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# Towards an Integrated Multimodal Transportation Dashboard

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*Abstract*— **Many sophisticated Information Systems (IS) focusing on management and supervision problems in the transportation arena exist in the contemporary world. Road traffic management systems, rail traffic management systems and many more are here to face everyday challenges. However, in spite of a huge progress in this area, systems that combine multiple transport modes for management purposes are a very few. This article proposes a solution for the monitoring of the operational state of multimodal transportation systems in a single dashboard. The experimental solution is applied to the transport network of the city of Porto, Portugal, as a case study. The problem includes such major components as (1) input information and its sources, (2) model (metrics, calculation algorithms) and (3) visualization metaphors. A proposed solution is a dashboard that provides a comprehensive view on the operational state, or Level of Service (LOS), of transportation systems of different types. Such a system is expected to become an essential tool for transport system monitoring and management, supplying the necessary information for strategic and emergency planning to the authorities and other decision makers in the sector.**

## I. Introduction

The growth of urban transport networks in size and complexity creates a challenge in managing transport at city-scale. The monitoring and control problems are often solved with the help of IS that now occupy an important place in the Transportation area: Intelligent Transportation Systems (ITSs), as well as Information and Communication Technologies (ICTs). These systems have been experiencing a significant progress and growth in their application. However, the majority of such systems address a single transport mode, and a very few solutions combine different modes at the same time. Nevertheless, demand exists for multimodal transport solutions that would provide a comprehensive view of local Transportation Network [1]. Such systems could offer a number of benefits to the public and authorities. One of the important features would be the possibility of monitoring the levels of service and performance of local transport networks, thereby providing support in the decision making process in case of emergency events, etc. Therefore, a need for a multimodal supervision dashboard arouse - a dashboard that would permit to combine transportation systems of different types and that would provide a comprehensive view in order to observe whether all systems are functional and operating at an acceptable LOS in a real-time mode. This work will address the above issues specifically for the ITSs used in the city of Porto, Portugal.

Our aim was first of all to study the possibility of providing a global view on the whole transportation network of any scale and type, in order to monitor its transportation systems at different levels of abstraction and evaluate their operational state based on that of the elements and subsystems they include, as well as the operational state of the transportation network as a whole. In order to achieve this aim, we have developed an hierarchical model of LOS evaluation inspired by the concept of ontology. For testing purpose we have implemented a prototype of the dashboard that combines the LOS measures of different transport modes and detail level and permits LOS analysis at different geographic scale: the entire monitored zone, its areas and sub-areas.

To make that possible, it was necessary to identify the protocols and other sources supplying data related to LOS for different transport means (aviation, road, waterborne, railway) in a real-time mode. Besides that, a study has been performed to identify and define the metrics, as well as their scale for the evaluation of LOS of each transport system and respective subsystems. The result of the research that has been carried out and the prototype architecture are described in this paper.

## II. Methodological Approach

The LOS evaluation model and system architecture were designed with the idea of versatility in mind, in order to make the solution described in the paper applicable to any transportation network at a varied geographic scale.

### A. Hierarchical LOS Evaluation

Taking into consideration the heterogeneity and hierarchical structure of such complex and large-scale system as the Transportation Network, this paper suggests using ontology for the evaluation of the operational status of the network components, as well as that of the entire network. This approach includes several phases as described below.

First step is the identification of abstraction levels that represent the vertical structure of our model. The levels identified for the Transportation Network are shown in Figure 1.

Next important phase is horizontal decomposition, i.e. identification of the elements each abstraction level consists of. In case of application area, the domain level consists of Aviation, Railway, Waterborne and Road transport. Each domain is further decomposed into modes (e.g. Road domain includes modes such as Road Traffic, Urban Public Transport, Interurban Public Transport, Bicycle, Taxi, etc.) The nodes from the Atomic level represent operational status

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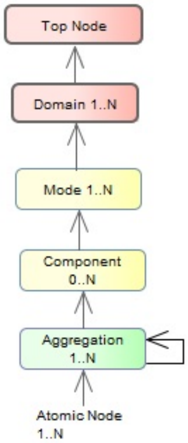


Fig. 1: Meta Model Vertical Structure

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).

Thirdly, dependency analysis and attribution of influences should be performed, i.e. each connection between the nodes represents dependency of the target node on the source node. In case 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 identifying and analysing 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 above the 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 more than one node. For this case study,thirteen functions have been identified in total.

The result of this process is an hierarchical LOS calculation model that can be classified as a weighted directed acyclic graph. The calculations in the dashboard prototype are based on graph algorithms, mainly such as Breadth-first search (BFS) and Depth-first search (DFS). The DFS algorithm is used for running calculations over the entire model at start-up to make sure that all values are up-to-date. During the execution in real-time mode, on the arrival of a new value, usually at Atomic Level (e.g. updated congestion status of road segments), the BFS based calculations are triggered, during which all the upper level values, which depend on the updated node, are recalculated. The model supports updates triggered at any level of abstraction, where the recently updated node serves as a "root" node for the BFS algorithm.

