, etc.);
- Points – any relevant fixed objects (Ex: bus stop, dock, airport, etc.);
- Calendars – a temporal category that includes schedules, planned and unplanned events for the above entities (Ex: train schedule, planned maintenance etc.).

Other relevant types of information are:

- TransportModes – listing possible transport modes;

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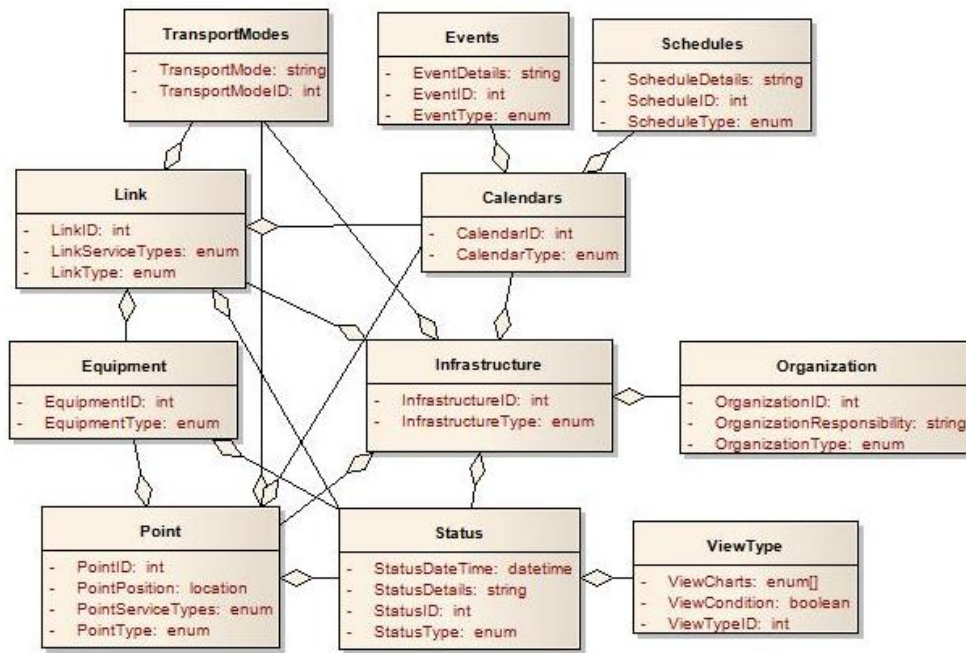


Figure 3.4: Metamodel Diagram.

- VehicleTypes – types of vehicles applicable to each transport mode; 6
- Equipment – equipment on links and points;
- Status – service status which represents the output value for the dashboard and may be 8
applied to links, points, their equipment and infrastructures in general;
- ViewType – presentation modes applicable to each type of status. 10

3.3.5 Values Classification And Presentation Rules

This section identifies the LOS parameters that should be measured or calculated in order to deliver 12
the information on transport systems performance levels.

The suggested LOS values, that differ both in nature and detail level, are listed in the Table 14
D.1, Appendix D, per each transport mode, along with important characteristics such as data type,
boundaries and whether it is a single value or an array. 16

Based on the output values and their characteristics identified on the previous stage, it was 18
possible to define rules for the graphic presentation of each piece of information. The result of this
phase is a set of chart types that are applicable to each type of output value.

The first step consists in the identification of output values classes based on common patterns 20
between some values. The identified classes are listed in the Table 3.3.

The second step is to define presentation rules for each output value class. The rules are 22
defined for three scenarios:

Table 3.3: Output Values Classification.

Nr	Array or single value	Type	Boundaries
1	Single	Enum	x values
2	Array	Enum	x values
3	Array	Float	[0,100], %
4	Single	Float	[0,100], %
5	Array	Int/Float	[0, 1440], mins
6	Single	Int	[0, MaxValue]
7	Single	Int	[0, Infinity]
8	Array	Text	

- current data, to show real-time information; 24
- Historical data – discrete time, to provide historical information per day, per week, per month, etc.; 26
- Historical data – continuous time, to show historical information in a continuous time for a certain period. 28

The Table 3.4 includes suggested charts for each class and scenario.

3.3.6 Hierarchical LOS Evaluation 30

Taking into consideration the heterogeneity and hierarchical structure of such complex and large-scale system as the Transportation Network, where LOS values differ in detail level and may depend on each other, this paper suggests using ontology for the evaluation of the operational status of the network's components, as well as that of the entire network. 32 34

This approach includes several phases described below.

First step is the identification of abstraction levels which represent vertical structure of the model. The levels identified for the Transportation Network are shown in Figure 3.5. 36

Next important phase is horizontal decomposition - identification of the elements each abstraction level consists of. In case of transport area, the domain level consists of Aviation, Railway, Waterborne and Road transport. Each domain is further decomposed into modes (e.g. Road domain includes such modes as Road Traffic, Urban Public Transport, Interurban Public Transport, Bicycle, Taxi), etc. The nodes from the Atomic level represent operational status indicators for the smallest units in the system, which in case of Transportation can be a Bus Stop Terminal LOS, Road Segment Congestion status, Subway Line Operational Status, etc. The types of atomic values have been identified for each transport mode based on a literature review. Aggregation level node in this model does not represent any network element's LOS, but rather aggregates the values from the level below (Atomic), which then contributes to the calculation of the LOS of a level above (Mode or Component). 2 4 6 8 10

Thirdly, dependencies analysis and attribution of influences should be performed - each connection between the nodes represents dependency of the target node on the source node. In case 12

Table 3.4: Presentation Rules.

Class	Current data	Historical data – discrete time	Historical data – continuous time
1	Colored brick, Colored text, icon	Table, Bar chart, Column chart, Line chart	Line chart, Area chart
2	Table, Bar chart, Column chart	Bar chart, Column chart, Line chart, Stacked bar chart, Area chart, Stepped Area Chart	Line chart, Area chart
3	Bar chart, Column chart, Pie chart, Stacked bar chart	Bar chart, Column chart, Line chart, Stacked bar chart	Line chart, Area chart
4	Colored brick, Colored text, Bar chart, Column chart, Gauge, Progress bar	Bar chart, Column chart, Line chart, Progress bars	Line chart, Area chart
5	Table, Bar chart, Column Chart, Scatter plot chart	Line chart, Bubble chart, Area chart, Stepped Area Chart	Line chart, Area chart
6	Colored brick, Colored text, Bar chart, Column chart, Progress bar	Bar chart, Column chart, Line chart, Progress bars	Line chart, Area chart
7	Colored brick, Colored text, Bar chart, Column chart	Bar chart, Column chart, Line chart	Line chart, Area chart
8	List	List	List

when one target node depends on several other nodes, the influence of each contributing node can be varied by its weight (a floating point value between 0 and 1). The absence of weights in the model means equal importance of all nodes.

The fourth phase consists in the identification and analysis of possible values, their data type, range and multiplicity (a single value or a collection).

And finally, the attribution of a function to each node on levels superior to Atomic should follow. These functions will then be used to calculate values for non-atomic nodes based on their dependencies. It is important on this stage to decrease the number of functions, identifying similar computation patterns, so that one function could be re-used in different nodes.

For this case study, there have been identified thirteen functions in total. The process of their identification included a detailed analysis of each non-atomic LOS measure and its dependencies. The following factors were taken into account:

- Input types and their homo- or heterogeneity;
- Output data type, its designation (e.g. if it is a percentage or a value measured in minutes) and whether it is a single value or a collection;
- Semantic similarity.

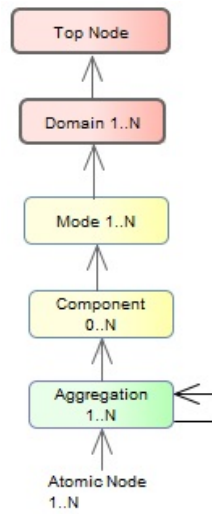


Figure 3.5: Meta Model Vertical Structure.

Four abstract function classes have been identified, based on semantics: functions that perform counting task, sum, select one value from the parameters or calculate an average. Due to inputs and outputs diversity, this resulted in thirteen functions, however, in future there will be attempts to decrease this number.

The result of the process described in this section is an hierarchical LOS calculation model that can be classified as a weighted directed acyclic graph. This implies the use of graph algorithms, mainly such as Breadth-first search (BFS) and Depth-first search (DFS) [CLRS09, pp. 594,603], for the calculations in the dashboard prototype.

The complete LOS Evaluation Model is included in the Appendix A.

3.3.7 Prototype

The design prototype is based in the analysis of output information and presentation rules explained earlier in this chapter. The challenge lies in combining multimodal performance measures at varied abstraction levels. Two alternatives of user interface approach were considered on this stage: (1) diagrams and (2) a map presentation.

Maps are often used in transport area related applications. In real-time dashboards they help the user perceive the current situation of transport service in the monitored geographical area. However, for a multimodal dashboard, a map representation requires solving such issues as distinguishing different modes of transport, analyzing LOS measures behavior over time and inappropriateness of presenting some types of information on a map (abundance of information, for instance).

Diagrams or charts, in turn, are efficient at such tasks as comparing values, historical information and analyzing tendencies. A diagrammatic approach was used in the project as initial suggested solution for the dashboard design prototype. This prototype was created keeping in

Problem and Methodology



Figure 3.6: Dashboard Prototype. Filled Work Area.

mind the idea of configurability. It consisted of two major elements: a menu with LOS values by infrastructure or domain and a work area. The values listed in the menu can be dragged into the main work area, where they will appear in a chart form, and then placed as preferred, depending on the purpose and objectives of monitoring.

Figure 3.6 demonstrates schematic view of the dashboard after filling the main area with LOS charts and selecting preferred chart types, when there is a choice. The menu on top left includes a hierarchical structure of LOS measures, where they may be dragged from. After a value is dragged to the work area, it appears there with a default view. The user is given an option then to select a different chart view, depending on those available for the selected value. Within the same view, the user is offered a choice to see the history of a value or select a more detailed view with a higher information granularity. User may also choose to view meta data on the observed value with the information on responsible organization.

An authenticated user may save the work area layout in order to avoid its repeat configuration. The customization feature example is shown in Figure 3.7, where the user is offered a possibility to set priorities and importance to values, when more than one value contribute to a higher level measure, by means of weights customization.

Customize Weights

Dashboard Home Save Changes Detailed View Logout

Top level

Transport LOS

Value	Weight
Domain 1	10 %
Domain 2	62 %
Domain 3	5 %
Domain 4	5 %
Total Weight	82 %

Apply

Domain level

Customize

Mode level

Road Traffic LOS

Value	Weight
Equipment LOS	40 %
Road Congestion	60 %
Total Weight	100 %

Apply

Urban Public Transport LOS

Value	Weight
Bus Avg Delay	20 %
Buses on time	20 %
Bus Stops Operational Status	20 %
Bus Lines Operational Status	20 %
Total Weight	100 %

Apply

Figure 3.7: Dashboard Prototype. Weights Customization.

During the implementation phase, however, it was decided to focus on a map view with the use of some features of the diagrammatic presentation described above. A map provides a better understanding of location-specific information, however, charts are preferable in some situations when information cannot be shown on a map in an efficient way. Besides, taking into account the variety of stakeholders and possible uses of the dashboard, the user should be offered a choice of selecting different views for efficient monitoring. That's why a combination of both approaches was chosen for the implementation.

3.3.8 Logical Architecture

Conceptually, the system's architecture behind the front-end consists of four layers:

- Connection layer – connects with protocols and other external sources supplying raw data and delivers it to the next layer;
- Data layer – the layer, where raw data is verified, mapped to system's data fields and then stored in database to be delivered to the layer above;

- Control layer – the layer where the output LOS values are calculated based on the input values from the data layer, with the help of LOS Evaluation Library containing calculation models;
- Presentation layer – the upper layer, where the output LOS values are displayed based on user options and the chart library that contains presentation rules.

This architecture is shown in Figure 3.8.

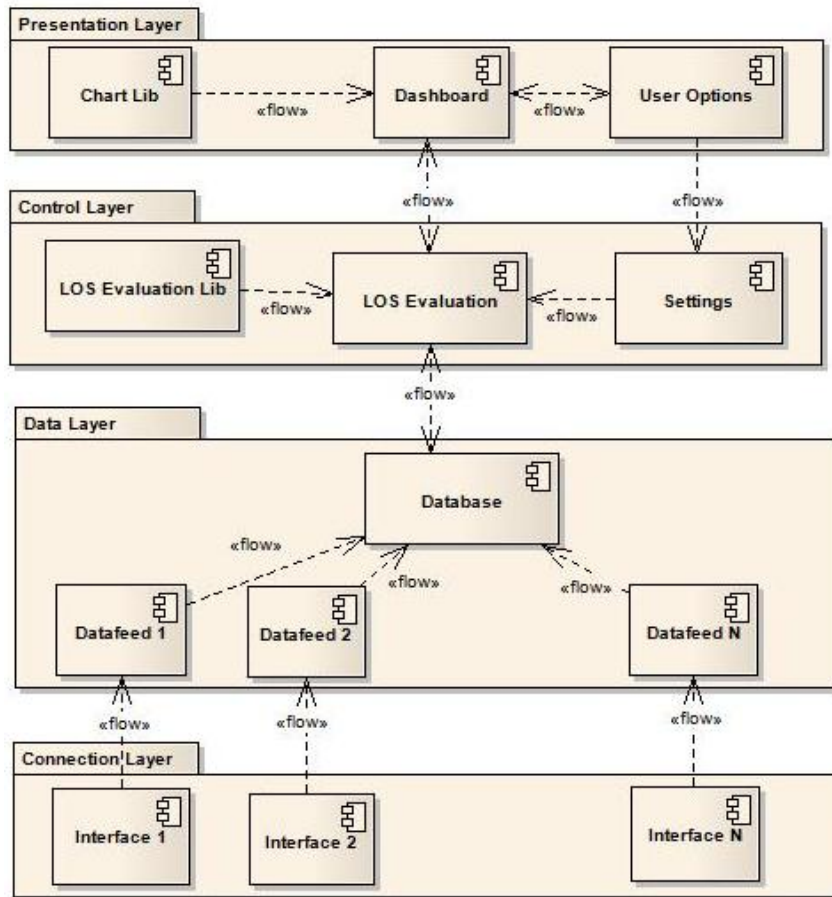


Figure 3.8: Logical Architecture.

3.4 Summary

The implementation of the dashboard was performed in accordance with the methodological approach described in this chapter. The architecture was designed to treat multiple sources of information. It is important that the multiple modes are not explicitly implemented in the system, instead, in order to make the system more general-purpose and since the choice of the modes of transport and transportation infrastructures may vary from one urban area to another, it is necessary to minimize the transport mode dependency and generalize data and output where possible.

Chapter 4

Implementation

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This chapter includes the overview of technology used in the project, systems architecture and explains the system's implementation nuances and major classes that were used in the solution in order to achieve the goals set for the project.

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4.1 Technology

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The choice of technology to use for the project implementation is crucial for its success. The following sections provide an overview of technologies used or considered for use for the development of the system.

4.1.1 Service Oriented Architecture

In terms of architecture, several factors influenced the choice of technology. The dashboard should provide a real-time, quickly updated information to the user. It is also convenient to use a client-server architecture principles, where server would be responsible for data storage and processing and a client would remotely request the necessary information. Due to the multimodal nature of the application and the variety of results that may or may not be available and necessary to the user, Service Oriented Architecture (SOA) with web services as its core feature appears to be the best choice. It brings such important advantages as platform and technology independence, module-based architecture (independent services) [HCT04, p. 17], which is extremely important for the dashboard, enabling customization and independence on a certain urban transportation infrastructure.

4.1.2 Server Side Technologies

In the world of SOA, there is a wide choice of frameworks, where the main competitors are .NET and Java EE/EJBs for Java development. .NET in turn offers .NET Remoting and a newer framework that combines functionalities of .NET Remoting and offers a number of other useful features, which is Windows Communication Foundation (WCF) [Cha10, p. 6]. Both technologies

are based on ASP.NET and C#/Visual Basic. Many disputes exist on the advantages of Java versus Microsoft solutions and vice versa in terms of performance, choice of functionalities and ease of development [COG13, Bie09] [ST, p. 5]. This paper however isn't aimed at comparing these technologies. Java EE was selected for the implementation of the server, since it provides all the necessary tools to achieve the goals set for the project.

It was also decided to use such technology as intelligent agents on server side. The advantages of agents-based systems consist in multi-threading and parallel computation, behavior paradigm, trigger handling, facilitated scheduling and communication between agents [NJ02, p. 3] [She02, p. 89]. The use of agents introduces a higher abstraction in process control which is beneficial for the application. For this purpose Jade (Java Agent DEvelopment Framework) was selected, as a free Java-based, FIPA (Foundation for Intelligent Physical Agents) compliant middleware [Cai04, p. 29] that has already proved to be a powerful tool for multi-agent based systems development.

4.1.3 User Interface Technologies

Two alternatives were considered for the dashboard's Graphical User Interface (GUI): a desktop application or a web-application. A web-application has such advantages as access to the dashboard from different locations/devices and facilitated deployment of the application, which should only be installed on a dedicated server and requires no installation on a client side. However, the Armis company had a ready framework developed using JavaFX for a desktop application that suited the needs and requirements of this project. That's why on this stage the decision was made in favor of a desktop GUI application, in order to speedup the development phase. In future, however, it is planned to provide a web-access to the dashboard as well.

The JavaFX is a Java-based platform developed by Oracle for rich enterprise client applications. It is a powerful tool for building rich high-performance graphical interfaces and possesses such beneficial features as separation of application UI and logic, possibility of creating scalable, graphics-rich applications without performance penalties, and extending existing Swing applications [Ora11, p. 1].

