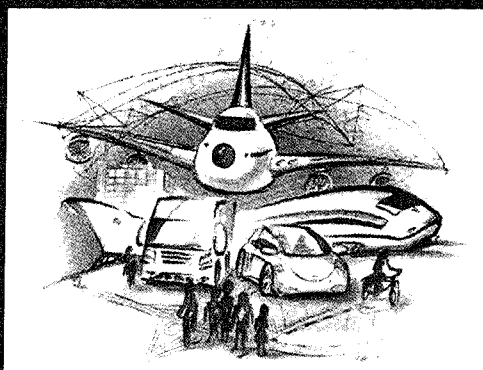


Dario Pacino  
Stefan Voß  
Rune Møller Jensen (Eds.)

LNCS 8197

# Computational Logistics

4th International Conference, ICCL 2013  
Copenhagen, Denmark, September 2013  
Proceedings



## Lecture Notes in Computer Science

The LNCS series reports state-of-the-art results in computer science research, development, and education, at a high level and in both printed and electronic form. Enjoying tight cooperation with the R&D community, with numerous individuals, as well as with prestigious organizations and societies, LNCS has grown into the most comprehensive computer science research forum available.

The scope of LNCS, including its subseries LNAI and LNBI, spans the whole range of computer science and information technology including interdisciplinary topics in a variety of application fields. The type of material published traditionally includes

- proceedings (published in time for the respective conference)
- post-proceedings (consisting of thoroughly revised final full papers)
- research monographs (which may be based on outstanding PhD work, research projects, technical reports, etc.)

More recently, several color-cover sublines have been added featuring, beyond a collection of papers, various added-value components; these sublines include

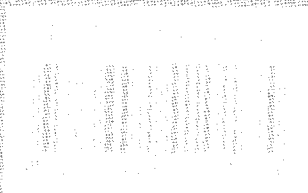
- tutorials (textbook-like monographs or collections of lectures given at advanced courses)
- state-of-the-art surveys (offering complete and mediated coverage of a topic)
- hot topics (introducing emergent topics to the broader community)

In parallel to the printed book, each new volume is published electronically in LNCS Online.

Detailed information on LNCS can be found at  
[www.springer.com/lncs](http://www.springer.com/lncs)

Proposals for publication should be sent to  
LNCS Editorial, Tiergartenstr. 17, 69121 Heidelberg, Germany  
E-mail: [lncs@springer.com](mailto:lncs@springer.com)

ISSN 0302-9743



**Lecture Notes in  
Computer Science**

LNCS

LNAI

LNBI

# An Integrated Simulation and Business Intelligence Framework for Designing and Planning Demand Responsive Transport Systems

José Telhada, Ana Cecília Dias, Paulo Sampaio, Guilherme Pereira,  
and Maria Sameiro Carvalho

Centro Algoritmi, Escola de Engenharia, Universidade do Minho, Campus de Gualtar,  
4710-057 Braga, Portugal

{jose.telhada, ana.dias, paulo.sampaio, guilherme.pereira,  
maria.carvalho}@algoritmi.uminho.pt

**Abstract.** Transportation planners, analysts and decision-makers usually make use of simulation tools in order to accurately predict the performance of new practices and policies before their implementation. Additionally, most of them, recently introduced new auxiliary Business Intelligence decision support tools in order to transform their available huge amount of real operating data into timely and accurate information for their decisions. However, although both of those types of automated decision support are valuable, very few attempts were already made by researchers to integrate them into a unified tool.

This paper proposes a general conceptual framework for a strategic and tactical decision support system that integrates both of these technologies, simulation and Business Intelligence, in order to enhance the overall practical interest for its usage by taking advantage of the foreseen synergy of the integration. This approach is then extended and illustrated to the case of demand responsive transport (DRT) systems. DRT systems provide transport on demand for users, using flexible schedules and routes to satisfy their travel needs.

The paper discusses the potential interest of the proposed integration, identifying a set of questions that can then be answered with effectiveness and more efficiently than before. In particular, such set comprises a list of strategic and tactical issues that are of crucial importance to the design and planning of sustainable DRT systems, before its implementation, thus overcoming the current lack of analytical tools to this end.

**Keywords:** Operations research, What-if simulation, Business intelligence, Integrated decision support system, Demand responsive transport (DRT).

## 1 Introduction

The design and planning of transportation systems are usually very difficult tasks due to the intrinsic high complexity of the interactions between the numerous stakeholders and physical elements involved. This is the main reason why simulation tools are widely used in such tasks, since they allow mimicking the functioning of systems,

testing and evaluating tion. Nowadays, evalu option(s) that are eco traditional analytical n

Business intelligence intelligence technique sion makers to transfo rate information for viewed as complemen attempts to make use tion) along with BI c literature. For exampl nated with BI to sup essential top-level ma simulation into an in management. This pap framework for a decis tion and BI, in a simi tion (Demand Respc integrated decision si designing and implen tive specifications of s

A literature review with a systematization systems, and therefor Since BI is a relativel such concept, reports generally describes th posal of a comprehen port system, and this a specific proposal to discusses the relevanc alization to enhance t able. Finally, Section

## 2 Literature I

Existing simulation to operational decision r model repeatedly, all standard deviations a

<sup>1</sup> Basically, both appro became aware about tl over, our paper is an e

testing and evaluating the performance of different plans, prior to their actual execution. Nowadays, evaluation of different alternative solutions is worthy to identify the option(s) that are economic, social and environmental sustainable. In most cases, traditional analytical methods are unable to fully address these issues.