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 and Sub-area abstraction, 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 non-instantiated branches of the graph in areas and sub-areas and improve performance, Area and Subarea calculations use only the BFS algorithm both at the startup and during execution. The only difference is that at start-up, the BFS algorithm for areas and subareas pushes the entire set of instantiated atomic nodes for the area/subarea to the queue instead of a single "root" node.

### B. System Architecture

Conceptually, the system consists of the following layers:

- Connection layer - connects with protocols and other external sources supplying raw data and delivers it to the next layer;
- Data layer - verifies the raw data, maps it to system's data fields and saves to database;
- Control layer - calculates LOS values based on the input values from the data layer;
- 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 has been implemented in the system prototype, as shown in Figure 2.

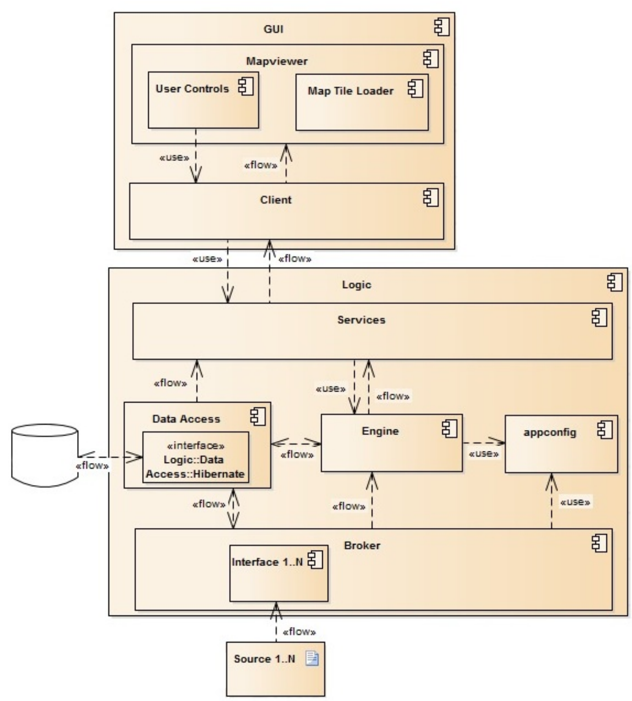


Fig. 2: Logical Architecture

The "Logic" package is responsible for the connection with the database and exterior information sources (the "Broker" component, in the diagram), as well as the calculation part (the "Engine" component, in the diagram). The calculations are based on the Hierarchical LOS Evaluation model described above and support three geographic abstraction levels: the entire monitored zone, its areas and subareas. The Graphical User Interface (GUI) represents the dashboard itself, which communicates with the Logic through REST Web Services.

### C. Experimental Setup

Tests have been performed on the application using input data from road sensors. The purpose of the tests was to observe system's behavior in different scenarios: with and without perturbations in public transport service. 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 the 26th of November, 2013, when STCP, one of the principal urban public transport providers in Porto, was at a strike and had a considerably reduced service [2]. In order to understand the effect of the strike, some other days were analyzed as well; one day before the strike and one day after it; and the same three days a week before and two weeks before the strike. 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 values such 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.

The analysis was made based on the occupancy measure for the road segments, which affected the higher level values. Generally, it was noticed that the major degradation of LOS on roads took place at morning and evening peak hours. Usually, in the morning between 7:40 and 11:30, and 17:40 to 20:00 in the evening. Between these periods 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.

**Road Congestion LOS**: an Aggregation level value which 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 an earlier than usual and more prolonged degradation of the LOS for the evening peak hours, when the degradation amplitude reached 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. Figure 3 allows comparing the measure variations for three consecutive Tuesdays, including the strike day, November 26th. The chart displays Road Congestion LOS values during the evening peak hours, i.e. period from 16:40 to 20:05, when major changes were noticeable.

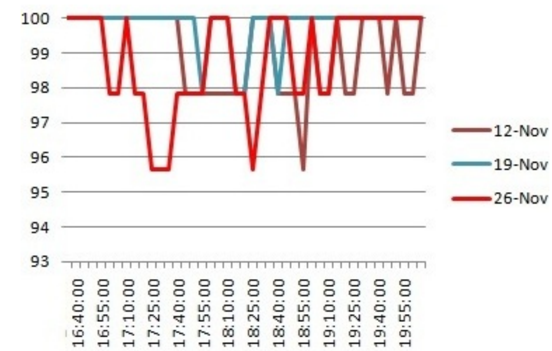


Fig. 3: Road Congestion LOS, three consecutive Tuesdays.

**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 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 modes such 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.

Based on the performed tests, it was observed 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 were not at strike. Besides, it should also be taken into account that the monitored roads did not include streets inside the city, only motorways, where quite a high LOS is observed on average.

## III. Related Work

### A. Data Communication Protocols

Data communication protocols are essential for applications comprising multiple exterior data sources, such as this project. Many protocols exist today in the world for transport related data exchange. Efforts have been and are being made toward their standardization and increased compatibility. Table I 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, supply of information on road traffic (RT) and/or public transport (PT), location referencing (LRef) and support of XML files for data transmission over the Internet.