4.1.4 Communication

As for the communication protocols, the main alternatives are SOAP and REST. Both have their drawbacks and advantages. REST-based web-services have such important benefit for real-time applications with an intensive communication of large amounts of data as "less overall latency and requires less bandwidth than the SOAP-based counterpart" [MG09, 1428]. Other advantages of REST web-services are loose coupling of components and the fact that client needs no routing information other than the initial process factory URI [zMNS05, p. 24]. Besides, RESTful messages support both XML and JSON data formats, while SOAP is a XML-based technology. These advantages of REST resulted in the choice of this communication method.

The data format implemented in the solution is JSON, which was selected due to its light weight and speed of processing and data transfer [NPRI09, p. 6]. The translation of Java objects

to JSON and vice-versa is performed with the help of Gson, an open source library developed and distributed by Google [Gooa].

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4.1.5 Database And Object-Relational Mapping

MySQL database was preferred to Oracle and MS SQL Server, due to such factors as low cost (it is an open source software), scalability, high performance, platform portability and ease of use [Sch09, Ehi14, Tru08].

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To facilitate the support of the MVC architecture, an Object-Relational Mapping (ORM), such as Hibernate, was integrated in the project. ORM technology brings in such inarguable advantages as database independence, abstraction of data access, efficient use of table dependencies, speeding development and object persistence [Fin, Kar09, Hib]. Among the existing ORM tools, Hibernate is a preferred one, since it is an open source technology widely spread on the market that proved to be efficient and its community has grown considerably during recent years.

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4.1.6 Graph Library

On the early stages of the implementation, due to the need of manipulations with LOS graphs, representing the Hierarchical LOS Model, a use of a graph library was considered, namely the JGraphT library. This free Java graph library has such features that might be beneficial for the project, as the support of various types of graphs, as well as vertices which can be any object, visualization tool with GUI-based editing and extensibility [Nav11]. Though, after the initial tests of the system with the use of JGraphT structures, it was decided to postpone its further integration into the solution due to certain performance issues. However, its visualization feature might be useful for the analysis and editing of the instantiated LOS model, which is planned to be implemented in the future.

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4.2 Data Structure

The application's data structure was built based on both the Hierarchical LOS Evaluation ontology described in Section 3.3.6 and meta model suggested in Section 3.3.4.

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Figure 4.1 serves as a schematic view of entities and their relationship. It only includes the table names, while the detailed view is available in the Appendix B.

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The vertical structure of the Hierarchical LOS Model is represented in the following tables: Domain, Mode, Component, Aggregation. The lower, Atomic, level includes three types of atomic entities: Link, Point and Equipment, as suggested in the meta model, Section 3.3.4. The AtomicEntityType table helps in referencing and distinguishing atomic entities, where a certain atomic entity can always be identified by two keys: AtomicEntityType Id and entity Id from a corresponding table (Link, Point or Equipment). In a similar way, LevelType table helps referencing the entities from different abstraction levels by means of a combination of LevelType Id, which identifies abstraction level, and entity Id from a corresponding table (Domain, Mode, Component

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Implementation

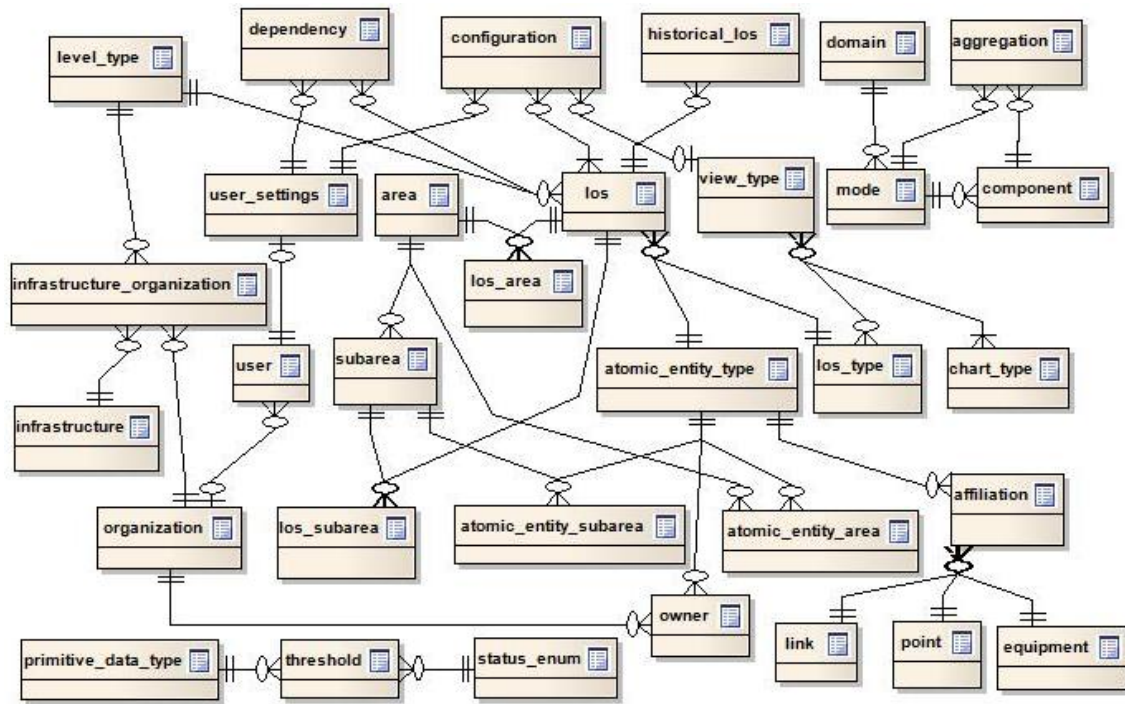


Figure 4.1: Data Model.

or Aggregation). Each entity in Mode, Component and Aggregation tables references the upper level entity, or entity, it contributes to (in case of Aggregation, an aggregation entity may reference another aggregation entity, component entity or mode entity). Together, these tables contain information on what LOS measures physically describe - a road segment, the aggregated status of bus stops or a whole transport domain, such as aviation.

The current LOS values for all entities and abstraction levels are stored in Los table, while connections between them - in Dependency table. The records in Los table contain information on which exact measure is being taken and its current value. Same entity may have several measures, for instance, in case of a Public Transport service line, the measures that might be taken are: frequency or operational status (full service or closure, etc.) and delays. The entity which is being measured is identified by three keys:

1. Level type Id, which identifies the abstraction level;
2. Atomic entity type Id, which in case of Atomic level identifies the corresponding table (Link, Point or Equipment);
3. Measured entity Id, which stands for the corresponding entity Id in the table identified by the two previous keys.

Together, the Los and Dependency tables represent an instantiated hierarchical LOS model for a specific geographical area, monitored by the application.

Implementation

The system was projected to support three geographical abstraction levels: entire monitored region, its areas and each area's subareas. 12

LosArea and LosSubarea entities, which are identified by area and subarea Id correspondingly, contain current LOS values for a given geographical unit at a corresponding geographical abstraction integrated in the system. Physically they store a replicated LOS model from the Los table for each area and subarea. 14 16

Old and expired LOS values from Los, LosArea and LosSubarea tables are stored in HistoricalLos table. Each record references the corresponding LOS from Los table and, in case of area or subarea specific values, a corresponding geographical subregion. 18

Other entities are listed below with a brief explanation of their designation: 20

- Affiliation - affiliation of atomic entities (links, points, equipment) to other atomic entities, since one entity may consist of a few smaller entities (e.g. terminals in an airport, road segments in a road, etc.); 22
- AtomicEntityArea - links atomic entities to areas; 24
- AtomicEntitySubarea - links atomic entities to subareas;
- ChartType - a list of possible chart types, such as Bar chart, Line chart, Stacked bar chart, Area chart, etc.; 26
- Configuration - user configurations for the dashboard layout; 28
- Infrastructure - transport infrastructures, e.g. city subway network;
- InfrastructureOrganization - associations between infrastructures and organizations (a many-to-many relationship); 30
- LosType - class of LOS value, as defined in Table 3.3; 32
- Organization - Organizations involved;
- Owner - organizations responsible for atomic entities (stops, lines, etc.); 34
- PrimitiveDataType - a list of primitive types and units they are measured in, that are used to calculate Atomic level LOS, such as traffic speed, traffic volume, etc.; 36
- StatusEnum - a list of possible enum values for LOS measures (e.g. literal values from 'A' to 'F' for road congestion status);
- 2 • Threshold - thresholds used in the solution to define enum value for a given numeric measure;
- 4 • User - a list of users with a reference to an organization each user belongs to or represents;
- UserSettings - settings defined for each user;
- 6 • ViewType - chart types corresponding to each los type, as defined in Table 3.4;

Implementation

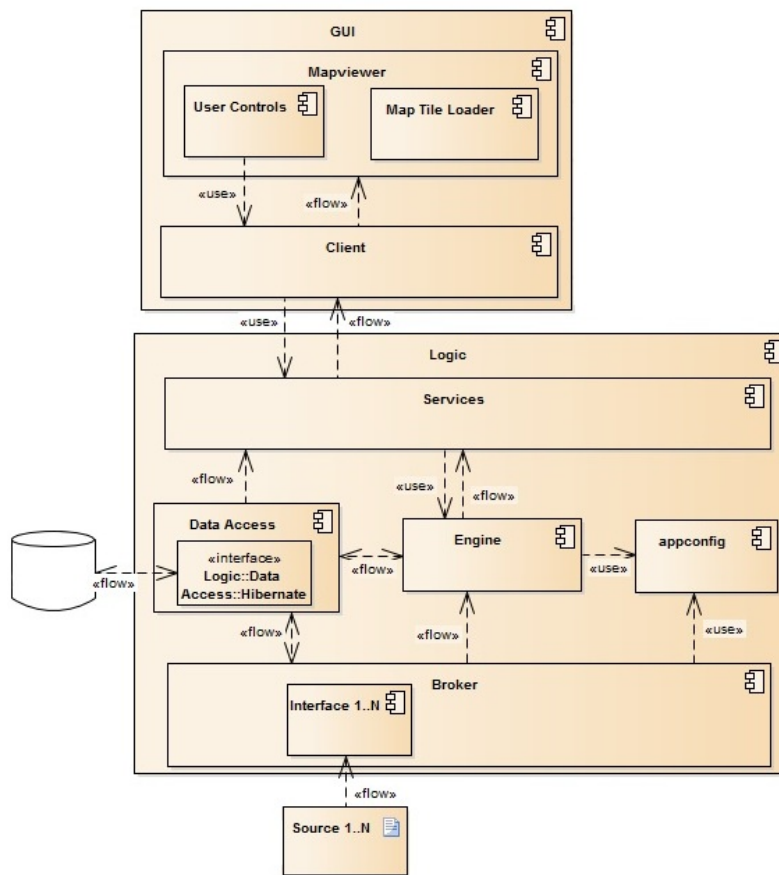


Figure 4.2: Component Model.

4.3 Application Architecture

The architecture that has been implemented in the system's prototype is shown in Figure 4.2. It consists of two major components: "Logic" on server side and "GUI" on client side.

The "Logic" is a separate project responsible for such tasks as:

- the connection with the database and entity mapping using Hibernate ORM as an interface ("Data Access" component in the diagram);
- obtaining data from exterior information sources ("Broker" component in the diagram), through dedicated interfaces;
- performing hierarchical calculations ("Engine" component in the diagram). The calculations are based on the Hierarchical LOS Evaluation model described in Section 3.3.6 and support three geographic abstraction levels: the entire monitored region, its areas and subareas. This component is also responsible for the transformation of local objects into a format that can be consumed by the GUI;
- storing system's configuration information ("Appconfig");

- providing web-services to other applications ("Services"), which use JSON format for data exchange.

The Graphical User Interface ("GUI") represents the dashboard itself. This project may be divided in two major parts: the graphics engine ("Mapviewer") responsible for the graphical output of the information and the interface ("Client") which communicates with the Logic through REST Web Services to obtain the information requested by the user. The Client receives object collections from the server and, when necessary, transforms them into the objects that can be placed on the map.

4.4 Server Side Classes and Implementation Nuances

The server side basically consists of one project called "Logic". In future, this may be divided into more granular projects for an easier maintenance. The "Logic" project consists of eight packages, each of which has its own designation. These packages are described in detail in the next subsections.

4.4.1 Agent Package

It was mentioned in the Section 4.1.2 that the system was implemented with the use of JADE, a Multi Agent System framework. Two agents exist at this stage of the project: *Initializer* and *MainAgent*.

The *Initializer* agent is launched at application startup and its main purpose lies in starting the necessary agents (*MainAgent* at the moment). The *Initializer* has one behavior, of the type *OneShotBehaviour*. In this behavior it launches the *MainAgent* and instantiates it with a Data Access Object (DAO).

The *MainAgent* performs the control of the application execution at startup and is responsible for scheduling the reception and processing of the new input values. At the moment, it executes two behaviors:

- *SimpleBehaviour*, which is "made by a single, monolithic task and cannot be interrupted" [JB]. It runs the calculations required at startup.
- *TickerBehaviour*, "that periodically executes a user-defined piece of code" [JB]. Its task consists in consuming new inputs on every tick, which is defined in the program. This feature can be extended in the next versions of the project with more complex schedules, in order to connect to the proper information sources at an appropriate time.

4.4.2 Appconfig Package

This package includes system's configuration information such as the constants and thresholds that are not present in the database and are shared between different components of the system.

At this stage of the project the amount of the information stored in the configurations package is small, but it is expected to grow with the system's further growth, improvement and tuning.

4.4.3 Broker Package

The Broker package is responsible for the acquisition of the inputs from the available data sources through the interfaces that are implemented in this package. At present, the interfaces with the data communication protocols analyzed in Section 2.6 haven't been implemented, due to a certain resistance in information sharing that exists in Portugal, where the relevant information sources are usually owned by private organizations. However, some information is available through the partners of Armis. That allows the Broker to be executed in two modes: random value generation and from the file. In the random value generation mode, the value generation is performed in several steps:

1. A type of LOS value from Atomic level is randomly selected. This could be an "Urban Bus Stop Terminal LOS" or "Metro Line Delays", etc.
2. A random LOS value is selected from the collection of the existing LOS values of the selected type;
3. A random value is generated for the selected LOS value, depending on its data type and the range of possible values.

In the file mode, the application consumes values from a specified file, containing a collection of inputs gathered by road sensors, and records the last read entry to avoid consuming the same input again.

After a new LOS value is obtained, recalculations are fired over the LOS graph by calling the Engine package, to ensure that the new value propagates necessary changes to the upper levels.

4.4.4 Dao Package

The DAO stands for Data Access Objects, which is what the Dao package is responsible for. It contains a rich functions library for the interaction with the database, such as queries, inserts and updates. The access to the database objects is performed by means of Hibernate query language, which introduces a higher abstraction from the classic SQL queries. Listing 4.1 contains an example of a typical data access method which performs a request for a collection of records from LosArea table filtered by the area they belong to.

4.4.5 Engine Package

As it was stated in Section 3.3.6 the Hierarchical LOS Evaluation model can be classified as a weighted directed acyclic graph, which implies the use of graph algorithms for the calculations in the dashboard prototype. The algorithms implemented in the solution are BFS and DFS.

Implementation

```
1 public List<LosArea> getLosAreaByArea(int areaId) {  
2     Query querySegments = this.sessionFactory.getCurrentSession()  
3         .createQuery("from LosArea where area.areaId = " + areaId);  
4  
5     List<LosArea> l = (List<LosArea>) querySegments.list();  
6  
7     return l;  
8 }
```

Listing 4.1: Example Data Access Method

34 The principle class of the package that represents the graph and contains the methods implementing graph algorithms is *LOSGraph*. It is initialized by accessing database through Dao object. The resulting graph represents the instantiated version of the Hierarchical LOS Model, where leaf nodes (nodes without children) are nodes from the Atomic level. 2

The DFS algorithm, *graphDFS()* method of *LOSGraph*, is used for running calculations over the entire LOS model at startup to make sure that all values are up-to-date. The algorithm begins its execution from the top node which corresponds to the LOS of entire transport network, and analyses each of its child nodes (in this case children are values that contribute to the parent node's value) in depth. The edges between the nodes are in fact dependencies stored in the database (Section 4.2). The calculations are done in a post order [Nel96], since it is first necessary to obtain the updated values of child nodes to be able to calculate the parent node's LOS value. Therefore, after all children of a node are explored, and if the node itself is not a leaf (does not belong to the Atomic level), the DFS algorithm calls *calculateLos* method which is responsible for the calculation of each non-atomic LOS value. 4 6 8 10 12

Since the DFS method is time-consuming, it is not used further during the system execution, apart from the startup. Instead, in real time mode, on the arrival of a new value, usually at Atomic Level (e.g. updated road segment's congestion status), the BFS based calculations are triggered (method *recalculateParentsLos*). The BFS algorithm is responsible for ensuring that all the upper level values, that depend on the updated node, are reviewed and recalculated if necessary. The model supports updates triggered at any level of abstraction, where the recently updated node serves as a "root" node for the BFS algorithm. In case of BFS, the graph traversal is an opposite direction to DFS, from lower levels to the Top of the Hierarchical LOS Model. The algorithm continues its execution while there remain non-recalculated upper level LOS values, that had their inputs changed, or till the Top node is reached. That means that if the algorithm has arrived to a node that was recalculated, but the value hasn't changed, this branch is not explored further. 14 16 18 20 22

2 The same method is used for different levels of geographic abstraction implemented in the prototype: the entire network, Area and Sub-area. In case of Area (class *LOSGraphArea*) and Sub-area (class *LOSGraphSubarea*) abstractions, an instance of the original graph is created, except that it includes only the nodes that exist in the specific area/sub-area. In order to ignore the non-instantiated branches of the graph in areas and sub-areas and improve performance, Area and 4 2

Implementation

Sub-area calculations use only the BFS algorithm implemented in the method *graphBFS* both at the startup and during execution. The only difference is that at startup, the BFS algorithm for areas and sub-areas pushes the entire set of instantiated atomic nodes (leaves) for the corresponding area or sub-area to the queue instead of a single "root" node, while in all other cases the node with a changed LOS value is set as a "root" node for the algorithm.