Business intelligence (BI) tools comprise a set of analytical, statistical and artificial intelligence techniques along with sophisticated graphical technologies enabling decision makers to transform their available (huge amount of) data into timely and accurate information for decision making. Therefore, simulation and BI tools can be viewed as complementary tools for supporting decision making. However, only a few attempts to make use of effective operations research (OR) technologies (e.g. simulation) along with BI capabilities of historical data analysis has been reported in the literature. For example, Sabbour et al. [1] use visual interactive simulations coordinated with BI to support decisions at the strategic level. They also present the essential top-level managerial requirements that would transform strategic decision simulation into an integral component of BI systems, in the field of supply chain management. This paper intends to do basically the same, i.e., to propose a conceptual framework for a decision support system (tool) integrating both technologies, simulation and BI, in a similar fashion as [1], but focused on a specific field of transportation (Demand Responsive Transport - DRT).<sup>1</sup> That is, this paper proposes an integrated decision support system (IDSS) targeted to support decision makers in designing and implementing a DRT system, by investigating the impacts of alternative specifications of such system on its viability and sustainability for a given area.

A literature review is provided in Section 2 on actual decision support tools, along with a systematization of the performance measures that are relevant to transportation systems, and therefore to be used as the output of the proposed advanced BI tool. Since BI is a relatively new concept for the OR community, Section 2 also introduces such concept, reports some examples of tools that are commercially available, and generally describes their main functionalities. The focus of this work is on the proposal of a comprehensive framework for a what-if simulation based BI decision support system, and this is the matter of Section 3, where particular emphasis is done on a specific proposal to tackle DRT design and planning modelling tasks. Section 4 discusses the relevance of this proposal, and Section 5 illustrates some forms of visualization to enhance the effective and efficient use of the data and information available. Finally, Section 6 summarizes the main conclusions of this work.

## 2 Literature Review

Existing simulation tools aim at strategic or tactical decisions, and rarely are used for operational decision making. In this sense, the key idea of simulation is to execute a model repeatedly, allowing the estimation of statistical measures, such as averages, standard deviations and their confidence intervals. As a result, analysts will foresee

<sup>1</sup> Basically, both approaches were developed independently, since the authors of this paper became aware about the referred work only in the final stage of completing this paper. Moreover, our paper is an extension of our own recent work [2-3].

the long-run (in most cases, the steady-state) behaviour of the system and its related set of performance measures, thus allowing to perform its evaluation, e.g. comparatively against a "competing" scenario for the best in the pool for sustainability.

Transportation systems are, in general, intrinsically complex in terms of designing, planning and analysis. For this reason, perhaps the majority of transportation planners and analysts (e.g., traffic and mobility management bodies and agents, consultants) already use simulation tools. There is a significant number of commercial solutions available, such as EMME2, AIMSUN, DYNASMART, VISUM, DRACULA, etc.

The main problem with such tools is that they are intended to be used by specialists since their outputs are usually very technical and do not integrate some other relevant data analyses (e.g., financial data). Therefore, further analyses are needed in order to reach to very specific and succinct relevant information that can deploy the decision making. In other words, these tools are devoid of such benefits (process wizards, clicks and drag-and-drops, and relevant-only information) that characterizes BI tools. Additionally, Intelligent Transportation Systems (ITS) integrate a broad range of IS/IT elements for gathering on-site data and transfer it to the central database(s) of the enterprises or organizations. ITS also integrate the required hardware and software to analyse and manage the information extracted from data. This means that usually a huge amount of (operational) data is available. However, only a small fraction of this amount is adequately translated into asset information that can be used by managers.

On the other hand, BI tools, as is, are aimed at enabling analysis of historical data only. Therefore, they are not capable of giving accurate anticipations of future trends as new scenarios of functioning are concerned. And, this is the usual shortcoming that decision makers are faced to when using Decision Support Systems (DSS) purely based on BI tools. Therefore, it is important to incorporate reliable predictive systems capable of evaluating beforehand the impact of alternative or small changes in strategic or tactical plans. This can be done by integrating what-if analysis, by means of simulation, whose goal is to inspect the behaviour of a complex system under a given scenario.

In recent years, what-if analysis has been incorporated in BI tools. For example: SAP and SAS dedicated modules, MicroStrategy, Pentaho, QlikView, Powersim Studio, etc. Also, Microsoft has been integrating this technology in spreadsheets and OLAP tools. However, these analyses rely on the application of forecasting models and data-mining techniques on static historical data, thus heavily limiting the capability of performing the evaluation of most scenarios, namely all those that are somewhat different from the existing one.

In order to overcome this shortcoming, we then propose, in Section 3, an integrated approach that fundamentally consists on setting up an iterative (and user interactive) loop between a compatible simulation model or tool and a BI tool to support decisions at the strategic and tactical levels.