TABLE I: Comparison of Data Communication Protocols (Y = Yes, N = No)

| Protocol | Geography | RT | PT | LRef | XML |
|---|---|---|---|---|---|
| TPEG | EU, Worldwide | Y | Y | Y | Y |
| DATEX I, II | EU | Y | N | Y | Y |
| SIRI | UK, EU | N | Y | Y | Y |
| NeTEx | EU | N | Y | Y | Y |
| TransXChange | UK | N | Y | | Y |
| GTFS | Worldwide | N | Y | Y | N |

To date, TPEG is the only protocol family covering data exchange both on road traffic (TPEG-RTM) and public transport (TPEG-PTI)[3]. DATEX is Europe-wide standard for road traffic information exchange. In Portugal it is used by INIR, Brisa and Estradas Portugal [4] [5]. SIRI is a European protocol for real-time public transport information exchange, which is widely used in Europe. It also served as a base for the development of NeTEx standard [6] [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 [7]. Some of its parts are still on the development phase. It is based on other protocols and standards, such as SIRI, Transmodel and IFOPT [7]. The standard is compatible with TPEG and some country-specific standards, such as VDV 452 and Neptune.

GTFS, defined as The General Transit Feed Specification, is a standard developed by Google for sharing public transport schedules and geographic information [9]. The protocol is not widely used in Portugal yet, but it is gradually gaining popularity.

The existence of such common standards and their continued spreading in transportation infrastructures as well as the existence of local standards make it perfectly possible to feed a system described in this work with the necessary information on all transport modes.

### *B. LOS Metrics*

The concept of Level of Service, or LOS, is widely used for measuring traffic flow on roads, however, in recent decades it was introduced for some other modes of transport, such as pedestrian, bus, public transport terminals [10]. In this paper the same term is used to measure the operational state of all transport modes, terminal types, as well as the entire transportation systems.

LOS concepts and their measurement methods are defined and standardized well for some transport modes and infrastructure elements, such as road traffic, airport and public transport terminals, waiting areas, flight delays. As mentioned earlier, the literature review on LOS metrics and evaluation methods served as a background for defining LOS hierarchy, especially the Atomic Level elements.

However, the identified 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, average speed or lanes occupancy rate [11], [12];
- 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 [10];
- 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 [13], [14];
- 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) [15] and have become an internationally recognized standard;
- Average Airport delays per flight (minutes) [16] [17];
- Total Airport delays (minutes)[18];
- Flights with 15 or more minutes delay (the threshold is set to 30 minutes in some sources) [19], [18].

### *C. Examples of Dashboard and Traveler Information Systems*

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 only a few of them are multimodal. Most 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 some examples is presented in Table II. Comparison criteria were chosen based on their relevance to this work and include the scope, presence of LOS-related information, real-time information (RT), multimodality (MM) and the form of presentation.

The CityDashboard [20] by University College London, is an example best fitting the goals of this work, being a properly multimodal dashboard, displaying real-time information and configurable to a certain extent. However it is

TABLE II: Dashboard and Traveler 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 | |

missing information on some modes of transport, such as airport and waterborne transport, and does not suggest a proper transport LOS related data, which might include road congestion levels, bus-on-time performance, etc.

## IV. Conclusions and Future Work

The Transport sector benefits from the growth and development observed in IT solutions existing for this sector, which facilitate considerably monitoring and management tasks and contributes to the service level improvement. Such solutions as well have 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 is also the key subject in this paper, where different approaches to the measurement of level of service are considered. LOS concepts and their measurement methods are defined and standardized well for some transport modes and infrastructure elements. 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 at several abstraction levels. 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 have suggested 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 address a single transport mode, and a very few solutions combine different modes at the same time. The existing multimodal systems usually do not address the issue of LOS monitoring. The identified examples of transport dashboards focused on LOS information are based on either unimodal or historical information, rather than truly multimodal real-time data. A need of such a service exists however and 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 has various solutions. Europe-wide and worldwide standards exist for transport-related data communication, which were reviewed in this paper. 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.

Based on the performed research and the analysis of various possibilities of a visualization approach for the dashboard, there has been developed a solution which permits a real-time monitoring of the current status of multimodal transport systems in the monitored region. The solution 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 its 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 performance analysis and decision-making process is the charts view of the transport system behavior over 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.

Further developments are still necessary to improve the implemented prototype, so as to test its full potential. Besides, major future steps in this research include:

- Further specification of data model depending on practical needs and applications;
- Specification and implementation of raw data verification and validation policies, to address issues of information conflicts, duplication, etc.;
- Implementation of interfaces with external data sources, such as communication protocols;
- Specification of mapping rules for raw data and database fields;
- Implementation of model configuration tool;
- Implementation of GUI customization feature;
- Evaluation and validation of usability issues;
- Validation of LOS inference models.

Although the challenges ahead are considerably many, current trends towards the multimodality and standardization in data communication are strong signs of potential applications of this research in real life. On the real-data testing and deployment phases, the support from public authorities and local transport operators is certainly imperative. Nonetheless, social media, social networks, and other types of collaborative data collection also stimulate potential development in this domain.

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