The *calculateLos* method obtains the instantiated child nodes and, depending on the type of LOS that should be calculated, prepares the parameters and calls the necessary method from a library containing LOS functions. The names of methods or functions corresponding to each LOS measure are stored in database and loaded as an attribute of LOS object. These methods are implemented in a dedicated library, in the *LosFunctions* class. As it was mentioned in the Section 3.3.6, there have been identified thirteen functions in total, out of which seven have been implemented for the current version of the application. A brief description of the implemented functions follows below:

- *average* - the function receives a list of strings with numbers in format "[n1, n2, ...]" and calculates and returns an average value. This method is usually used to calculate an average delay for public transport service lines, such as average bus lines delay, etc.

- *enumListToPercentageList* - the method consumes a list of enum values representing atomic LOS values in string format, calculates the total share of each enum value compared to the entire collection of values and returns a string with enum-percentage pairs in the following format: "enum1-percentage1,enum2-percentage2,...". For instance, if the method receives as a parameter a collection of road congestion statuses ["A", "A", "C", "F"], the result would be a string "A-50.0,C-25.0,F-25.0". The *enumListToPercentageList* is typically used at the Aggregation level to understand the share of each status value compared to other values.

- *enumPercentageListToPercentage* - the method receives a string with enum-percentage pairs in format "enum1-percentage1,enum2-percentage2,...", built by *enumListToPercentageList* function, and list of keys or enums to look for. The output of the method is a percentage share of the searched enums (keys). The purpose of this LOS function consists in determining, what percentage of measured facilities are operating at an acceptable LOS level. For instance, based on the example above, if the acceptable LOS level includes such LOS statuses as "A", "B" and "C", the total share of road segments with an acceptable LOS would be 75.0: 50.0 (the share of "A" LOS) plus 25.0 (the share of "C" LOS).

- *FloatListToPercentage* - a function depending on two parameters: a list of strings with numbers in format "[n1, n2, ...]" and a threshold (Float data type). This method returns the percentage of numbers that are less or equal to the threshold. The semantics of this method consists in calculating the share of public transport vehicles arriving on time (for urban and interurban bus and railway service, as well as flights), where the threshold represents maximum allowed time span for the given transport mode within which the arrival is considered as "on-time". The method is typically applied to Aggregation Level LOS values.

- *MixedValuesToPercentage* - the method receives as an input a list of strings with values and their types in format "value1:type1" and a list of weights attributed to the values. The result of the function is a percentage, which represents an aggregated evaluation of the values received based on their weights. This method may be used on Aggregation, Component and Mode levels. As reflected in its name, the method is capable of consuming heterogeneous values both in their semantics and data type, such as an average delay measured in minutes, total accumulated delay in minutes, or a percentage. Later, even more value types should be integrated. In order to generate a single result based on these diverse values, it is first necessary to normalize them, which implies a transformation to a single type - a percentage in this case. After the normalization is done, it is possible to derive a weighted average reusing a method already implemented in the library for the calculation of other LOS values and described further: *PercentageListToPercentage*.
 - *or* - the function receives a list of objects of Float type and a list of weights corresponding to the values. Only one of the values is returned, unchanged: the first one if no weights were specified or the one with highest weight. This function is used in situations when the same LOS value may be measured by more than one method. For instance, when evaluating Road Equipment LOS, two aggregating methods may serve as a metrics: the total share of roads with operational equipment or simply the share of operational equipment.
 - *PercentageListToPercentage* - this function has already been mentioned earlier. It receives a list of values in percentage format (Float numbers from 0.0 to 100.0) and a list of their weights. The returned result is an average percentage (if weights were not specified) or a Weighted Average otherwise. This method is typically used for higher level LOS: Top, Domain, Mode and Component levels. Sometimes it is applied however to the Aggregation level LOS measures as well. This method is available in the Listing 4.2.
- The Engine package also contains methods for translating the collections of objects used in graphs as nodes to the objects that are understood by GUI. In these translation methods (*LosToGuiLos* method in *LOSGraph* class and *toGuiLos* method in *LOSGraphArea* and *LOSGraphSubarea*), the GUI objects receive all information associated to a LOS value that is required for the user interface, such as the identification of the LOS measure, its value, geographical position, area or sub-area the LOS belongs to, etc.
- The translation is made purely for the purpose of embodying the information related to a single LOS value that is spread over several entities into one object, avoiding at the same time passing unnecessary or redundant information which is only used on the server side.

4.4.6 Guiobjects Package

- The package contains classes used to communicate information to the user interfaces. At this stage there is only one class in the package, which is *GuiLos*. In future however the package may grow depending on the types of uses and diversity of information required by user interfaces. There are

Implementation

```
1 public static Float PercentageListToPercentage(List<Float> values,
2     List<Float> weights) {
3     if (values == null || values.isEmpty())
4         return null;
5     if (weights != null)
6         System.out.println("values size = " + values.size() + " : "
7             + values + " ; weights size = " + weights.size() + " : "
8             + weights);
9     else
10        System.out.println("values size = " + values.size()
11            + " ; weights = null");
12    Float result = 0.0F;
13    for (int i = 0; i < values.size(); i++) {
14        // if weights weren't provided, result = sum of values / number of
15        // values
16        if (weights == null || weights.isEmpty()) {
17            result += values.get(i) / values.size();
18        } // otherwise result = sum of value*weight
19        else {
20            result += values.get(i) * weights.get(i);
21        }
22    }
23
24    return result;
25 }
```

Listing 4.2: Example of a method calculating a LOS value.

three major constructor types in *GuiLos* for three types of situations: (1) based on an object of *Los* type and its position for the highest geographical abstraction, (2) with a *Los* object, a *LosArea* object and position as input parameters for area abstraction, (3) with a *Los* object, a *LosSubarea* object and position as input parameters for sub-area abstraction. In the latter two cases, the *GuiLos* object simply receives additional information related to the corresponding area or sub-area.

4.4.7 Pojo Package

The Pojo is a dedicated package for the database entities, where each entity corresponds to a table in the database. The term POJO stands for Plain Old Java Object, and refers to simple Java objects that have a certain set of attributes and provide the access to them through getters and setters [Fou]. Some of the POJO objects in the solution were supplemented with additional business logic and attributes not included in the database table fields, such as *visited* property of boolean data type in the *Los* object, which is used for graph traversal algorithms.

4.4.8 Service Package

The Service package implements RESTful web-services for data communication between applications, using *javax.ws.rs* package which provides a high-level interfaces and annotations for the creation of RESTful services [Cor11]. It contains an abstract web-service with a data access

object as an attribute and three classes that extend the abstract web-service: *LosService*, *AreaService* and *SubareaService*. The web-service methods are grouped in these classes depending on the geographic abstraction that they require.

Most of web-service methods implemented in this version of the solution fulfill information requests, therefore the results of the requests are typically collections of *GuiLos* or *HistoricalLos* objects. Before the response is sent to the client, these objects are encapsulated into a *Parcel* object which is then transformed to JSON string and returned to the client in this format.

4.5 GUI Classes and Implementation Nuances






As it was mentioned in the Section 4.1.3, the user interface was built on top of an existing framework, *JavaFXMapView*, that was implemented by *Armis*. This freeware framework was created for graphic representation of road traffic information on a map. It provides a view of a certain geographic area, specified in the framework, at several zoom levels. For the needs of this project, some new elements were added to the framework, such as:

- Interface with the server - a package, containing classes corresponding to the objects transmitted by the server (*GuiLos* and *HistoricalLos*), RESTful client responsible for the request-response communication with the server and configurations with application-wide constants;
- New map objects - LOS indicators on the map, *MapLos* class, which contains the information on the LOS value that should appear on the map, attributes referring to how the value should be visualized (e.g. its color, graphic elements, such as panes, etc.) and a collection of necessary methods (building and populating charts, updating indicator's position on the map, etc.);
- Additional graphic elements - a number of panes and other necessary graphic elements, that were necessary in the dashboard, in addition to the already existing map view in the framework.
- User controls and filters - elements allowing an interaction of the application with its user. These controls allow user to modify the abstraction level of LOS values that appear on the map from Atomic to Domain level and geographical abstraction from the entire region to sub-areas. The controls also permit filtering the visualized values by Domain, Mode, Component or Aggregation. For example, setting filters to "Train Average Delay per Line" for all modes (Metro, Urban Bus, etc.) and abstraction level to Atomic, will result in viewing only atomic LOS indicators for public transport line delays on the map. Another control allows the user to view or hide legends pane containing information on graphic indicators' semantics.
- New behavioral features - the GUI application was also supplied with threads which ensure the concurrency of the indicators on the dashboard with the current real state of transport

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network. For this purpose, the threads periodically connect to the server and update the information on the map when any changes have been detected.

The status of a certain transport system's facility or the whole transport domain is perceived through its indicator's color, as illustrated in the dashboard's screen-shots listed in Appendix C. Colors and their general significance are as follows: green stands for good LOS, yellow means acceptable LOS, orange indicates low LOS and may be a sign of a certain problem, and red - very low, unacceptable LOS. Color semantics for various LOS types is available for the user in a "Legend" pane, Figure 4.3.

Status (%)	Average Delay (min)	Terminal LOS	PT and RW Line LOS
 75.00-100.00	0 - 15	A, B	Good Service
 50.00-74.99	16 - 30	C	Minor Delays
 25.00-49.99	31 - 60	D	Severe Delays, Part Closure
 0.00-24.99	more than 60	E, F	Closure
 No information or not an interpreted value			

Hide Legend

Figure 4.3: Legend For LOS Indicators.

The same approach applies to the filters which appear on the left menu in a tree view with icons representing a status of a corresponding Domain, Mode, Component or Aggregation respectively, Figure 4.4. This is helpful in situations when, due to filter settings, not all transport modes are present on the map, however it is still important to have an extensive view of the transport network in the monitored region.

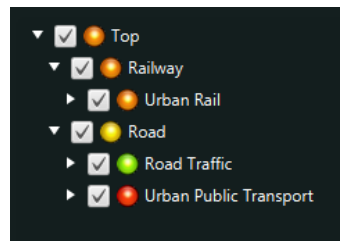


Figure 4.4: LOS Tree View with Filters.

For a clearer view of the dashboard and a more efficient information perceiving, only LOS measures with a valid value are visualized on the dashboard. On mouse hover, a pane appears with basic information about the measure, such as its name, current value and date and time when it was received or calculated, Figure C.5. By clicking on an indicator it is possible to view a chart with its recent history, Figures C.3 and C.4. Chart type varies depending on the type of LOS value, which is stored in the database exactly for this purpose. Whenever a new value is loaded or updated on the map, an animation is triggered on the indicator to notify the user of the change.

4.6 Summary

The result of the implementation phase is a ready application that allows monitoring and analysis of transportation network in a real-time mode, applied to the city of Porto. The examples of its execution are illustrated in the Appendix [C](#).

The technologies that were chosen for the implementation of the dashboard prototype helped to achieve the goals set for this phase. The next steps would consist in further improvement of the application and performance optimization, the dashboard's design refinement, adding a chart choice feature and implementation of protocol interfaces.

Implementation

Chapter 5

Preliminary Results

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This chapter describes the tests that have been performed on the application using historical data. The purpose of the tests was to observe system's behavior in different scenarios: with and without perturbations in public transport service. The sections below explain in detail the system's setup to conduct the experiment, illustrate the results obtained and discuss them, comparing with the expectations.

5.1 Experimental Setup

The tests performed on the system included two transport domains: Road and Railway. The database was populated with the following information available for the transport systems of the city of Porto:

- Metro lines and stops for Urban Rail Mode;
 - Funicular lines and stops for Urban Rail Mode;
 - Bus stops and bus lines for Urban Public Transport (Urban Bus) Mode;
 - Road segments on major motorways equipped with sensors for Road Traffic Mode;
- The LOS related information for Metro, Funicular and Urban Bus was randomly generated, while the status of monitored road segments was obtained from the road sensors.
- For the Road Traffic test case, the idea of the experiment consisted in the analysis of LOS values for road traffic on the day when public transport was at a strike and comparing them to those recorded during days without strikes. It was expected that during hours with strike there should be a certain degradation of road traffic LOS, since more travelers were expected to switch to other transport means, including personal cars, therefore contributing to the road traffic.

The strike occurred on 26 of November, 2013, when STCP, one of the principal urban public transport providers in Porto with a fleet of 481 vehicles and 2,458 stops per information on 2012

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1	dataId	value	recordedDate	dataTypeId	wayId
2	900508	78.00	2013-11-11 00:00:00.000	1	17
3	900509	88.37	2013-11-11 00:00:00.000	2	17
4	900510	2.10	2013-11-11 00:00:00.000	3	17
5	3578413	38.00	2013-11-11 00:00:00.000	1	51
6	3578414	88.29	2013-11-11 00:00:00.000	2	51
7	3578415	2.05	2013-11-11 00:00:00.000	3	51
8	5890492	26.00	2013-11-11 00:00:00.000	1	50
9	5890493	82.58	2013-11-11 00:00:00.000	2	50
10	5890494	1.51	2013-11-11 00:00:00.000	3	50

Listing 5.1: Example of Raw Data from Sensors.

[STC], was at a strike and had a considerably reduced service [dN13]. In order to understand the effect of the strike, some other days were analyzed as well, such as one day before the strike and one day after, same three days a week before and two weeks before the strike. Therefore the exact days used to run the tests were the following:

- 11, 12, 13 of November;
- 18, 19, 20 of November;
- 25, 26 (strike day), 27 of November;

During the experiment, the LOS values for Metro, Funicular and Urban Bus were maintained on the same level in order to observe the influence of the LOS of road traffic on the status of the entire Road domain and that of the whole Transportation Network in the city. The traffic related values were obtained from sensors for all monitored road segments on city's major motorways for every 5 minutes. The information available from the sensors included such values as traffic volume, average speed and lanes occupancy rate. According to the road LOS calculation methods, one of these values is selected and matched to a letter from "A" to "F", designating Road LOS, as described in the Section 2.2.1.1.

The Listing 5.1 serves as an example of raw data from sensors read from a file. The columns from the left to the right represent and Id of data entry, recorded value, date and time the value was recorded, the type of the value (traffic volume - type 1, average speed - type 2, or occupancy rate - type 3) and an identification of the road segment.

Based on the values obtained from the sensors, the system had to perform calculations in several steps consecutively for every set of data from the same date and time:

1. Read a set of value with identical record time and calculate congestion LOS for every road segment;
2. Calculate a share of each LOS status, node "Road segments per congestion status";
3. If a change was detected on step 2, calculate the next higher level LOS: "Road Congestion LOS", otherwise continue to the next data set, step 1;

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4. If a change was detected on step 3, calculate "Road Traffic LOS", measuring entire mode LOS. Otherwise continue to the next data set, step 1; 10
5. If a change was detected on step 4, calculate "Road LOS", measuring entire domain which includes other modes as well. Otherwise continue to the next data set, step 1; 12
6. If a change was detected on step 5, calculate "Transport LOS", measuring the status of the entire transportation network. Otherwise continue to the next data set, step 1; 14

5.2 Results Analysis

The analysis was made based on the occupancy measure for the road segments, which affected the higher level values mentioned above. Generally, it was noticed that the major degradation of LOS on roads took place at morning and evening peak hours. Usually, between 7:40 and 11:30 in the morning and 17:40 to 20:00 in the evening. Between these periods, during the morning and evening hours and at night, the LOS measures for road traffic on motorways were maintained at a very high level with insignificant variation. The behavior of the relevant higher level values during the strike in comparison with the days without strike is described below. 22

Road Congestion LOS: the value measures a percentage of road segments operating at a sufficient LOS. This includes LOS statuses "A", "B" and "C". The maximal amplitude registered for the period of observation was %6.52. During the strike hours, there was noticed a more prolonged degradation of the LOS for the evening peak hours, when the degradation amplitude was reaching %4.35 and the average LOS value for the period between 17:00 and 20:00 was equal to %98.64, which is the lowest value for the same period for the observed days. The Figures 5.2 and 5.1 allow comparing the measure variations for the same day of the week (Tuesday) and for all days that were observed. The charts display Road Congestion LOS value during the period 7:40 - 20:05, when some changes were noticeable. 2

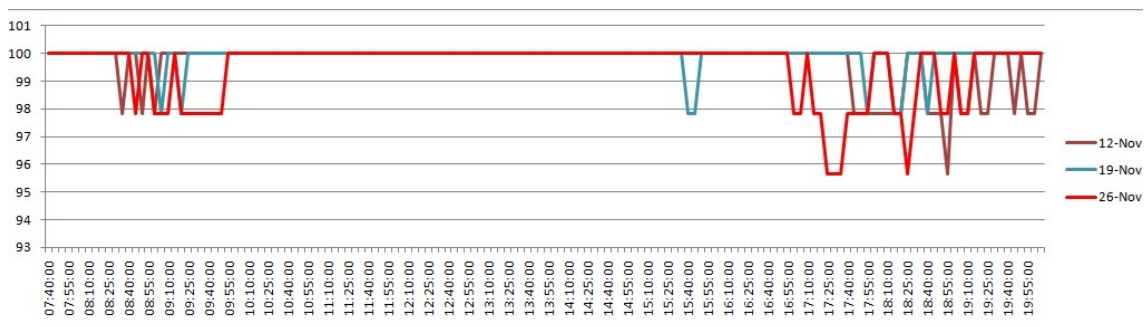


Figure 5.1: Road Congestion LOS, Tuesday.