The herein proposed approach is particularly welcome for the designing and planning of DRT systems. Its potential interest relies on identifying a set of questions that can then be answered with effectiveness and more efficiently than before. In particular, such set comprises a list of strategic and tactical issues that are of crucial

importance to the d  
thus overcoming the

DRT systems pr  
and routes to satis  
requests either for  
routes and schedul  
aiming to respond  
DRT system, no re  
strategic and tactical

On the other har  
evaluation methods

Nowadays, a pa  
performance meas  
categorization is ol  
ing and new projec

The absence of  
and therefore prec  
are a necessity for  
discard the unsucc

## 2.1 Performance

The evaluation of  
are based on the  
usually named per  
perspective, the set c  
general, and DRT

Performance n  
goal. It is also a p

Traditionally, |  
ever, today trans  
complicated and  
transportation pr  
impacts of those |

Based on the l  
tion, there is a lar  
of assets, mobil

The Transport  
tion organization

- identify  
assessing  
and cons
- integrate  
gaging s

importance to the design and planning of DRT systems, before their implementation, thus overcoming the current lack of analytical tools to this end.

DRT systems provide transport on demand from users, using flexible schedules and routes to satisfy their travel needs. A DRT system operationally receives trip requests either for an immediate service or as an advanced reservation and organizes routes and schedules (e.g. using OR methodologies) to accommodate trip requests aiming to respond in real time to user's mobility needs. At the design phase of the DRT system, no real information exists yet on its functioning, so it is considered as a strategic and tactical decision process.

On the other hand, even after implementation, there is a lack of research work into evaluation methods and definition of real time evaluation and monitoring systems [4].

Nowadays, a particular focus is given to three fundamental broader categories of performance measures (or indicators) – economic, social and environmental. This categorization is obviously related to recent concerns about the sustainability of existing and new projects (e.g., for DRT, [5-6]).

The absence of measurement limits organizations ability to evaluate the changes and therefore precludes systematic improvement. Thus, good performance measures are a necessity for any progressive organization to recognize successful strategies and discard the unsuccessful.

## 2.1 Performance Measurement in Transportation Systems

The evaluation of the systems performance and all related decision making processes are based on the knowledge and analysis of quantitative and qualitative measures, usually named performance indicators. In this section, it is reported, in a broader perspective, the set of these indicators that may be relevant in transportation systems in general, and DRT in particular.

Performance measurement is a way of monitoring progress towards a result or goal. It is also a process of gathering information to make well-informed decisions.

Traditionally, performance measures have been largely technical in nature. However, today transportation executives and managers must address an increasingly complicated and wide-ranging set of issues regarding the best solutions on balance to transportation problems, the cost-effectiveness of proposed projects and estimated impacts of those projects.

Based on the literature related to performance measurement systems for transportation, there is a large number of measures within the following categories: preservation of assets, mobility and accessibility, operations and maintenance, and safety.

The Transportation Research Board had developed a framework [7] that transportation organizations should use in order to:

- identify performance measures that are most useful for asset management: assessing existing performance measures that are in place, identifying gaps, and considering new measures to fill gaps;
- integrate these performance measures effectively within the organization: engaging stakeholders to ensure buy-in, designing families of measures that can



be used at different organizational levels and for different types of decisions, ensuring consistency across measures, identifying needed improvements to data collection and analytic tools, designing communication devices, and documenting measurement and reporting procedures; and

- set of performance targets: establishing both long-term goals and short-to medium-term targets for performance measures.

Rather than a single prescriptive set of measures that might provide a good textbook example (but surely would not be suitable for all companies), the framework is in the form of guidance on the preferred types and forms of measures and the process by which companies should identify and implement them. The framework was developed with the recognition that each company will have a different set of circumstances and needs to consider in selecting and implementing performance measures [7].

One could not define the best set of performance measures for transportation companies, because each company has their own characteristics. However, the TRB suggests a set of "good measures" that, if implemented properly, will produce good results. Detailed information can be consulted from the referenced work [7].

In general, several measures or indicators can be used to evaluate a DRT service. Examples of those are [8-11]: the service reliability (customers' satisfaction, willingness to pay, non-accomplished valid requests, general mobility improvement), core background information, service passenger restrictions (ex, only disabled and elderly people, or other mobility-constrained persons), trip purpose, coverage of service (which days it works, where it works), easiness of reservations, pre-booking antecedence and time windows for reservations, passenger convenience (the time spent in transit becomes less satisfactory as the service area increases), need for intermodal transfers, driver satisfaction, walking time to stops, waiting time for delayed vehicles.

## 2.2 The Actual Business Intelligence Concept

Business Intelligence solutions create learning organizations by enabling companies to follow a virtuous cycle of collecting and analyzing information, devising and acting on plans, and reviewing and refining the results. To support this cycle and gain the insights that BI delivers, organizations need to implement a BI system comprised of data warehousing and analytical environments.

According to Eckerson [12], smart companies recognize that the systems that support BI solutions are very different from other systems in the company. Well-designed BI systems are adaptive by nature and they continually change to answer new and different business questions. The best way to adapt effectively is to start small and grow organically. Each new increment refines and extends the solution, adjusting to user feedback and new requirements. Additionally, the BI solutions combine data with analytical tools in order to provide information that will support top management strategic decisions [13].

The main goal of a BI solution is to collect data, store the data collected and analyse the data gathered in order to produce knowledge [13-14]. Figure 1 shows the main components of a BI tool. As part of its data warehousing environment, it takes

as input histori  
phases globally  
cleaning, and tr  
internal a gene  
cubes, allowing  
triggered "on-t  
part of the BI,  
intelligence (e.