Road Traffic LOS: a Mode Level value that aggregates the measures for all the components of road traffic including road Equipment LOS, Roads Status (measuring road condition such as 4

Preliminary Results



Figure 5.2: Road Congestion LOS. All observed days.

pavement, etc.), Parking LOS and Road Congestion LOS. Since the Road Congestion LOS was the only input value available for this measure during the experiment, both measures were equal.

Road LOS: the value measures the status of the Road Transport domain which includes such modes as Road Traffic, Urban and Interurban PT, Bicycle and Taxi. In the experiment, the only instantiated modes were Road Traffic and Urban PT. Here the observed fluctuation has reached a maximum amplitude of %3.3, which is quite insignificant.

Transport LOS: the status of the entire Transport Network, which is also measured in percentage, had an even smaller variation of %1.63 at maximum, since it was influenced by the Railway Domain LOS value which was maintained at the same level during the tests.

The actual bus service availability was indeed at a low level on the strike day, as it was observed by the sensors installed on a significant number of STCP vehicles for the Vehicular Ad-hoc Networking within the Future Cities Project. The information obtained from the sensors for the Monday to Wednesday period of the strike week and the same period of the week before (18 - 20 and 25 - 27 of November 2013) are displayed on the Figure 5.3. As it may be noticed on the Figure, the number of available vehicles during the day usually maintains at a similar level, while during the strike it decreased considerably. The values on the chart represent a number of buses that showed some movement during the last 5 minutes.

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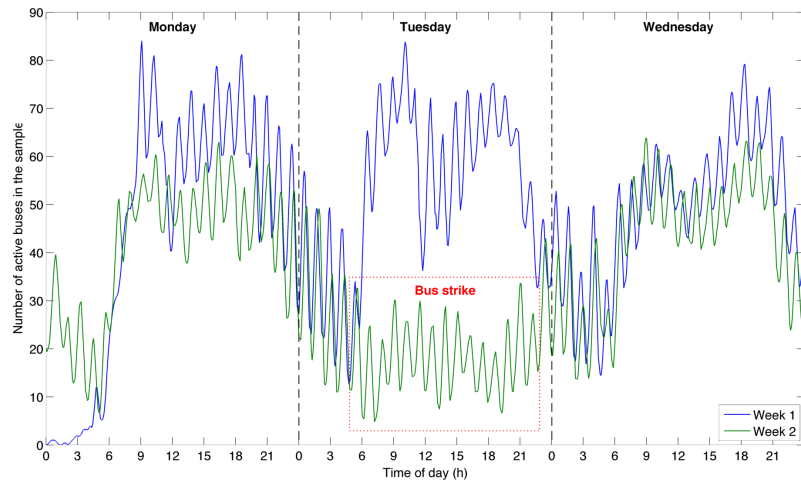


Figure 5.3: Number Of Buses On The Route.

5.3 Summary

Based on the performed tests, it was proved that the system is capable of detecting a degradation in the Transport Network of the monitored region. The impact of the strike of a major urban bus operator on road traffic was noticed in the evening peak hours, when it caused a longer than usual degradation of motorways LOS, if compared to the similar period for other days of the week and previous weeks. However, the difference was quite insignificant, which may be explained by the variety of transport choice in the city which includes Metro and other urban bus operators which weren't at a strike. Besides, it should also be taken into account that the monitored roads did not include streets inside the city, only motorways, where a quite high LOS is observed on average.

Preliminary Results

Chapter 6

Conclusions and Future Work

The Transport sector benefits from the growth and development observed in IT solutions existing for this sector, which facilitates considerably monitoring and management tasks and contributes to the service level improvement, as well as has a positive impact on safety, by improved control of transport facilities, and ecology, by reducing emissions with a more efficient mode choice and logistics.

One of the key issues in the management of transport sector is performance measurement. This was also the key subject in this project, where different approaches to the measurement of level of service were considered. The Literature Review chapter describes the metrics existing in the world that were discovered during the research. LOS concepts and their measurement methods are well defined and standardized for some transport modes and infrastructure elements, such as road traffic, airport and public transport terminals, waiting areas, flight delays. Where metrics were not detected in the literature, they were defined for the project. It was detected that the existing metrics are usually focused on a single transport mode. Therefore, the innovative approach of this work to the LOS measures monitoring consists in the combination of the measures received from different transport modes. For the purpose of generalization of this project, it considers all possibilities of LOS evaluation for each mode. An Hierarchical LOS Evaluation Model was created for this purpose, allowing the evaluation of the operational status of the Transport Network's components, as well as that of the entire network. The model includes several abstraction levels: Top Level measuring the LOS of the entire Transport Network, Domain Level which includes LOS measures for the principle transport domains (Aviation, Railway, Waterborne and Road transport), Mode Level represents major modalities and their statuses (e.g. Road Traffic, Airports, Urban or Interurban Public Transport, Bicycle, etc.), Component Level (where a further specification of mode is necessary or its components, such as Ports, Docks and Locks for Waterborne transport or Equipment, Road Congestion and Parking for Road Traffic Mode, etc.), Aggregation Level (aggregates the values received from the level below), Atomic Input Level (operational status indicators for the smallest units in the system, e.g. Bus Stop Terminal LOS, Road Segment Congestion status, Sub-

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way Line Operational Status, etc.). The suggested model incorporates the heterogeneous structure of the Transport sector and offers such important features as an easy extensibility and priorities customization by means of weights attribution to the incoming values.

As for the multimodal IS, the review of the background, related works and studies and existing dashboards has proved the lack of a dashboard that would provide a comprehensive view on the level of service of all transport networks in an urban area. The majority of IS in transportation area address a single transport mode, and very few solutions combine different modes at the same time. The existing multimodal systems usually do not address the issue of LOS monitoring. The few examples of transport dashboards focused on LOS information were either unimodal or contained historical rather than real-time data, or both. A need of such a service exists however. It could be beneficial to public authorities facilitating transport networks monitoring and providing support in the decision making process in cases of emergency events and other situations.

The problem of data supply for the real-time applications in transport area has various solutions. Europe-wide and worldwide standards exist for transport-related data communication, which were reviewed in the Literature Review chapter as well. However, due to the fact of some technologies and standards being in the state of deployment or development, as well as the varied sets of protocols used in different countries and/or urban areas, a certain degree of abstraction from the concrete data sources was used in the project. Referring to Portugal, various ITS systems already exist locally or are being introduced. Though the only real-time transport data exchange protocol, which use in Portugal was confirmed during literature review, is DATEX. Some Public Transport information exists in GTFS format as well, which within the context of this project would be helpful at the deployment and setup phase.

Based on the performed research and the analysis of various possibilities of a visualization approach for the dashboard, this paper proposes a solution which was developed during the project. The solution permits a real-time monitoring of the current status of multimodal transport systems in the monitored region. It consists of two major components. The Dashboard GUI offers a map-based view on the local transport systems performance state, allowing a choice of LOS abstraction from the Domain Level to the Atomic Input Level and geographic abstraction of three levels, from entire monitored region to sub-areas. It also permits filtering the information on the dashboard by transport domains, modes, components, and aggregations for any LOS and geographic abstraction. Another feature of the dashboard relevant for the performance analysis tasks and decision-making process is the charts view of the transport systems behavior over the time. The Logic component performs all necessary calculations, includes interfaces with varied data sources and provides information through services to the exterior applications based on RESTful communication. It can be executed independently on the GUI and used to feed any other systems with the LOS-related data in a real-time mode.

This chapter includes further the Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of the project and the future work and perspectives for the dashboard as seen on the current stage.

8 6.1 SWOT Analysis

The SWOT analysis provides a better view on the strong and weak sides of the project as well as its opportunities and major threats.

6.1.1 Strengths

- 12 • Multimodality and comprehensive view of all transport modes, which may substitute single mode tools;
- 14 • Multimodal transportation LOS evaluation method;
- 16 • A monitoring tool for the entire transport network and quick detection of degradation of transport systems;
- 18 • Access to historic data, which allows detection of weak points of the transportation network and thus may help in strategic transport management;
- 20 • Independence of the LOS evaluation model on the location of its application;
- 20 • The Service-oriented Architecture which enables flexibility and ease of development and deployment of new features and functions [HCG⁺].

22 6.1.2 Weaknesses

- 24 • Dependency on exogenous information providers – public and commercial organizations that own and process the transport related information;
- 26 • Absence of digitalized information and/or access to it for some transport modes;
- 26 • Amount of data and processing which has a negative impact on application's performance.
- Complexity and heterogeneity brought by the multimodal nature of the project.

28 6.1.3 Opportunities

- 30 • Popularization of multimodal transport applications and data sharing as well as data communication standardization in EU [SAT⁺13, p. 2] [TR11, p. 3] [GST11, p. 8], that open the doors for this project in terms of access to the information;
- 32 • Active cooperation with local public and commercial transport infrastructures and authorities for further project development and growth;
- 34 • Becoming a tool for transport systems monitoring and strategic planning for the authorities on city, district, state or country scale;
- 36 • Adding decision support elements for various needs, possibly such as emergency planning and strategic transport planning;

- 38 • Feeding artificial traffic control systems, such as the one described in [RFBO08];
- Integration with simulation systems for innovative transport, such as for instance the autonomous vehicles simulation system [PR12], for the evaluation of the perspectives of their integration into transportation networks; 2
- Further re-usage of the hierarchical calculation model as a background for multimodal supervision solutions in other areas besides transportation. 4

6.1.4 Threats

- Temporal or long-term lack of real-time digital information on some components of the LOS model, which may result in the absence of some output values. Such situation would have a negative impact on the validity of LOS values at higher abstraction, which may fail to reflect transport system's actual state; 6 8
- Insufficiency of data sources, which presents a threat to the idea of multimodality; 10
- Lack of support from local public and commercial transport infrastructures and authorities which may reduce the information supply to the dashboard; 12

6.2 Future Work

Due to its size, complexity and interdisciplinary nature, the project hasn't achieved its final state yet and leaves space for further investigation and design. The future work foreseen at this stage includes the following major steps: 14 16

- Further specification of data model depending on practical needs of the stakeholders and its application; 18
- Specification and implementation of raw data verification and validation policies, to address issues of information conflicts, duplication, etc.; 20
- Implementation of interfaces with external data sources, such as communication protocols;
- Implementation of model configuration tool; 22
- Specification and implementation of importance (weights) attribution framework;
- Implementation of GUI customization feature; 24
- Performing questionnaires and other forms of validation for the suggested dashboard design approach and its usability evaluation; 26
- Validation of LOS calculation models with the professionals involved in transportation area;

Conclusions and Future Work

- Validation of the correct execution of the proposed solution by means of Artificial Transportation Systems (ATS), as proposed in [RLT11, p. 309]; 28
- System's technical and architectural improvements to increase software quality, in accordance to the quality requirements defined in Chapter 3, Section 3.1; 30
- Implementation of a web-application for GUI to allow the access to the dashboard from a browser, independently on device and location; 32
- Where little data is available on exact routes of PT lines or roads positioning on a map, this problem could be solved by integrating the system with the tools for correcting routing information through GPS data, as proposed in articles [FCR09, FCR10]; 34 36
- Extension of the Hierarchical LOS Model by means of measures for the status of the inter-modal and multimodal connections; 38
- Introduction of the concepts of infrastructure and organization into the LOS Model and output filters. 2

The project in general is reasonably ambitious and presents a number of challenges, but current trends towards the multimodality and standardization in data communication field present good opportunities for its further introduction into real life. During the further extensive real-data testing and deployment phases, the support from public authorities and local transport operators may contribute significantly to the success of the dashboard.

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8 References

- [aN11] Centre for Transport and Navigation. *Waterway Guidelines 2011*. 2011.
- 10 [BBC] BBC. Public Transport Information Tables Index. http://www.bbc.co.uk/travelnews/xml/pti/pti_index.html, accessed on 23 January, 2014.
- 12 [Bie09] Adam Bien. Java EE or .NET - An Almost Unbiased Opinion : Adam Bien's Weblog. http://www.adam-bien.com/roller/abien/entry/java_ee_or_net_an, accessed on 16 June, 2014, 2009.
- 14
- [BLA12] LOÏC BLAIVE. Data Exchange Interfaces, DATEX II. Deployment Guideline. (January):1–30, 2012.
- 16
- [BOA00] TRANSPORTATION RESEARCH BOARD. *HIGHWAY CAPACITY MANUAL*. 2000.
- 18
- [Cai04] Giovanni Caire. JADE : the new kernel and last developments Summary. 2004.
- 20 [CEN09] CEN/TC 278. NeTEx — Network and Timetable Exchange — Part 1 : Network Topology Contents. Technical report, CEN/TC 278, 2009.
- 22 [CEN13] CEN/TC 278. Public transport — Service interface for real-time information relating to public transport operations — Part 3 : Functional service interfaces. Technical report, CEN, 2013.
- 24
- [Cha10] David Chappell. Introducing Windows Communication Foundation. (January), 2010.
- 26
- [CLRS09] Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest, and Clifford Stein. *Introduction to Algorithms. Third Edition*, volume 21. The MIT Press, Cambridge, 3rd edition, January 2009.
- 28
- 30 [COG13] JEFF COGSWELL. Java vs. C#: Which Performs Better in the 'Real World'? - Dice News. <http://news.dice.com/2013/01/17/java-vs-c-which-performs-better-in-the-real-world-2/>, accessed on 16 June, 2014, 2013.
- 32
- 34 [Com05] Performance Review Commission. Punctuality drivers at major European airports. Technical Report May, European Organisation for the Safety of Air Navigation (EUROCONTROL), Brussels, 2005.
- 36
- [Con] DSDM Consortium. 10. MoSCoW Prioritisation | DSDM CONSORTIUM. <http://dsdm.org/content/10-moscow-prioritisation>, accessed on 13 June, 2014.
- 38

REFERENCES

- [Con13] MIELE Consortium. MIELE. Part of Priority Project 21, 2013.
- [Cor11] Oracle Corporation. javax.ws.rs (Java EE 6). <http://docs.oracle.com/javase/6/api/javax/ws/rs/package-summary.html>, accessed on 18 June 2014, 2011.
- [Dir13] Network Manager Directorate. NM Monthly Network Operations Report - Analysis - October 2013. Technical Report October, The European Organisation for the Safety of Air Navigation (EUROCONTROL), Brussels, 2013.
- [dN13] Jornal de Noticias. STCP alerta clientes para "perturbações significativas" na terça-feira devido a greve - JN. http://www.jn.pt/paginainicial/pais/concelho.aspx?Distrito=Porto&Concelho=Porto&Option=Interior&content_id=3549876, accessed on 20 June, 2014, 2013.
- [Dos10] Siddharth Doshi. *DESIGNING A MULTI-MODAL TRAVELER INFORMATION PLATFORM FOR URBAN TRANSPORTATION*. PhD thesis, Georgia Institute of Technology, 2010.
- [DRF⁺08] Richard Dowling, David Reinke, Aimee Flannery, Paul Ryus, Mark Vandehey, Theo Petrirsch, Bruce Landis, Nagui Roupail, and James Bonneson. Multimodal Level of Service Analysis for Urban Streets. Technical report, TRANSPORTATION RESEARCH BOARD, WASHINGTON, 2008.
- [EfAtP] The United Nations Economic (ESCAP), Social Commission for Asia, and the Pacific. Multimodal Transport Operations.
- [Ehi14] Benjamin Ehinger. MySQL vs Oracle | ITX. <http://itxdesign.com/mysql-vs-oracle/>, accessed on 16 June, 2014, 2014.
- [Ens12] James Oliver Ensley. *Application of Highway Capacity Manual 2010 Level-of-Service Methodologies for Planning Deficiency Analysis*. PhD thesis, 2012.
- [ET] DIRECTORATE-GENERAL FOR MOBILITY EUROPEAN COMMISSION and TRANSPORT. ICT Infrastructure. http://ec.europa.eu/transport/themes/its/road/application_areas/ict_infrastructure_en.htm, accessed on 6 June, 2014.
- [(EU14] The European Organisation for the Safety of Air Navigation (EUROCONTROL). NOP Network Operations Portal. <https://www.public.cfm.eurocontrol.int/PUBPORTAL/gateway/spec/index.html>, accessed on 14 June, 2014, 2014.
- [Eze10] Stephen Ezell. Intelligent Transportation Systems. *The Information Technology & Innovation Foundation*, 2010.
- [FCR09] Tiago R. M. Freitas, Antão Coelho, and Rosaldo J. F. Rossetti. Improving digital maps through GPS data processing. In *2009 12th International IEEE Conference on Intelligent Transportation Systems*, pages 1–6, St. Louis, MO, October 2009. IEEE.
- [FCR10] Tiago R. M. Freitas, Antonio Coelho, and Rosaldo J. F. Rossetti. Correcting routing information through GPS data processing. In *13th International IEEE Conference on Intelligent Transportation Systems*, pages 706–711, Funchal, September 2010. IEEE.