The main fe  
tion and analy  
on the overall  
intended to pr  
ganization, tim  
of the system,

Organization  
benefits. Altho  
resulting from  
a "single versi  
making and m  
literature are t  
and plans, bett  
customer and  
ment, new reve

## 3 Propo

The cornerstor  
what-if compo  
signed wizard

as input historical data (e.g. operational details) that is then treated in three different phases globally designated by ETL, which means: data extraction, transformation and cleaning, and transfer and load. As a result, all the relevant information is stored into internal a general-purpose database and then into multi-dimensional (specific-data) cubes, allowing a fast execution of dashboards, analysis and reports which is (ideally) triggered "on-the-fly" by a simple mouse click – this is the analytical environment part of the BI, which is powered by statistical, OR (e.g. forecasting) and artificial intelligence (e.g. data-mining) techniques.

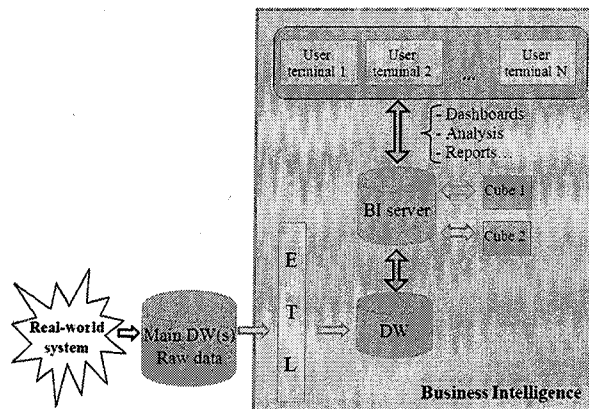


Fig. 1. Business intelligence components

The main features of a BI solution is therefore the creation of reports, the exploration and analysis of data and the creation of dashboards, which provide information on the overall system performance in a simplified form. The use of BI solutions are intended to provide managers and agents responsible for decision making in an organization, timely and accurate critical information about the (overview) performance of the system, so that they can make better decisions to improve such performance.

Organizations that have deployed BI solutions cite many tangible and intangible benefits. Although it is difficult to associate a concrete return of investment (ROI) resulting from these benefits, most enlightened executives place huge value on having a "single version of the truth", better information for strategic and tactical decision making and more efficient processes [12]. The most common benefits cited in the literature are the followings: time savings, "single version of truth", better strategic and plans, better tactics and decisions, more efficient processes, cost savings, greater customer and supplier satisfaction, greater employee satisfaction, return of investment, new revenues, total cost of ownership, and shareholder value.

### 3 Proposed What-If Simulation and BI Conceptual Framework

The cornerstone module of this new integrated model or tool will be the "so-called BI what-if component". The idea for this component is to provide it with properly designed wizards in order to create (new) scenarios that can be simultaneously



understood by managers and by the simulator component. As part of the scenario, the simulation model is inputted with all relevant information gathered by the traditional components of the BI (that, in turn, are based on historical data or previously simulated data), e.g. probability distributions of possible events. The approach fundamentally consists on setting up an interactive loop between a compatible simulation model or tool and a BI tool to support decisions at the strategic and tactical levels.

Figure 2 illustrates the proposed framework, an extension of the previously discussed BI decision support system (Section 2, Figure 1).

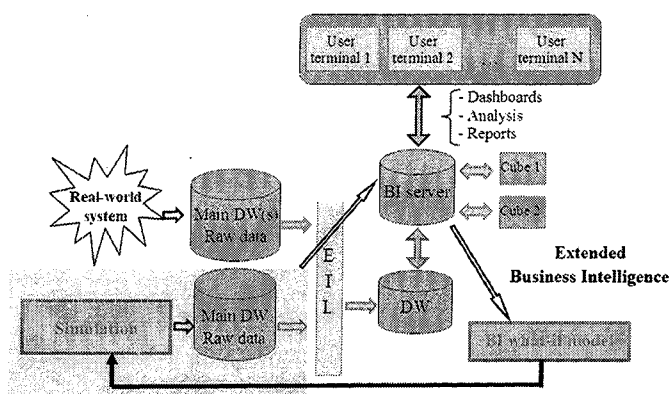


Fig. 2. Integrated general BI and simulation-based decision support system

In this proposed approach, the BI environment triggers the simulation runs that are necessary to estimate the performance of new scenarios. The simulation model mimics the functioning of the (new) system, and populates its proper data warehouse. This data is extracted by the BI server (if it is correctly "cleaned" already) or by the ETL component, following then the normal analytical processes of the BI. (Note, however, that it will be important to being able to distinguish between real and simulated data and derived information at any moment and at any BI component.)

### DRT Framework

In the design phase of a DRT, an integrated decision support system (IDSS) is proposed next, aiming to support decision makers in designing and implementing by firstly investigating the impacts of alternative potential specifications of the DRT system on its viability and sustainability for a given territorial area. This framework combines supply and demand data with analytical and simulation tools in order to provide information that will support top management strategic and tactical decisions.

Since the outcome of the evaluation is highly dependent on the DRT specification (in terms of operational parameters), this framework must comprise an iterative approach that consists on defining an initial DRT specification, estimating their impacts in terms of performance indicators, redefining the specification and re-estimating the

new impacts, until a viability and sustaina

Figure 3 illustrates the DRT system, pointing out the relationships and the differ



Fig.

The ODSS component receives trip calls, processing and scheduled service performance and records

At the design phase, so it is consistent with the simulator component world scenario, in context of system objectives and account of their remaining operation

Trip requests are processed (reduces user's mobility sign stage) or using

Routes and schedules are selected according to groups of persons. Vehicle Routing Problem is the general case where at/to different stop times are taken from database and obtained between two point

the scenario, the  
by the traditional  
previously simu-  
roach fundamen-  
simulation model  
levels.  
e previously dis-

new impacts, until a suitable solution is found, in terms of technical and economic viability and sustainability.

Figure 3 illustrates a proposed integrated decision support system (IDSS) for a DRT system, pointing out its main components and sub-components, their relationships and the different levels of decision: strategic, tactical and operational (ODSS).

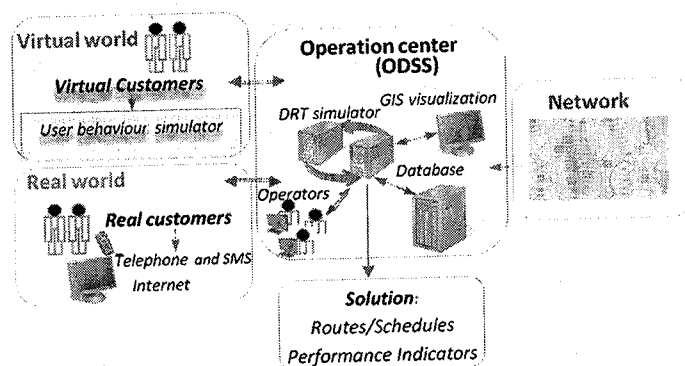


Fig. 3. IDSS for different levels of decision in DRT systems

The ODSS component represents the heart of the physical operations centre, receiving trip calls, processing them in terms of rational/optimized service (route) plans and scheduled services, giving advanced information to customers, monitoring performance and recording detailed historic data.

At the design phase of the DRT system, no real information exists yet on its functioning, so it is considered as a strategic and tactical decision process. In this case, the simulator component must be used in order to emulate what could happen at a real-world scenario, in order to allow the evaluation of different options (essentially, system objectives and rules) by the analyst component. The simulator will take implicitly account of their necessary functions of the ODSS, communicating directly with the remaining operational sub-components.

Trip requests are added to the system using a trip request generator which reproduces user's mobility needs for a given period (when using this approach in the design stage) or using a web application designed for this purpose.

Routes and schedules are solved by applying alternative algorithms, automatically selected according to the patterns of trips. For example, in the case where groups of persons are at the same stop (work-, market- and school-to-home trips), a Vehicle Routing Problem (VRP) savings-like heuristic can be applied, whereas in the general case where vehicles have to pick up and drop off different customers at/to different stops across the territory, a dial-a-ride problem should apply. Mean times are taken from origin-destination trip times previously stored in the system database and obtained by invoking Google Maps internet services (shortest route between two points).

The simulation component comprises two main models: (1) a demand-side model implemented as a travel request generator and users' behaviour simulator, and (2) a supply-side simulator that simulates the functioning DRT services, including the decisions made by the ODSS and the vehicles operations.

Both of these models are based on a micro-simulation event-driven approach. The main demand-side events are: trip reservation, trip cancelation, user arrival to stops (origin and destination), user no-show and non-reserved shows at stops. The main supply-side events are: trip planning events (such as hourly and daily time-scheduled planning of advanced reservations, real-time acceptances or rejections and re-planning), vehicle departure and arrival from/to stations, stops and strategic waiting and interface points.

Travel requests are generated based on socio-economic characteristics of the resident population (from Census), from domiciliary questionnaires and local authorities interviews, as well as acquired knowledge about the main attracting poles for visiting (workplaces, schools, hospitals, markets, general services, transfer stops to inter-urban transport services, etc.).

The analyst component is used to properly analyse and evaluate DRT options. It is powered by a BI type framework that starts to extract relevant data from the historic main database, transform such data and load it into a proper database system for multi-specialized analyses. It comprises different methodologies: simple and advanced statistical reporting and inference techniques, data mining and operational research inference and prospective models.

Thus, it is important to incorporate reliable predictive systems capable of evaluating beforehand the impact of alternative or small changes in strategic or tactical plans. This can be done by integrating simulation tools whose goal is to inspect the behaviour of a complex system under different scenarios. This referred framework is used to determine the system performance to evaluate the alternative specifications for a certain area. It allows choosing the better specifications and the better working rules, as illustrated in Figure 4. This figure shows how the analytic component of the system generates new alternatives to be simulated and how their performance is compared with the previous solutions already tried.

An iterative approach is used between the simulator and the analyst components. At each iteration, a solution option is simulated and evaluated by performing an assessment process. And, for each iteration (option) a large set of simulation runs (days) are realized and their operational details are stored into the main database of the operational decision support system (ODSS). The number of days is set in order to infer statistics (e.g., mean values) within a given high level of accuracy.

The result of the assessment process will provide guidelines and required feedback to adjust system resources and operating parameters, as illustrated by feedback arrows in Figure 3. Additional analysis is performed to assess solution viability and sustainability, encompassing several dimensions such as: social, economic and environmental.