REFERENCES

- [FdMV09] Mario Fruianu, Gordon de Munck, and Hans Voerknecht. Cycling in the Netherlands. Technical report, Ministry of Transport, Public Works and Water Management Directorate-General for Passenger Transport, Hague, 2009.
- [FERO08] Paulo Ferreira, Edgar Esteves, Rosaldo J F Rossetti, and Eugénio C Oliveira. A Co-operative Simulation Framework for Traffic and Transportation Engineering. *Lecture Notes in Computer Science*, 5220:89–97, 2008.
- [Fin] Findbestopensource.com. Advantages and Disadvantages of using Hibernate like ORM libraries. <http://www.findbestopensource.com/article-detail/orm-advantage-disadvantage>, accessed on 16 June, 2014.
- [Fle] Ian Fleming. ISO9126 - Software Quality Characteristics. An overview of the ISO 9126-1 software quality model definition, with an explanation of the major characteristics. <http://www.sqa.net/iso9126.html>, accessed on 12 June, 2014.
- [Fou] Eclipse Foundation. Help - Eclipse Platform. Plain old Java objects. <http://help.eclipse.org/juno/index.jsp?topic=/org.eclipse.jst.ejb.doc.user/topics/cpojosandee5.html>, accessed on 18 June, 2014.
- [GeOa] GeOps. TRAVIC - Transit Visualization Client. <http://tracker.geops.ch/>, accessed on 20 June, 2014.
- [GeOb] GeOps. Worldwide Transit Tracker | geOps. <http://geops.de/node/117?language=en>, accessed on 21 June, 2014.
- [Gooa] Google. google-gson - A Java library to convert JSON to Java objects and vice-versa - Google Project Hosting. <https://code.google.com/p/google-gson/>, accessed on 18 June, 2014.
- [Goob] Google. What is GTFS? - Transit — Google Developers. <https://developers.google.com/transit/gtfs/>, accessed on 22 June 2014.
- [GST11] Patrick Gendre, Bernard Senach, and Brigitte Trousse. Current Trends of Real-Time Multimodal Urban Mobility Information Services (RTMMIS). (June):1–10, 2011.
- [Hau11] Duncan Haughey. MoSCoW Method. *Project Smart*, page 2011, 2011.
- [HCG⁺] Chris Harding, Tony Carrato, Mats Gejnevall, Chris Greenslade, Jorge Diaz, Ali Arsanjani, Jack Fujieda, Alex Heublien, Harry Hendrickx, Kerrie Holley, Dave Ings, and Heather Kreger. The SOA Source Book. chapter Service Or.
- [HCT04] Kerrie (IBM Global Services) Holley, Kishore (IBM Global Services) Channabasavaiah, and Edward M (IBM Software Group) Tuggle. Migrating to a service-oriented architecture. (April), 2004.
- [Hib] Hibernate.org. What is Object/Relational Mapping? - Hibernate ORM. <http://hibernate.org/orm/what-is-an-orm/>, accessed on 16 June 2014.
- [Hux91] William E. Huxhold. *An Introduction to Urban Geographic Information Systems*. Oxford University Press, City of Milwaukee, 1991.

REFERENCES

- [JB] JADE-Board. Jade.core.behaviours (JADE v4.3.2 API). <http://jade.tilab.com/doc/api/jade/core/behaviours/package-summary.html>, accessed on 17 June, 2014.
- [JP07] D. R. Jones and D. E. Pitfield. The Effectiveness of Conceptual Airport Terminal Designs. *Transportation Planning and Technology*, 30(5):521–543, October 2007.
- [Kar09] Bill Karwin. Keeping it Simple: Why Should You Use an ORM? <http://karwin.blogspot.pt/2009/01/why-should-you-use-orm.html>, accessed on 16 June, 2014, 2009.
- [Kee13] Matthew Keep. Railway performance and subsidy statistics. Technical Report October, House Of Commons Library, Social and General Statistics Section, 2013.
- [Kit99a] Inc. In Kittelson & Associates. Transit Capacity and Quality of Service Manual. PART 4 TERMINAL CAPACITY. 1999.
- [Kit99b] Inc. In Kittelson & Associates. Transit Capacity and Quality of Service Manual. PART 5 QUALITY OF SERVICE. 1999.
- [Kit12] Inc. Kittelson & Associates. Regional Congestion Management Program. Technical Report 209, San Joaquin Council of Governments, Stockton, 2012.
- [Kop03] Dietmar Kopitz. TPEG Final Project Report (2000 – 2003). Technical report, European Broadcasting Union, 2003.
- [KW10] Adib Kanafani and Rui Wang. Measuring Multimodal Transport Level of Service. Technical Report August, University of California Transportation Center, Berkeley, 2010.
- [LG09] Peide Liu and Zhongliang Guan. Evaluation Research on the Quality of the Railway Passenger Service Based on the Linguistic Variables and the Improved PROMETHEE-II Method. *JOURNAL OF COMPUTERS*, 4(3):265–270, 2009.
- [Lit14] Todd (Victoria Transport Policy Institute) Litman. Introduction to Multi-Modal Transportation Planning Principles and Practices. 2014.
- [Lon] University College London. CityDashboard: London. <http://citydashboard.org/london/>, accessed on 22 January, 2014.
- [Ltd10] Oxera Consulting Ltd. How can a quality of service index be created ? Service quality report. 2010.
- [MBBI10] C Hair Michael R Morris, Allen D Biehler, Larry L Brown, and Randell H Iwasaki. *Airport Passenger Terminal Planning and Design. Guidebook.*, volume 1. Washington, 2010.
- [Mck13] Jeff Mckee. Inland Marine Transportation System Levels of Service Update. 2013.
- [MG09] Gavin (Virginia Tech) Mulligan and Denis (Virginia Tech) Gracanin. A comparison of SOAP and REST implementations of a service based interaction independence middleware framework. In *Simulation Conference (WSC), Proceedings of the 2009 Winter*, pages 1423–1432, Austin, TX, 2009. IEEE.

REFERENCES

- [Mob12] Intelomatics Australia Connected Mobility. European update Traffic & Traveller Information Standards Focus. Technical report, Intelomatics Australia Connected Mobility European, 2012.
- [Nat11] Ireland National Transport Authority. National Cycle Manual. 2011.
- [Nav11] Barak Naveh. Welcome to JGraphT - a free Java Graph Library. <http://jgrapht.org/>, accessed on 19 June, 2014, 2011.
- [Nel96] Randal C. (Department of Computer Science University of Rochester) Nelson. Graphs: Search. https://www.cs.rochester.edu/u/nelson/courses/csc_173/graphs/search.html, accessed on 18 June, 2014, 1996.
- [Net13] Network Manager (Eurocontrol). Monthly Network Operations Report. Technical Report October, Eurocontrol, 2013.
- [NJ02] Timothy J (University of Aberdeen) Norman and Nicholas R (University of Aberdeen) Jennings. Constructing a Virtual Training Laboratory using Intelligent Agents. *International Journal of Continuing Engineering Education and Life Long Learning*, 12(Numbers 1-4/2002):201–213, 2002.
- [NPRI09] Nurzhan (Department of Computer Science Montana State University – Bozeman) Nurseitov, Michael (Department of Computer Science Montana State University – Bozeman) Paulson, Randall (Department of Computer Science Montana State University – Bozeman) Reynolds, and Clemente (Department of Computer Science Montana State University – Bozeman) Izurieta. Comparison of JSON and XML Data Interchange Formats : A Case Study. In *ISCA 22nd International Conference on Computer Applications in Industry and Engineering, CAINE 2009*, San Francisco, 2009.
- [OCMA13] A. Luis Osório, Luis M. Camarinha-Matos, and Hamideh Afsarmanesh. Enterprise Collaboration Network for Transport and Logistics Services. *Collaborative Systems for Reindustrialization*, 408(2013):267–278, 2013.
- [oG] San Joaquin Council of Governments. RCMP Roadway Performance Dashboard. <http://www.sjcog-rcmp.org/rcmp-roadway-performance-dashboard>, accessed on 23 January, 2014.
- [Ora11] Oracle. THE PREMIER PLATFORM FOR RICH ENTERPRISE CLIENT APPLICATIONS. 2011.
- [oTa] Maryland Department of Transportation. New MDOT Site. <http://www.mdot.maryland.gov/2012HomeContent.html>, accessed on 23 January, 2014.
- [oTb] Virginia Department of Transportation. VDOT Dashboard v3.0. <http://dashboard.virginiadot.org/>, accessed on 23 January, 2014.
- [oT09] Florida Department of Transportation. *FDOT QUALITY/LEVEL OF SERVICE HANDBOOK*. Tallahassee, 2009 edition, 2009.
- [oT13] Florida Department of Transportation. *2013 QUALITY/ LEVEL OF SERVICE HANDBOOK*. Tallahassee, 2013 edition, 2013.

REFERENCES

- [PL96] Richard H. Pratt and Timothy J. Lomax. Performance Measures for Multimodal Transportation Systems. *Transportation Research Record: Journal of the Transportation Research Board*, 1518(Volume 1518 / 1996 Transportation Planning Applications):86, 1996.
- [PotE10] European Parliament and Council of the EU. DIRECTIVE 2010/40/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport. *Official Journal of the European Union*, pages 1–13, 2010.
- [PPM10] I Padayachee, P. Kotze, and A. van Der Merwe. ISO 9126 external systems quality characteristics , sub- characteristics and domain specific criteria for evaluating e-Learning systems. 2010.
- [PR12] José L. F. Pereira and Rosaldo J. F. Rossetti. An integrated architecture for autonomous vehicles simulation. In *Proceedings of the 27th Annual ACM Symposium on Applied Computing - SAC '12*, pages 286–292, New York, New York, USA, 2012. ACM Press.
- [ptpL] Mais Perto Soluções para transportes públicos Lda. Transportes Públicos em Portugal. <http://www.transportespublicos.pt/faq/>, accessed on 21 June, 2014.
- [QA13] Kashif Naseer Qureshi and Abdul Hanan Abdullah. A Survey on Intelligent Transportation Systems. *Middle-East Journal of Scientific Research*, 15(5):629–642, 2013.
- [Rai] Network Rail. Performance and punctuality (PPM) - Network Rail. <http://www.networkrail.co.uk/about/performance/>, accessed on 25 January, 2014.
- [RAKG13] Rosaldo J.F. Rossetti, Joao Emilio Almeida, Zafeiris Kokkinogenis, and Joel Goncalves. Playing Transportation Seriously: Applications of Serious Games to Artificial Transportation Systems. *IEEE Intelligent Systems*, 28(4):107–112, July 2013.
- [RB99] Rosaldo José Fernandes Rossetti and Sergio Bampi. A software environment to integrate urban traffic simulation tasks. *Journal of Geographic Information and Decision Analysis*, 3(1):56–63, 1999.
- [RCS13] Jean-Paul Rodrigue, Claude Comtois, and Brian Slack. *The Geography of Transport Systems*. New York, 2013.
- [RFBO08] Rosaldo J. F. Rossetti, Paulo A. F. Ferreira, Rodrigo A. M. Braga, and Eugenio C. Oliveira. Towards an Artificial Traffic Control System. In *2008 11th International IEEE Conference on Intelligent Transportation Systems*, pages 14–19, Beijing, October 2008. IEEE.
- [RLT11] Rosaldo J. F. Rossetti, Ronghui Liu, and Shuming Tang. Guest Editorial Special Issue on Artificial Transportation Systems and Simulation. *IEEE Transactions on Intelligent Transportation Systems*, 12(2):309–312, June 2011.

REFERENCES

- [ROB07] Rosaldo J F Rossetti, Eugénio C Oliveira, and Ana L C Bazzan. Towards a specification of a framework for sustainable transportation analysis. In *13th Portuguese Conference on Artificial Intelligence*, Guimaraes, Portugal, 2007.
- [(RT)] The Regional Transportation Commission of Southern Nevada (RTC). Freeway Travel Times: Interactive Dashboard - Performance Monitoring & Measurement System (PMMS). <http://bugatti.nvfast.org/>, accessed on 6 June, 2014.
- [Sal12] Gyula Sallai. Defining Infocommunications and Related Terms. *Acta Polytechnica Hungarica*, 9(6):5–15, 2012.
- [SAT⁺13] Beasley Simon, Blaquiere Alexandre, Brown Tony, Franco Gino, and Jensen Helge. URBAN ITS EXPERT GROUP. GUIDELINES FOR ITS DEPLOYMENT IN URBAN AREAS. MULTIMODAL INFORMATION. (January), 2013.
- [Sch09] Robin Schumacher. MySQL :: Why Move to MySQL from Microsoft SQL Server? http://dev.mysql.com/tech-resources/articles/move_from_microsoft_SQL_Server.html, accessed on 16 June, 2014, 2009.
- [She02] Weiming Shen. Distributed manufacturing scheduling using intelligent agents. *Intelligent Systems, IEEE*, 17(1):88 – 94, 2002.
- [Sof] SmartBear Software. What is soapUI? | About SoapUI. <http://www.soapui.org/About-SoapUI/what-is-soapui.html>, accessed on 19 June, 2014.
- [ST] Microsoft NET Stocktrader and IBM Websphere Trade. .NET 3.0 vs. IBM WebSphere 6.1 Benchmark Results.
- [STC] SA STCP. STCP. <http://www.stcp.pt/pt/institucional/governo-societario/indicadores-chave/>, accessed on 23 June, 2014.
- [TEM02] TEM Project Central Office. TEM STANDARDS AND RECOMMENDED PRACTICE. Technical Report February, United Nations Economic Commission for Europe, Warsaw, 2002.
- [TIS12] TISA. TISA Guideline TPEG – What is it all about ? (April):1–14, 2012.
- [TR11] Rémi Tempier and Peter Rapp. ITS ACTION PLAN. Study “Towards a European Multi-Modal Journey Planner”. Technical Report September, EUROPEAN COMMISSION, Directorate-General Mobility and Transport, Brussels, 2011.
- [Tra] Trafiken.nu. Trafiken.nu. <http://www.trafiken.nu/Stockholm/>, accessed on 23 January, 2014.
- [Tru08] George Trujillo. MySQL versus Oracle Features/Functionality (A DBA’s Journey in the Sun). https://blogs.oracle.com/GeorgeTrujillo/entry/mysql_versus_oracle_features_functionality, accessed on 16 June, 2014, 2008.
- [vdVLW13] Tom van de Ven, James Long, and Mark Wedlock. ITS ACTION PLAN. Free Road Safety Traffic Information. Technical Report January, EUROPEAN COMMISSION, Directorate-General Mobility and Transport, Brussels, 2013.

REFERENCES

- 2094 [zMNS05] Michael zur Muehlen, Jeffrey V. Nickerson, and Keith D. Swenson. Developing web
2096 services choreography standards—the case of REST vs. SOAP. *Decision Support Systems*, 40(1):9–29, July 2005.

Appendix A

LOS Evaluation Model Diagrams

The diagrams below show the dependencies of higher level values from lower level, where detail degree is higher. The corresponding level of abstraction is indicated on the left, where the "Atomic Entity" row serves for the identification of the measured facility, equipment or service at the Atomic input level and its corresponding type in the data model (value in brackets). The facility in this case may designate a bus stop, an airport terminal, etc., and is associated to the "point" type. A Service, on its turn, is an entity of the "link" type and could be a port cruise, a flight, a bus line, etc. The values in the boxes contain the following information: the name of the LOS measure, the unit it is measured in (optional value in brackets), an indicator of a collection of values "1...n" if the LOS represents a collection and not a single value, then, following a colon ":" a function used for calculating the LOS value (does not apply to the Atomic level), and finally function parameters in brackets. The values in the brackets representing LOS value type may be set to the percentage symbol, "%", which means that the corresponding LOS value is a percentage, or symbol "#" which designates a numeric data type and, finally, it could be an "enum" data type, which means that the LOS may take one of the defined values.

In some cases, there appears an word "AND" in LOS value names which means that the corresponding cell represents in fact two or more LOS values, each of which has a its own sub-graph of lower level LOS values. E.g. "Urban Public Transport LOS AND Interurban Public Transport LOS" in Figure A.3 . In such cases these sub-graphs do not intersect but have identical structure. This was made solely for the purpose of a more compact view of the diagrams.

Weights may be attributed to all connections, where several inputs contribute to the calculation of a LOS value, since the inputs may have different priorities and importance.

Due to the dimensions on the LOS Model diagram, it was divided into several parts which appear in this appendix in the following order:

1. High level LOS structure, which includes Top, Domain and Mode levels, Figure A.1. Each node from the Mode level on this diagram is illustrated in the figures that follow;
2. Road Traffic LOS Diagram, Figure A.2;
3. Urban and Interurban Public Transport LOS, Figure A.3;

LOS Evaluation Model Diagrams

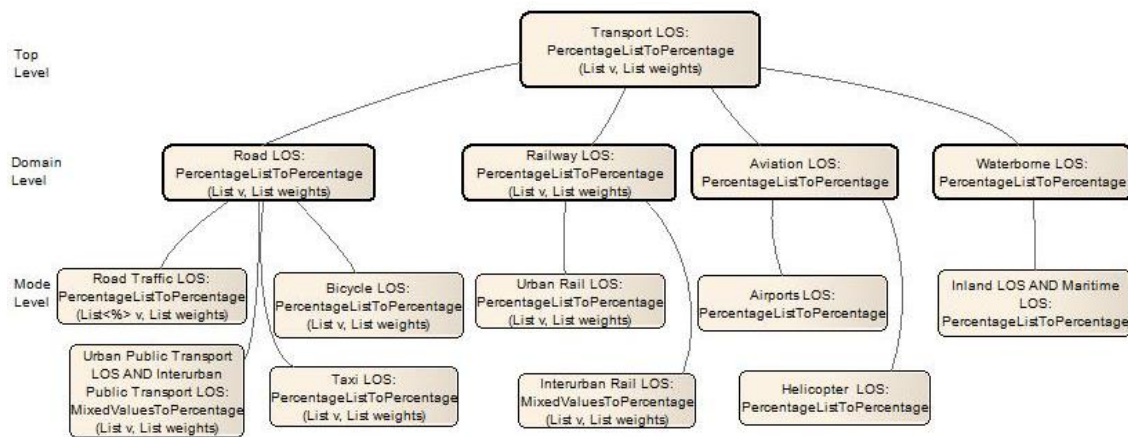


Figure A.1: High level LOS structure.