These impa  
ments. To tak  
computes, a se  
aim (e.g., eval

The IDSS c  
as knowledge-  
vices, map vi  
IDSS which c  
trieval functio  
have the adva  
coordinated, a  
ferent levels o

#### 4 Discu

In general, th  
conditions) is  
lated into info  
the informatio  
tions and gra  
means and da  
maps. But, ir  
data: (1) furtl  
(2) deeper in  
applying mor

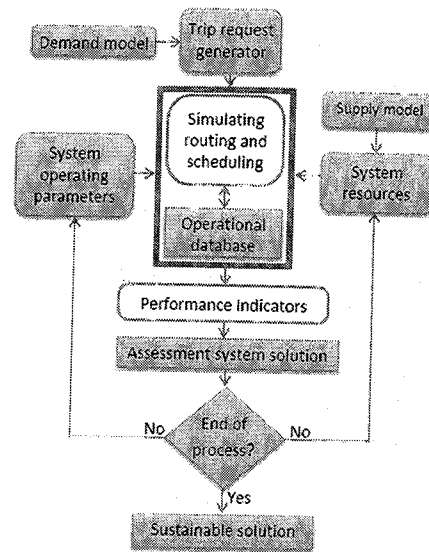


Fig. 4. Conceptual framework of the DSS

These impacts are increasingly important aspects of decision in transport investments. To take care of this, the analyst component incorporates, and automatically computes, a set of key performance indicators (KPIs) hierarchized by their measuring aim (e.g., evaluate client satisfaction, financial and organizational performance).

The IDSS can integrate several types of other advanced modern technologies, such as knowledge-based modules, and internet and web capabilities (e.g., free map services, map visualisation and on-line trip requests. According to Liu et al. [15], an IDSS which combines the use of models, analytical techniques, data access and retrieval functions, by using advanced differentiated technologies (this is the case), will have the advantage (in relation to traditional "static" DSS) in providing consistent, coordinated, active and global support for the various managers/analysts on their different levels of decision-making processes.

#### 4 Discussion

In general, the amount of data available (e.g. detailed traffic operations events and conditions) is huge, and only a relatively small fraction of that is adequately translated into information that is used by managers. In most cases, this is restricted to the information that is easily obtained by applying traditional query database operations and graphical displays, including standard statistical elements (e.g. historical means and deviations of traffic volumes) in general-purposed tables, graphs and maps. But, in fact, much more information can be potentially gathered from real data: (1) further performance measures can still be obtained by traditional forms; (2) deeper information, somehow hidden in the databases, can be highlighted by applying more advanced analytical methods, such as data mining, optimization and

simulation, as well as advanced forecasting (e.g. auto-correlative, multi-regressive) and statistical techniques; and, very important, (3) most of all this information can be better highlighted by using alternative, more adequate forms of visualization such as well-designed graphs and maps; also, some information (e.g. spatial-temporal trends) can be exclusively evidenced by specific forms of visualization. It is widely recognized that it is easier to detect a pattern from a "picture" than from a textual or numeric explanation.

From the above, it is obvious that one of the most important problems of ITS is the analysis and management of information. This problem is becoming further relevant due to permanent increase on the availability of data and their inexpensive storage and processing power as a result of the wide implementation of modern IS/IT systems.

On the other hand, ITS planners and decision-makers need to foresee the performance of systems (existing or desired to be implemented), and therefore they need to use suitable simulation tools. The integrated framework helps DRT managers (TDC coordinators, system designers and analysts) at their different levels of decision.

At the strategic level, planners are supposed to set up the objective, aim, and the broader strategy and policies of the system. For example, in a recent work on the design and planning of demand-responsive transportation system, Dias et al. [5] report the following set of decisions at this level: How the system should be operating in the long-term in order to be viable and sustainable in the three basic terms: economic, social and environmental? What are the main objectives of its existence? Which type of services must it offer? At what level(s) of flexibility? At what price levels (whether taking account or not potential subsidisation)?

At the tactical level, decisions aim to devise ways to implement the transport system according to the strategy previously defined. The analyst component of the model monitors and analyses current performance of the system, tries to identify hidden patterns of operational data, and continually tries to devise better solutions to tackling operational problems; some solutions are automatically devised and incorporated into the ODSS component (e.g., a recurrent set of day to day fixed travel patterns are identified and a shortcut route planning procedure automatically generates a fixed service plan); however, the most part of solutions requires the investigation and validation of human analysts before their practical implementation. This planning stage is crucial for the design of the transport scheme and several authors had identified the most critical decisions. For example, for the case of demand-responsive transport [16-17]):

- Which exact level(s) of flexibility should be adopted, in terms of routes, timetables, frequencies, time-windows (e.g., arrivals at stops)?
- Which pre-booking mechanisms and rules should be adopted?
- Which resources will be used (fleet, drivers, informatics, operations centre and staff)?
- Which fare structure should be implemented?
- Which level of integration with public transport network (schedule buses/train network, etc.)?

Additionally, th  
receiving travel re  
vehicle? which rou

The proposed e  
formance measure  
form of traditiona  
dashboards. Most  
to their specific ne

Data visualizati  
ual form (usually  
ers) to perceive the  
make more effecti  
tional. For example  
deciding on the re  
sure the normal fu  
event (incident) tha

In the next secti  
ess is reported and  
mand is defined ra

## 5 Illustrati

In the following pa  
patterns according

The examples a  
system, before its  
so it is considered  
simulation model  
any tested real-wo  
(essentially, system

In order to dete  
worth using simple  
system, as a funct  
average figures for  
Such information  
of time arrivals at  
are very interesting  
discovery interacti

In order to perc  
urban center (e.g.  
peak), may be wor  
vice or group of se

Additionally, the ODSS component drives the DRT control and managing centre, receiving travel requests and determining the most appropriate service plans (which vehicle? which route? which schedule?).

The proposed extended and integrated BI solution can implement most of the performance measures reported before (Section 2), and easily translate them into the form of traditional tables, graphs and reports. This includes making use of simple dashboards. Most of these elements can be easily customized by end users, according to their specific needs and options.

Data visualization can be seen as the process of translating information into a visual form (usually graphs and maps), enabling users (scientists, engineers and managers) to perceive the features of the data available, and, from that point, to help them to make more effective decisions at different levels: strategic, tactical or (even) operational. For example, deciding on the design of service operations strategies or, simply deciding on the realization of a functional regulatory (e.g. corrective) measure to ensure the normal functioning of the system or to minimize the impact of an anomalous event (incident) that has occurred.

In the next section, some illustrative results of a given iteration of the above process is reported and discussed. It shows the software viability in theoretical terms (demand is defined randomly).

## 5 Illustrative Examples

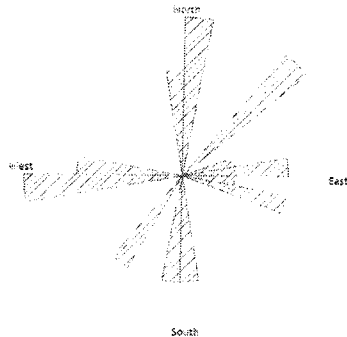
In the following paragraphs, examples show the importance of adequate visualization patterns according to specific nature of data recorded and information needed.

The examples are related to the design phase of a particular DRT transportation system, before its implementation. No real information exists yet on its functioning, so it is considered as a purely strategic and tactical decision process. In this case, the simulation model component must be used in order to emulate what could happen at any tested real-world scenario, in order to allow the evaluation of different options (essentially, system objectives and rules).

In order to detect peak periods and understand correlation to service delays may be worth using simple line charts of average traffic volumes and delays estimated in the system, as a function of day-time. This should be done by taking into account the average figures for relevant zones or intersections that affects each transport service. Such information (patterns) can be also incorporated into adequate predictive models of time arrivals at stops (e.g. for public panel information). Also, panels or dashboards are very interesting and useful to the analyst, allowing an overview of the system and discovery interaction between its various elements (tables, charts, combo box, etc.).

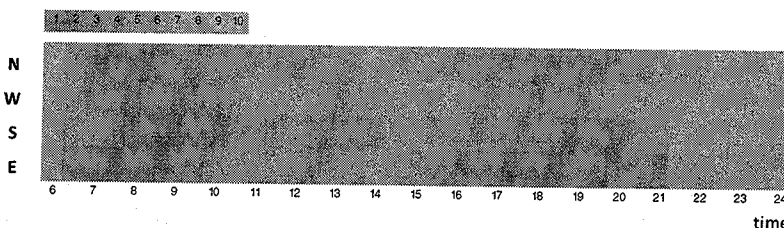
In order to perceive and monitor service levels in different directions from a given urban center (e.g. incoming PT services bringing people to work at the morning peak), may be worth using a rose-like diagram (Figure 5). This can be done per service or group of services in each direction (e.g., north, west, south and east bands).





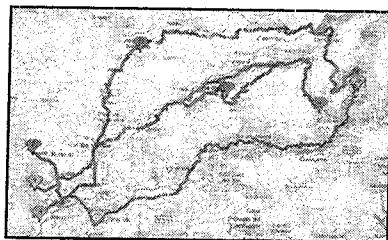
**Fig. 5.** Rose-like graph of frequencies for 12 outbound service calls at the evening peak: each route is represented by a triangle illustrating its direction and relative frequency

In order to infer the patterns of transit volumes in each direction per time of day (on average), may be worth using clustering analysis, e.g. putting in evidence similar directional service patterns among different time intervals. In these cases, the use of colored “graph-image” may be useful (Figure 6).



**Fig. 6.** Average inbound and outbound public transit volume by direction and time of day (30 min clusters)

The ODSS uses GIS technology by integrating the Google Maps service that allows the representation of geo-referenced information on a map. So, the graphical visualization of a particular day run, for a particular vehicle, is displayed in Figure 7. Green points represent pick up points and red points represent drop off points (or both, if there is anyone to pick up there).



**Fig. 7.** Routes of a vehicle during a particular day

This techn  
see their plan  
lation model  
allow analysts  
(or in use, if t  
from a series  
DRT specifica

## 6 Concl

This paper pr  
evaluation of  
ported in the  
portation com  
into simulation  
model. (Most  
relevant variab

One of the  
formation gat  
BI solution he  
able software  
easily creates  
transmits all n

Real and/or  
translated into  
customization  
tools that, alon  
tive what-if si  
formance mea  
and managing  
ments, and ev  
performance a

The genera  
lar problem c  
lack of analy  
proposed wha  
can be answe  
The approach  
run sets) thus  
ferent scenari  
ance. It may  
DRT for a giv

This technology integration would be also interesting for customers, as they can see their planned trips online (Web-Portal), for example for a given week. The simulation model plus to produce solutions, also print reports on systems performance to allow analysts and decision-makers to assess the DRT specification being simulated (or in use, if the system was implemented). Appropriated sets of KPIs can be obtained from a series of simulation runs (working-day unchanged pattern) for a particular DRT specification, i.e. set of fixed rules and parameters.