4. Bicycle LOS and Taxi LOS Mode structures are represented together in Figure A.4;
5. Urban Rail LOS Diagram, Figure A.5;
6. Interurban Rail LOS Diagram, Figure A.6;
7. Airports LOS Diagram, Figure A.7;
8. Helicopter LOS Diagram, Figure A.8;
9. Inland and Maritime LOS Diagram, Figure A.9;

LOS Evaluation Model Diagrams

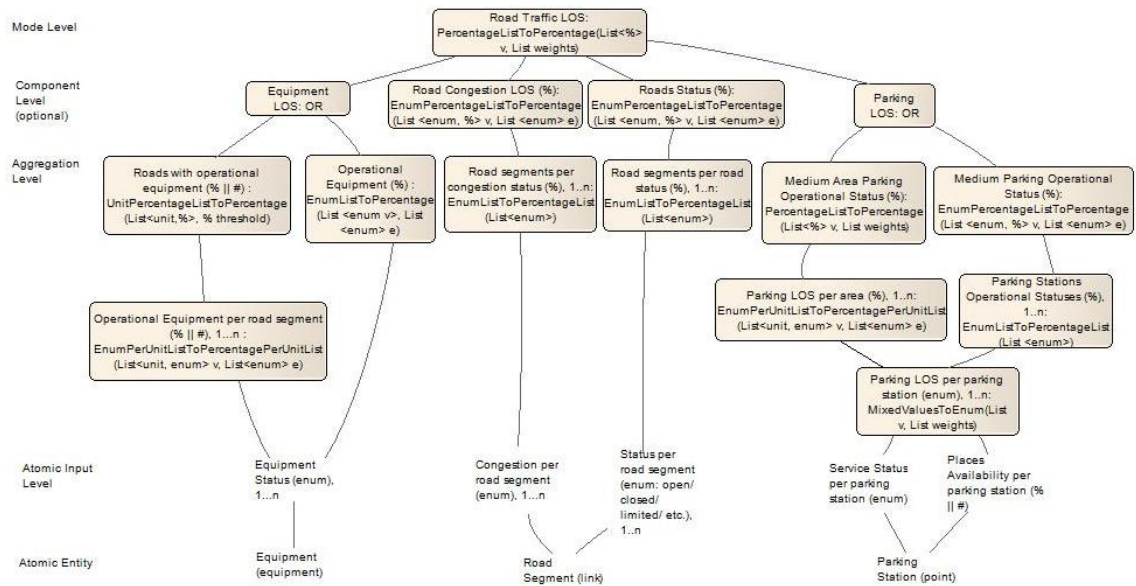


Figure A.2: Road Traffic LOS Diagram.

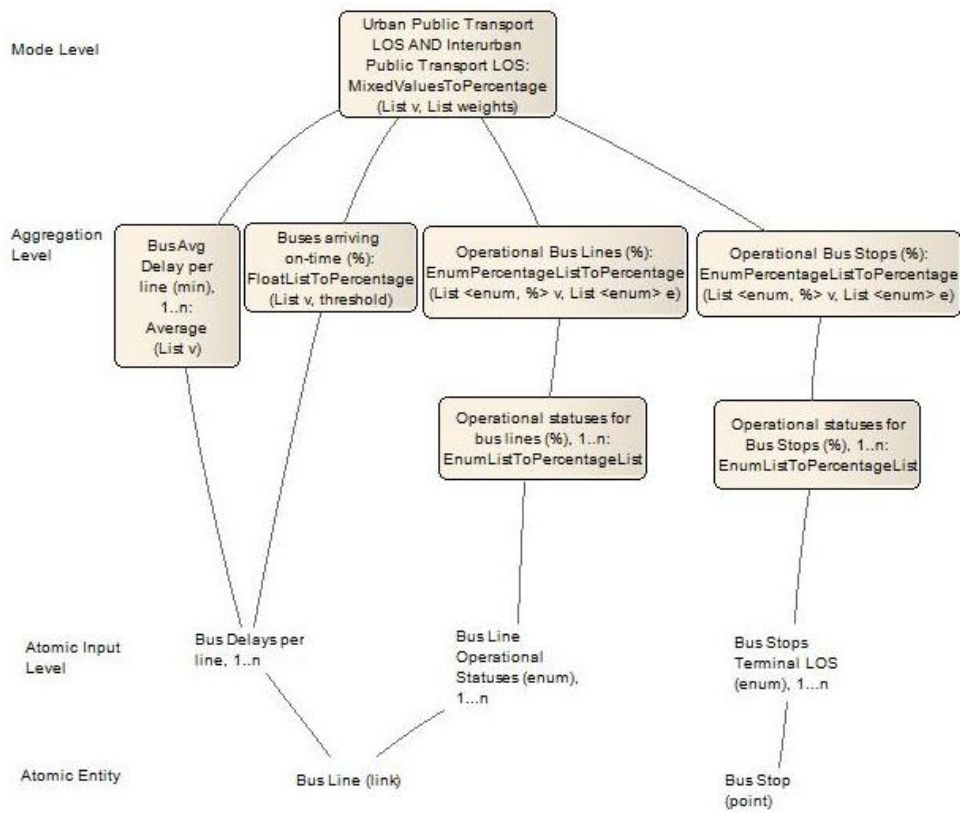


Figure A.3: Urban and Interurban Public Transport LOS Diagram.

LOS Evaluation Model Diagrams

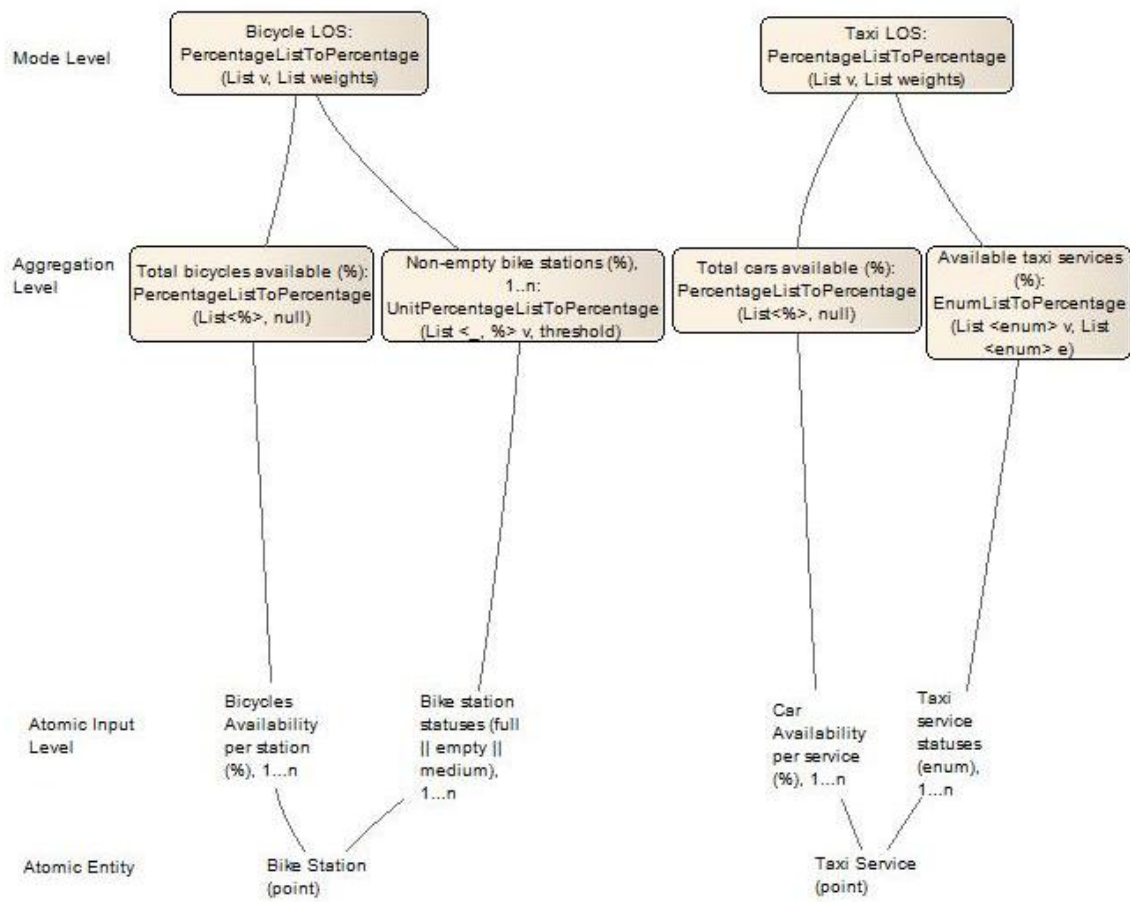


Figure A.4: Bicycle LOS and Taxi LOS Mode Diagrams.

LOS Evaluation Model Diagrams

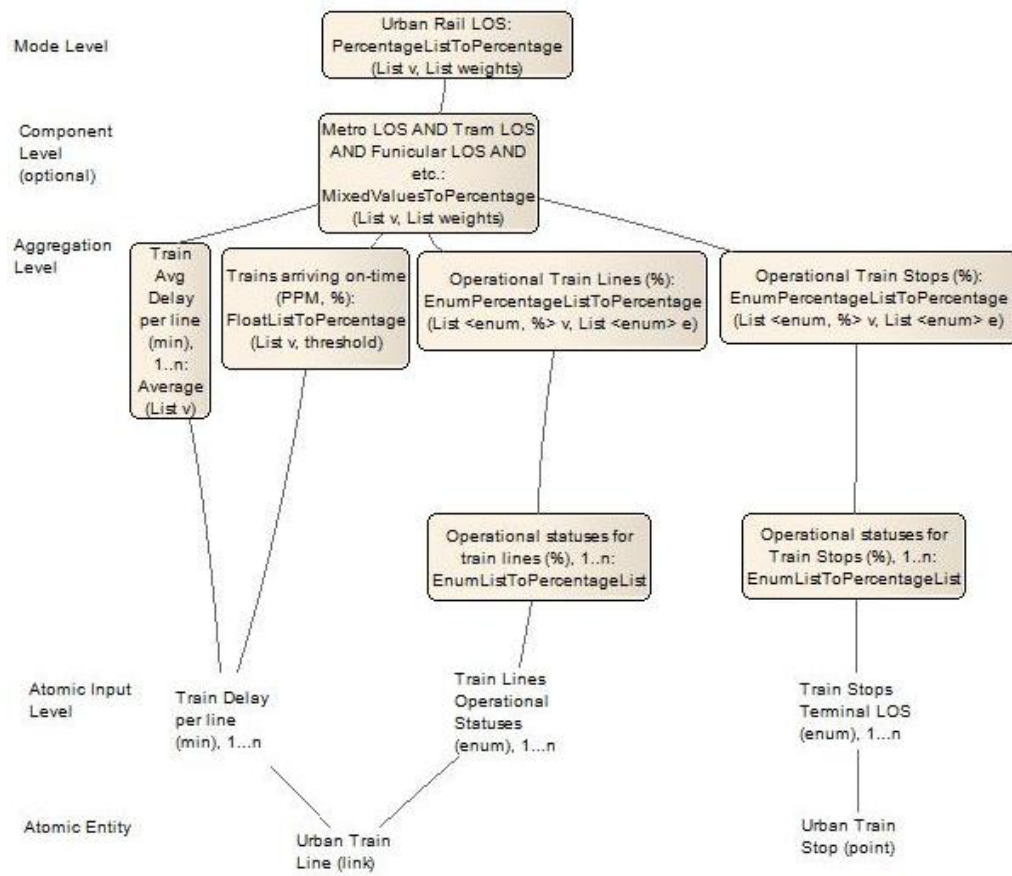


Figure A.5: Urban Rail LOS Diagram.

LOS Evaluation Model Diagrams

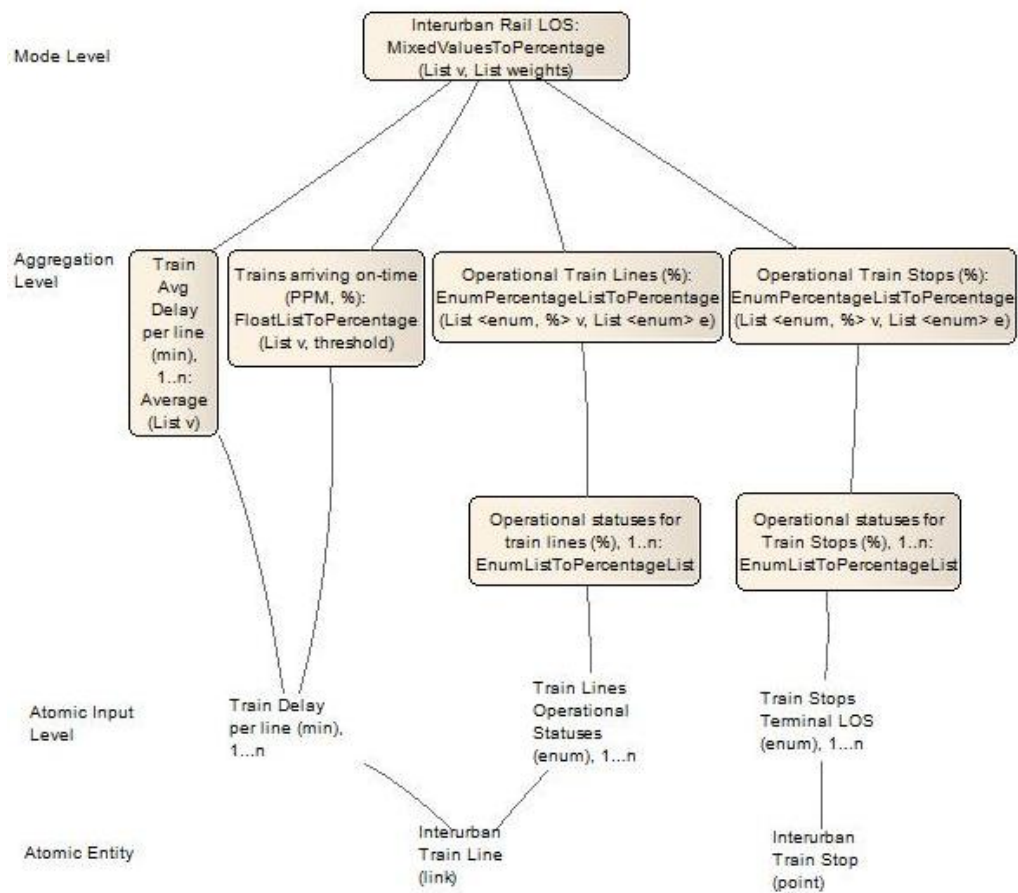


Figure A.6: Interurban Rail LOS Diagram.

LOS Evaluation Model Diagrams

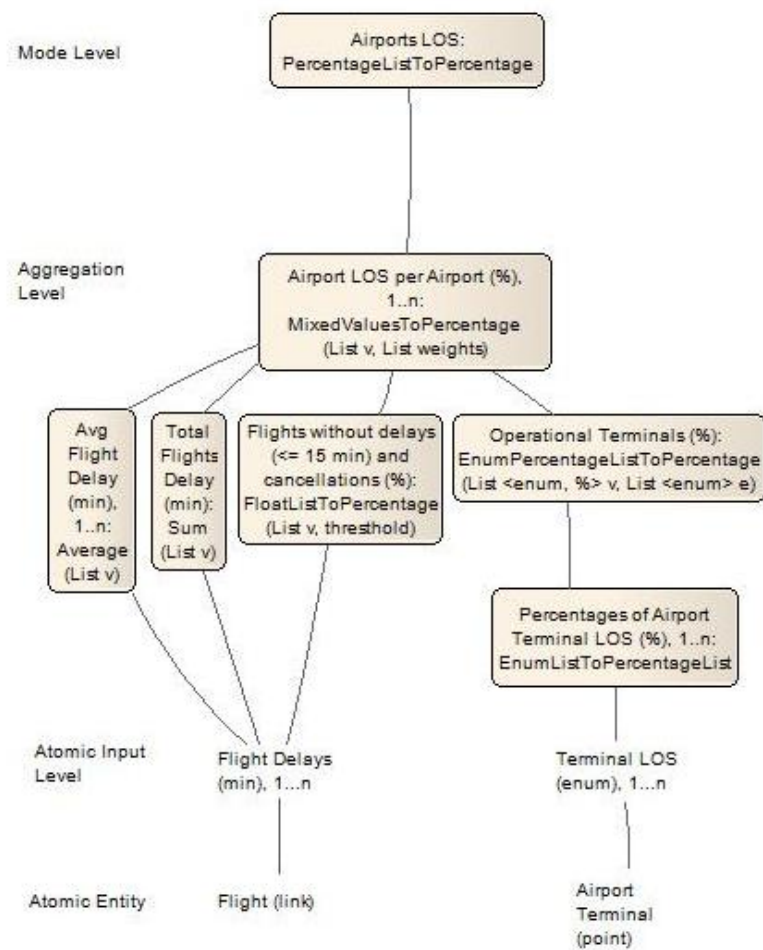


Figure A.7: Airports LOS Diagram.

LOS Evaluation Model Diagrams

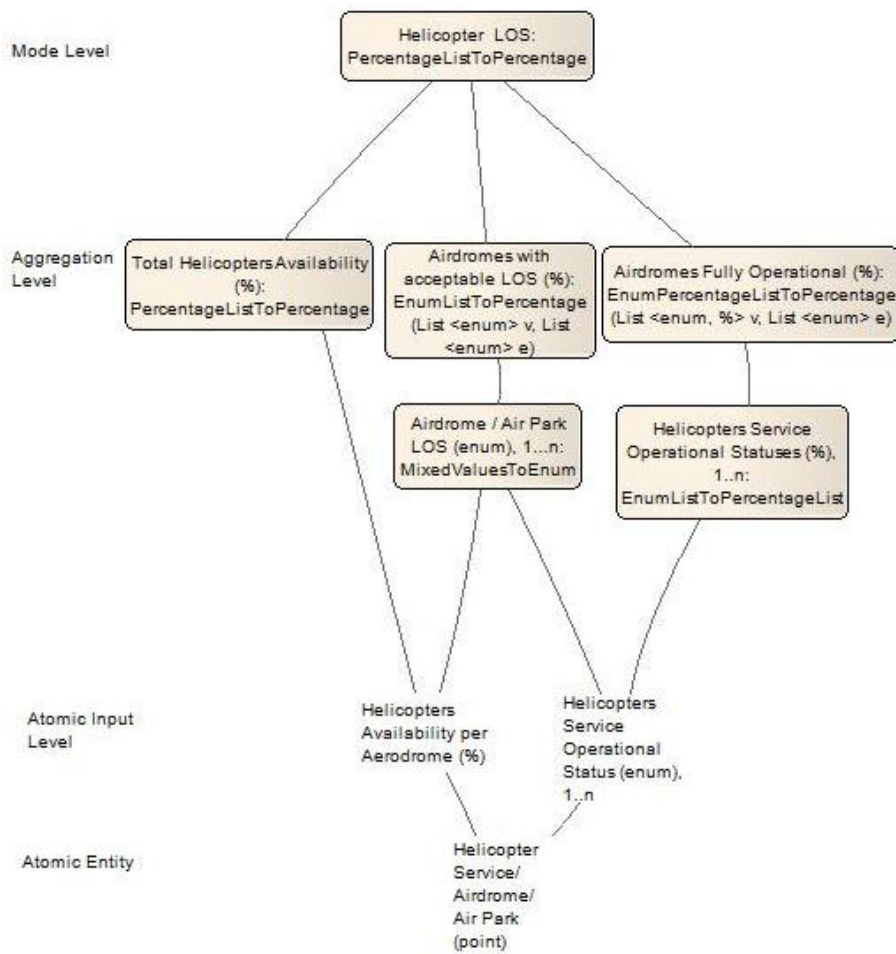


Figure A.8: Helicopter LOS Diagram.

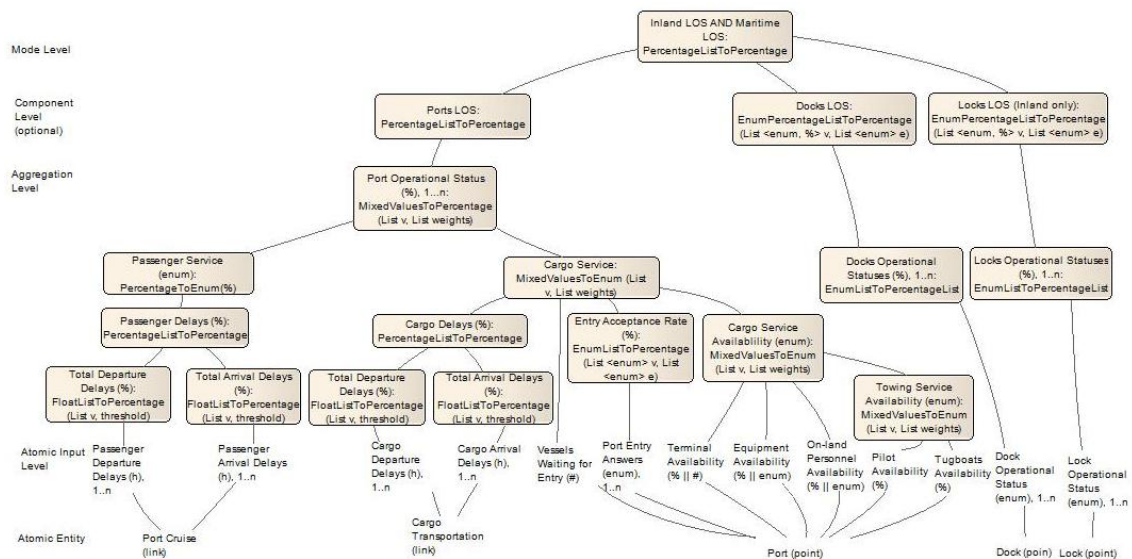


Figure A.9: Inland and Maritime LOS Diagram.

2132 **Appendix B**

Data Model Detailed View

Data Model Detailed View

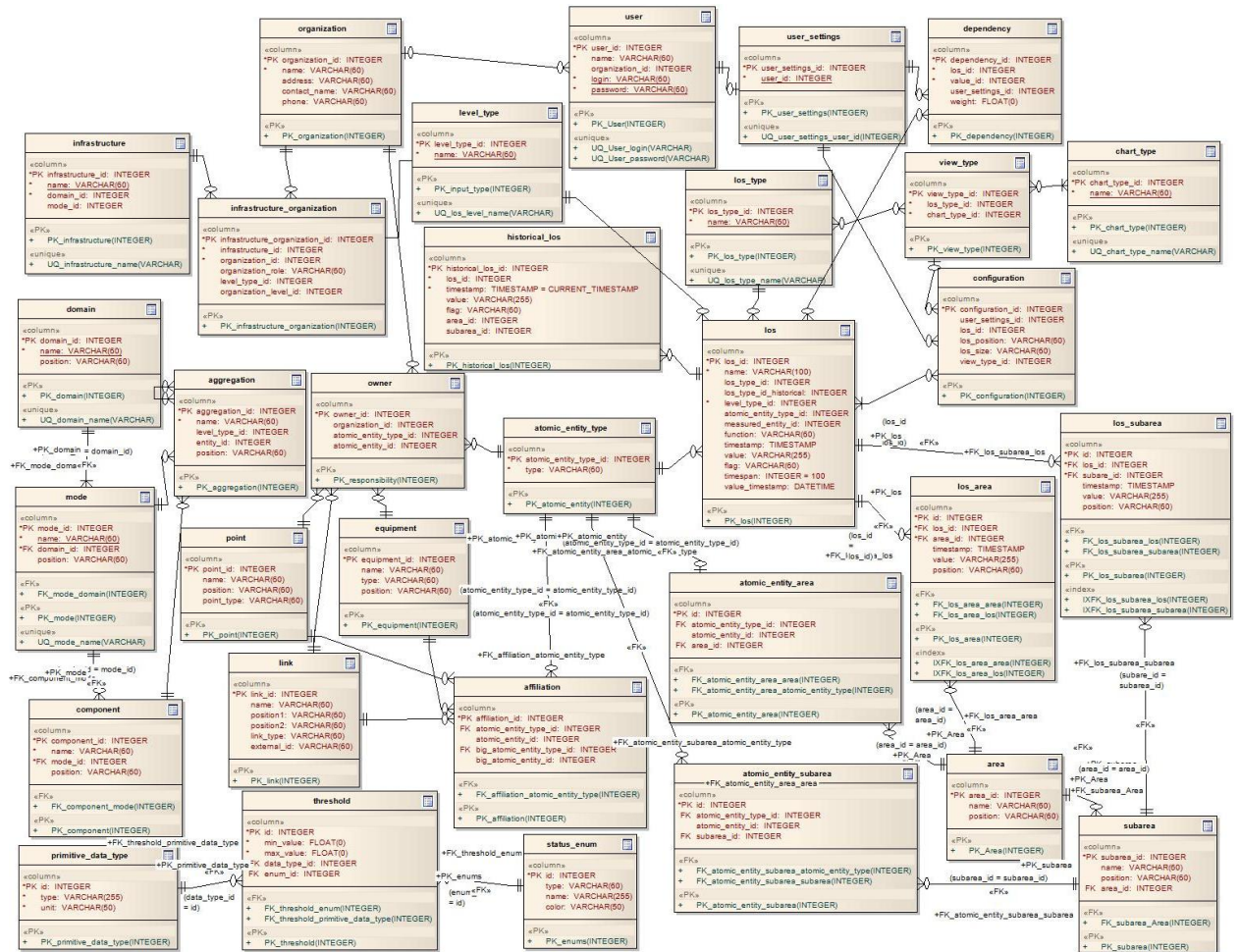


Figure B.1: Data Model Detailed View.

2134 **Appendix C**

Dashboard Screen-shots

Dashboard Screen-shots

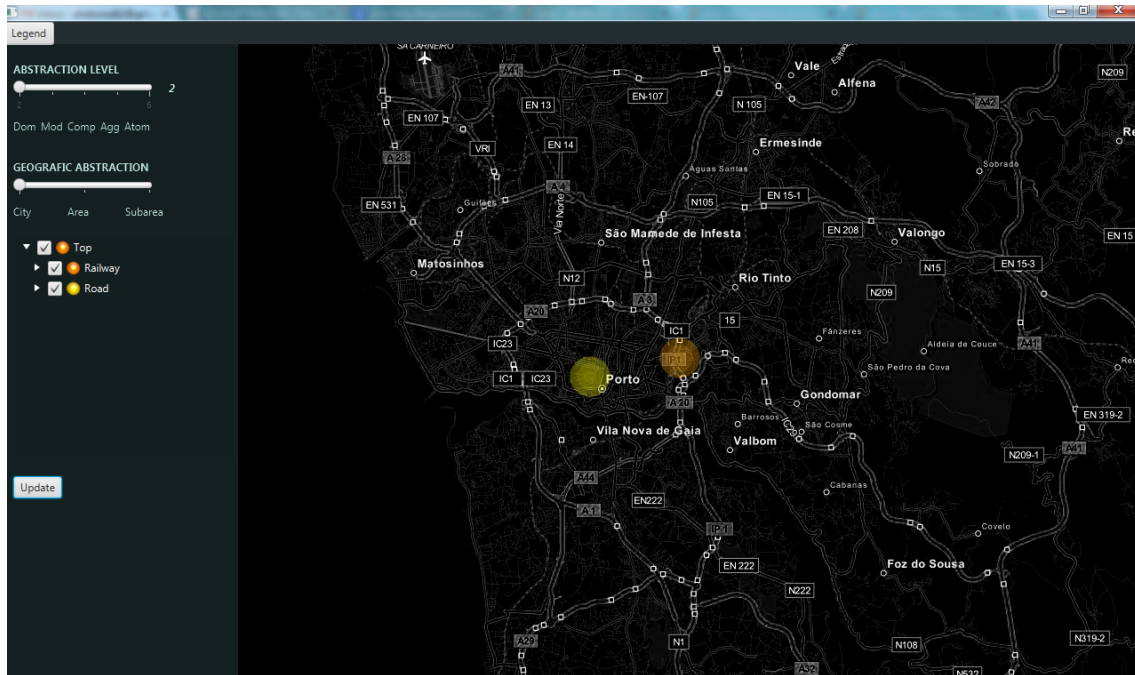


Figure C.1: Dashboard Default View. Domain level LOS indicators at City abstraction with all domains selected.

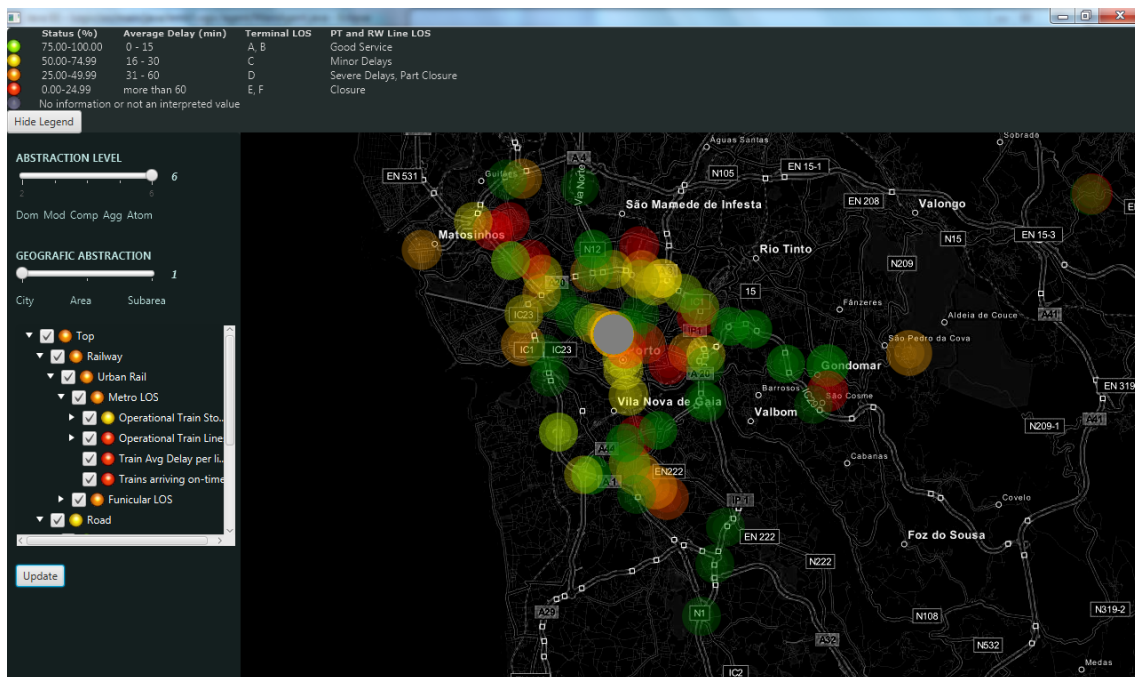


Figure C.2: Dashboard View with Legend and Atomic LOS Indicators at City Abstraction.

Dashboard Screen-shots

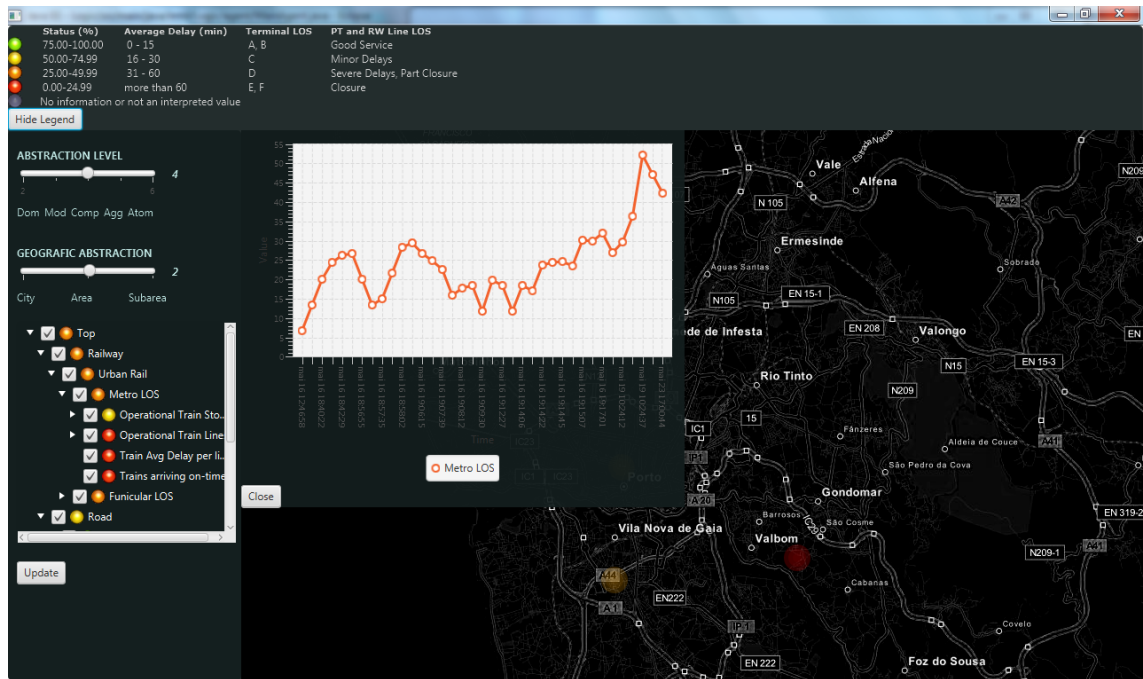


Figure C.3: Line Chart View with Historical Values For Metro LOS. Indicators on the map correspond to Component level at Area abstraction.

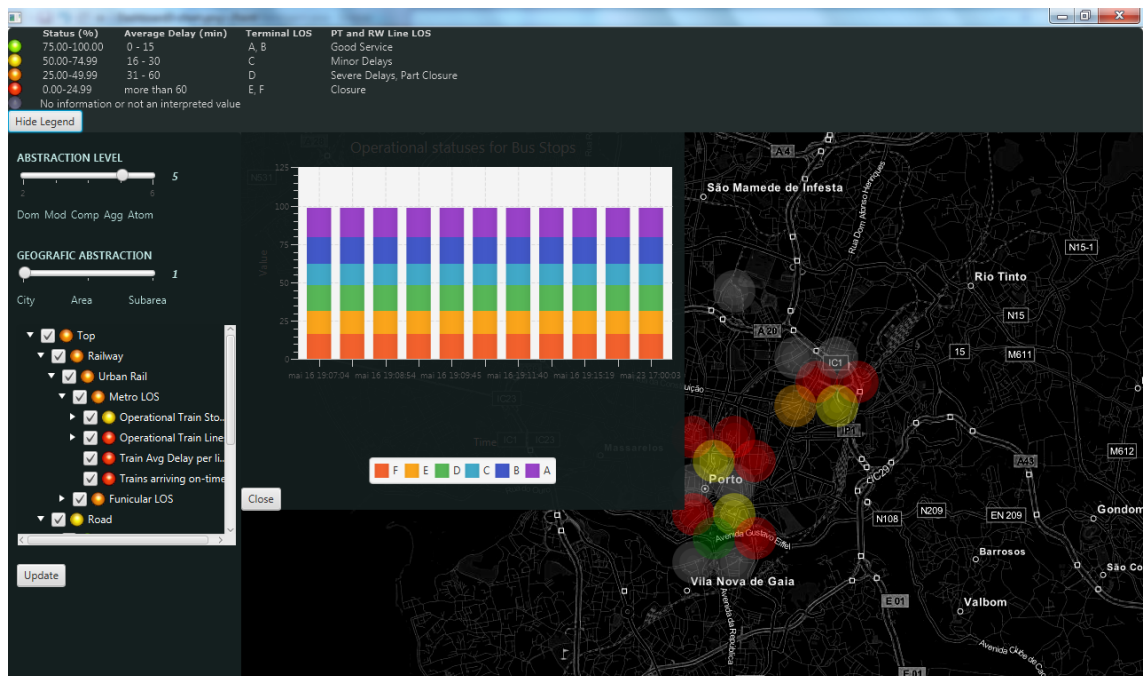


Figure C.4: Stack Bar Chart View with Historical Values for Operational Statuses For Urban Bus Stops. Indicators on the map correspond to Aggregation level at City abstraction.

Dashboard Screen-shots

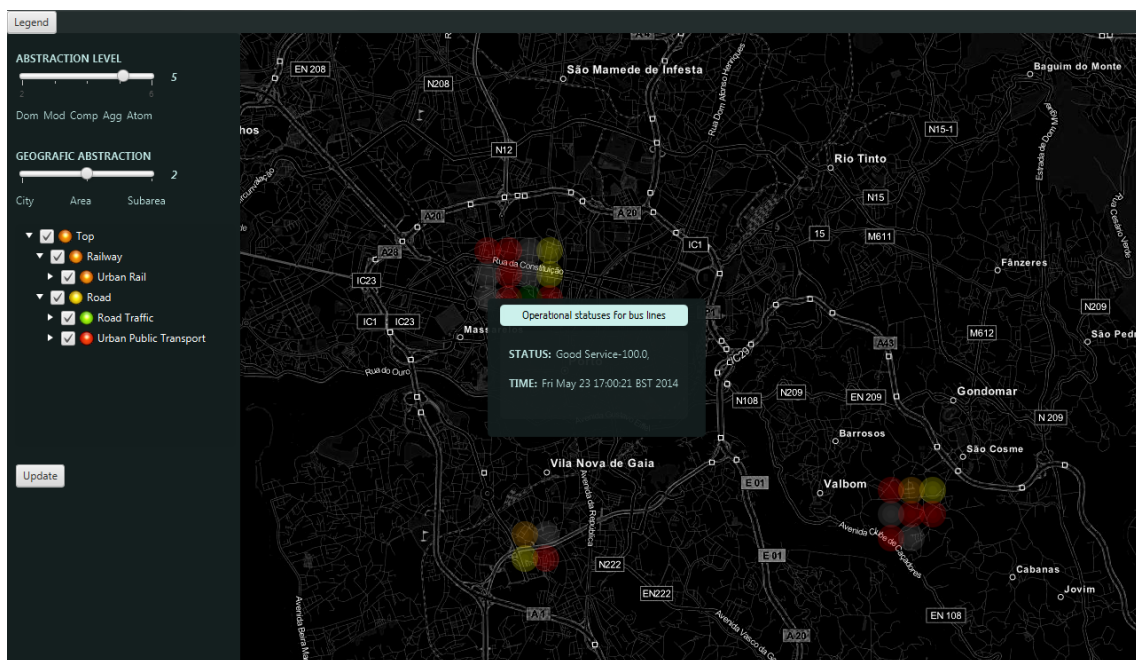


Figure C.5: Information Pane For a LOS Indicator. Indicators on the map correspond to Aggregation level at Area abstraction.

Appendix D

Output Values

Table D.1: Output Values.

Transport Mode	Output Value	Array or single value	Data Type	Boundaries
Maritime	Maritime LOS	single	float	[0,100]
Maritime	Sea LOS	single	float	[0,100]
Maritime	Inland LOS	single	float	[0,100]
Maritime	Ports LOS	single	float	[0,100]
Maritime	Locks LOS	single	float	[0,100]
Maritime	Docks LOS	single	float	[0,100]
Maritime	Port Operational Status	array	enum	x values
Maritime	Percentage of available locks	single	float	[0,100]
Maritime	Percentages of operational statuses for locks	array	float	[0,100]
Maritime	Lock LOS	array	enum	x values
Maritime	Lock Operational Status (open/closed/full)	array	enum	x values
Maritime	Lockages Operational Status	array	enum	x values
Maritime	Percentages of operational statuses for docks	array	float	[0,100]
Maritime	Percentage of available docks	single	float	[0,100]
Maritime	Docks Operational Status	array	enum	x values
Road	Road LOS	single	float	[0,100]
Road	Road Traffic LOS	single	float	[0,100]
Road	Public Transport LOS	single	float	[0,100]
Road	Bicycle LOS	single	float	[0,100]
Road	Congestion per road segment	array	enum	x values

Output Values

Road	Percentage of non-congested roads	single	float	[0,100]
Road	Percentage of road segments per congestion status	array	float	[0,100]
Road	Equipment Statuses	array	enum	x values
Road	Percentage of Operational Equipment per road segment	array	float	[0,100]
Road	Percentage of Roads with operational equipment	single	float	[0,100]
Road	Percentage of Operational equipment	single	float	[0,100]
Road	Percentages of operational statuses for Bus Stops	array	float	[0,100]
Road	Bus Stops Terminal LOS	array	enum	x values
Road	Bus Lines Operational Status	array	enum	x values
Road	Percentages of operational statuses for bus lines	array	float	[0,100]
Road	Bus Lines Avg Delay per line, min	single	float	[0, 1440]
Road	Percentage of buses arriving on-time	single	float	[0,100]
Road	Delays per Bus line, min	array	int	[0, 1440]
Road	Percentage of buses arriving on-time	single	float	[0,100]
Road	Total Bicycles Available	single	float	[0,100]
Road	Bicycles Availability per station	array	int	[0, Max-Value]
Road	Bike station statuses (full / empty / medium)	array	enum	x values
Road	Percentages of non-empty bike stations	array	float	[0,100]
Aviation	Aviation LOS	single	float	[0,100]
Aviation	Medium Airport LOS	single	float	[0,100]
Aviation	Airports LOS	single	float	[0,100]
Aviation	Helicopter LOS	single	float	[0,100]
Aviation	Avg Delay per Flight per airport, min	array	float	[0, 1440]

Output Values

Aviation	Total Flights Delay per airport, min	array	int	[0, Infinity]
Aviation	Percent of Flights with big delays (≥ 30 min) and cancellations per airport	array	float	[0,100]
Aviation	Flight Delays, min	array	int	[0, 1440]
Aviation	Percentages of Airport Terminal LOS	array	float	[0,100]
Aviation	Airport LOS per Terminal	array	enum	x values
Aviation	Helicopters Medium LOS	single	float	[0,100]
Aviation	Total Helicopters Availability	single	float	[0,100]
Aviation	Percentage of Aerodromes Fully Operational	single	float	[0,100]
Aviation	Percentages of Helicopters Service Operational Statuses	array	float	[0,100]
Aviation	Aerodrome / Air Park LOS	array	float	[0,100]
Aviation	Helicopters Availability	array	int	[0, Max-Value]
Aviation	Helicopters Service Operational Status	array	enum	x values
Rail	Railway LOS	single	float	[0,100]
Rail	Urban Rail LOS	single	float	[0,100]
Rail	Interurban Rail LOS	single	float	[0,100]
Rail	Metro/Rail Stops Terminal LOS	array	enum	x values
Rail	Metro/Rail Lines Operational Status	array	enum	x values
Rail	Percentages of operational statuses for metro/rail lines	array	float	[0,100]
Rail	Percentages of operational statuses for metro/rail Stops	array	float	[0,100]
Rail	Percentage of metro/rail trains arriving on-time	single	float	[0,100]
Rail	Metro/Rail Avg Delay per line, min	single	float	[0, 1440]
Rail	Metro/Rail Delay per line, min	array	int	[0, 1440]

Output Values

News,MM	Events	array	text	
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Table D.1: Output Values.

2138 **Appendix E**

Software Engineering

2140 **E.1 Use Cases**

There are two types of dashboard users: non-authenticated user and authenticated user who has access to a wider range of functionalities. Another actor represents data sources, the number of which can be more than one.

2144 Non-authenticated user has access to the following uses:

- Authenticate
- 2146 • Observe the system
- Select to view certain specific information

2148 Authenticated user's possible uses consist in the following:

- Observe the system
- 2150 • Select to view certain specific information
- Receive alarms and notifications in case when there is a degradation of a certain LOS value
- 2152 • Customize the dashboard in order to monitor only the most important and critical information
- 2154 • Configure the system in accordance to the needs and interests of the organization or institution the user belongs to
- 2156 • Subscribe to or unsubscribe from notifications, depending on their importance to the user and/or organization

2158 The Data Source actor is responsible for delivering the raw data, which should then be verified, validated, mapped and finally inserted to the database.

2160 The detailed Use Case diagram is presented in Figure [E.1](#).

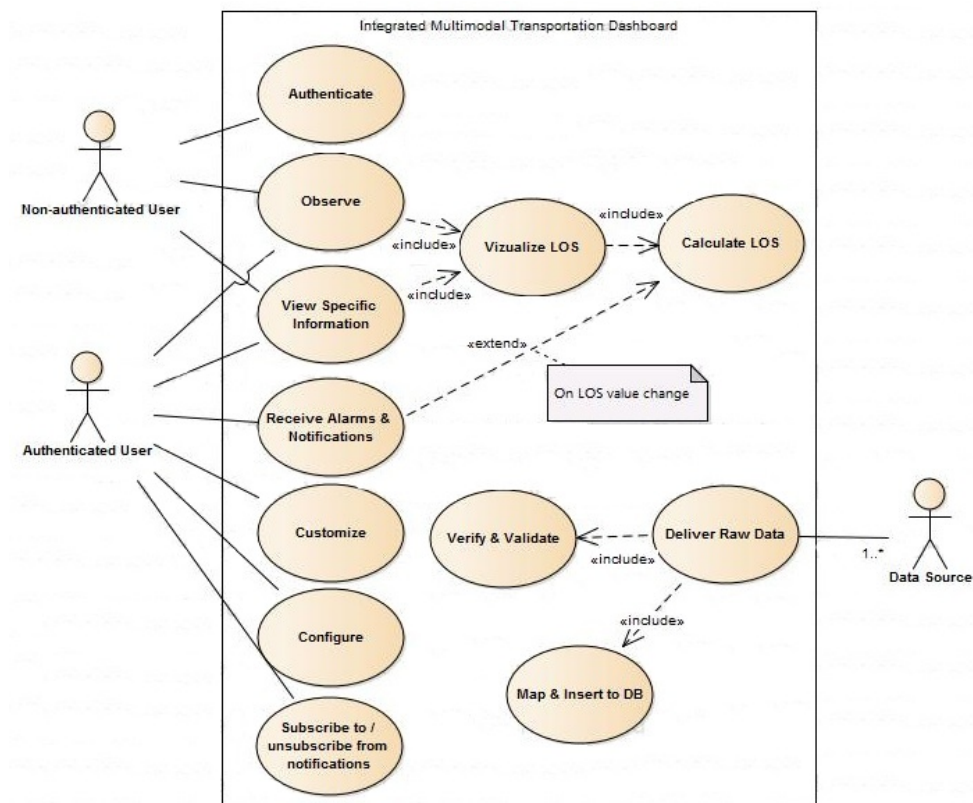


Figure E.1: Use Case Model Diagram.

E.2 User Stories

The User Stories (US) have been defined for the system implementation in two levels of detail: high level US and Detailed US. The high level US are as follows:

1. As a General User, I want to have a clear vision of all transport systems (TSs) that are monitored on the dashboard in real time, so that I could see their current LOS and make decision based on this information.
2. As an Authenticated User, I want to be alarmed or notified by the system in case some TS suffers LOS degradation, so that I could perform a necessary action with a minimal delay.
3. As a General User, I want to see the details on the TS that suffered LOS degradation, such as TS infrastructure details, problem/event details, time and date problem/event occurred, details of affected area (road segment, etc.), responsible authorities (name, contacts, etc.), so that I and/or responsible authorities could treat the problem properly.
4. As a General User, I want to have access to historical data on TSs LOS, so that I could spot the weak points and analyze tendencies.

2176 5. As an Authenticated User, I want to customize the dashboard, so that the LOS values were
calculated in accordance with the existing priorities and dependencies, as set by my organi-
zation.

2178 6. As an Authenticated User, I want to configure dashboard, so that it would display only the
necessary information with a required detail level using an optimal layout.

2180 7. As an Authenticated User, I want to subscribe or unsubscribe from notifications about LOS
change, so that I would only receive notifications I am interested in.

2182 The detailed user stories are listed in the Table E.1, where a priority value is attributed to each
requirement, based on MoSCoW Prioritisation Method, which defines four priority levels, from
2184 the highest to the lowest: Must, Could, Should, Won't or Would [Con, Hau11].

Table E.1: User Stories

US ID	As an	I want to	So that	Priority (MoSCoW)
101	General User	Have access to the top level LOS that evaluates the status of the entire transport network	I could instantly perceive the general status of local transport	MUST
102	General User	Have access to the domain level LOS that evaluates the status of the entire transport domain, such as Aviation, Road, Rail and Maritime	I could instantly perceive the status of the corresponding transport domain	MUST
103	General User	Have access to the mode level LOS that evaluates the status of the entire transport mode, such as Road Traffic, Urban Bus (PT), Interurban Bus, Bicycle, Taxi, Urban Rail, Interurban Rail, Airport, Helicopter, Inland Waterborne Transport, Maritime Transport	I could perceive the status of the corresponding transport mode	MUST

104	General User	Have access to the Aggregation Level LOS values on various transport modes that aggregate the atomic inputs for a conjunction of elements such as bus stops, lines, road segments, flights, etc., in percentage, numeric format or in the form of an average status	I could analyze the operation of a certain transport mode in more detail	MUST
105	General User	Have access to the Atomic and Input level values	I could analyze details of the operation of a certain transport mode or its component and localize the elements with LOS degradation	SHOULD
106	General User	Authenticate in the system	I could view the LOS values in accordance with the customization and configuration performed for my account	SHOULD
201	Authenticated User	Be alarmed by the system in case of Top, Domain or Mode Level LOS degradation	I could immediately inform of the problem the responsible organization/person and/or make informed decision/planning	SHOULD
202	Authenticated User	Be notified by the system about Component or Aggregation Level LOS degradation	I could immediately inform of the problem or request information from the responsible organization/person and forecast possible consequences for other modes/TSs	SHOULD
203	Authenticated User	View notifications about Atomic and Input Level LOS degradation	I could quickly localize the elements with LOS degradation and/or causing LOS degradation on a higher level and forecast possible consequences for other modes/TSs	SHOULD

301	General User	See the details on the TS that suffered LOS degradation, such as TS infrastructure details, Problem/event details, time and date problem/event occurred, details of affected area (road segment, etc.), responsible authorities (name, contacts, etc.)	I and/or responsible authorities could treat the problem properly	COULD
401	General User	Be offered a choice to access historical data on each LOS value	I could check the tendencies and evolution of each LOS value over the time	SHOULD
402	General User	After selecting a certain LOS value historical view, to view a chart with its dynamics for a certain period of time	I could analyze the tendencies of a certain TS/component/element LOS	COULD
403	General User	After selecting a certain LOS value historical view, to be able to choose a period and time format (daily/ weekly/ monthly/ etc. or continuous time)	I could analyze the tendencies of a certain TS/ component/ element LOS for a certain period of time	WON'T
501	Authenticated User	Customize the set of LOS values to be included in the system	The dashboard would calculate LOS values that are applicable to the given geographic area	COULD
502	Authenticated User	Customize the set of inputs for each LOS value from lower levels	The system would calculate LOS values in an adequate and correct way	COULD
503	Authenticated User	Customize the weights of inputs when there are more than one inputs to the next level LOS value	The system would calculate LOS values based on inputs priorities and importance, which may not be uniform	SHOULD
504	Authenticated User	Have my setting saved after the customization	I wouldn't need to repeat customization every time at authentication	SHOULD

601	Authenticated User	Select the LOS values to be displayed on the dashboard	It would display only the necessary values in order to avoid information overwhelming	COULD
602	Authenticated User	Change layout of LOS values on the dashboard (their position and size)	I had a more convenient presentation of the information for its better perception	COULD
603	Authenticated User	For each displayed LOS value, to be able to choose a chart type (or other presentation mode)	I had a more convenient presentation of the information for its better perception	WON'T
604	Authenticated User	After selecting a certain LOS value historical view, to be able to choose a chart type (or other presentation mode)	I had a more convenient presentation of the information for its better perception	WON'T
605	Authenticated User	Have my setting saved after the configuration	I wouldn't need to repeat configuration every time at authentication	SHOULD
701	Authenticated User	Subscribe for notifications about LOS change that I am interested in	I would receive information on the change of LOS values that are important to me	WON'T
702	Authenticated User	Unsubscribe from notifications about LOS change	I would only receive notifications I am interested in	WON'T

Table E.1: User Stories

E.3 Work Plan

2186 The implementation process was divided into fifteen macro tasks which are described in this section. The tasks are listed in their chronological order, however it is understood that the implementation process followed an incremental development model, where software components developed at earlier phases may suffer changes and improvements during following phases.

- 2190 1. Implementation of database structure;
2. Populating database which includes the LOS Model, as well as some transport systems data necessary for testing purposes;
- 2192 3. Integration of development tools (IDE, Hibernate, libraries, etc.);
- 2194 4. Creating a prototype representing software architecture (projects, major packages and classes);

5. Implementation and tests of LOS functions;
- 2196 6. Implementation of graph traversal algorithms for two scenarios: the startup calculations over the entire LOS Model and re-calculations on the arrival of a new value;
- 2198 7. Testing graph algorithms and triggered calculations;
- 2200 8. Implementation of web-services and their testing using the SoapUI tool, an open source functional testing solution [[Sof](#)];
- 2202 9. Implementation of Broker component, responsible for the communication with information sources and obtaining new values;
10. Integration of the GUI framework into the project;
- 2204 11. Implementation of the interface with the server on client side (GUI);
12. Testing the correct execution of GUI in conjunction with the server;
- 2206 13. Implementation of user controls and filters on GUI;
14. Testing the application in real-time mode with random value generation;
- 2208 15. Testing the application in real-time mode with real values read from a file.