## 6 Conclusions

This paper presents a systematization of performance measures to be used for the evaluation of the performance of transportation systems. The model adopted is supported in the framework developed by the Transportation Research Board for transportation companies. These performance measures are supposed to be incorporated into simulation and BI transportation models, by properly designing their computation model. (Most of the measures, such as averages and standard deviations of a given relevant variable, are easy to implement, but others may not.)

One of the most important problems of ITS is the analysis and management of information gathered either from historical data or simulated data. The simulation-based BI solution herein proposed is funded on a framework that extends commercial available software by explicitly incorporating a "what-if analysis" BI component that easily creates new scenarios (of the functioning of the system) and automatically transmits all needed information (data) to the simulation model as its input.

Real and/or simulated data can be extracted by BI system, and then processed and translated into the form of traditional tables, graphs and reports, and allowing easy customization by end users. Thus, this work promoted the use of general proposed BI tools that, along with the integration of advanced analytical techniques and prospective what-if simulation, support the inference of both strategic and operational performance measures helping decision makers in the transportation sector in monitoring and managing their working system, in designing new strategic and tactical improvements, and even in designing new sustainable systems by accurately predicting their performance and related economic, social and environmental impacts.

The general framework herein proposed was extended and adapted to the particular problem of designing and planning DRT systems, thus overcoming a current lack of analytical tools to this end. The paper shows the potential interest of the proposed what-if simulation and BI integration, identifying a set of questions that can be answered with effectiveness and more efficiently before implementation. The approach is based on a iterative procedure (between BI analysis and simulation run sets) thus producing and comparing alternative DRT parameterization for different scenarios, and proactively foreseeing the correspondent effects on performance. It may contribute to implement the most probable effective and sustainable DRT for a given area.

**Acknowledgements.** The authors gratefully acknowledge the financial support provided by the European Union through FEDER-“Programa Operacional Factores de Competitividade” (POFC) and by the Portuguese Government through FCT-“Fundação para a Ciência e a Tecnologia” under projects FCOMP-01-0124-FEDER-016099 and FCOMP-01-0124-FEDER-022674.

## References

1. Sabbour, S., Lasi, H., Tessin, P.: Business intelligence and strategic decision simulation. *World Academy of Science, Engineering and Technology* 61, 1130–1137 (2012)
2. Dias, A., Carvalho, M.S., Telhada, J.: Simulation approach for an integrated decision support system for demand responsive transport planning and operation. In: *Proc. of the 10th Annual Ind. Simulation Conference*, Brno Univ. of Technology, Czech Republic (2012)
3. Telhada, J., Sampaio, P., Pereira, G., Carvalho, M.: Integrating simulation and business intelligence analyses for tactical and strategic decisions in transportation systems. In: *Congreso Latino-Iberoamericano de Investigación Operativa*, Rio de Janeiro (2012)
4. Battellino, H.: Transport for the transport disadvantaged: A review of service delivery models in New South Wales. *Transport Policy* 16, 123–129 (2009)
5. Dias, A., Carvalho, M.S., Telhada, J.: Economic evaluation of a demand responsive transport in rural area. In: *Proceedings of the First International Conference on Project Economic Evaluation*, Guimarães, Portugal, pp. 269–277 (2011)
6. Oliveira, J., Afonso, P., Telhada, J.: An activity-based costing model for strategic decisions in transportation on demand projects. In: *Proceedings of the First International Conference on Project Economic Evaluation*, Guimarães, Portugal, pp. 127–134 (2011)
7. TRB, Performance Measures and Targets for Transportation Asset Management. NCHRP Report 551. Transportation Research Board, USA (2006)
8. Mageean, J., Nelson, J.: The evaluation of demand responsive transport services in Europe. *Journal of Transport Geography* 11, 255–270 (2003)
9. Brake, J., Nelson, J.: A case study of flexible solutions to transport demand in a deregulated environment. *Journal of Transport Geography* 15, 262–273 (2007)
10. Fernández, J., Cea, J., Malbran, R.: Demand responsive urban public transport system design: Methodology and application. *Transportation Research A* 42, 951–972 (2008)
11. Quadrifoglio, L., Li, X.: A methodology to derive the critical demand density for designing and operating feeder transit services. *Transportation Research B* 43, 922–935 (2009)
12. Eckerson, W.: *Smart Companies in the 21st Century: The Secrets of Creating Successful Business Intelligence Solutions*. The Data Warehousing Institute, USA (2003)
13. Cody, W.F., Kreulen, J.T.: The integration of business intelligence and knowledge management. *IBM Systems Journal* 41, 697–713 (2002)
14. Santos, M.Y., Ramos, I.: *Business Intelligence: Tecnologias da Informação na Gestão do Conhecimento*. FCA-Editora de Informática, Portugal (2006)
15. Liu, S., Duffy, A., Whitfield, R., Boyle, I.: Integration of decision support systems to improve decision support performance. *Knowledge Inf. Systems* 22, 261–286 (2010)
16. Giannopoulos, G.: The application of information and communication technologies in transport. *European Journal of Operational Research* 152, 302–320 (2004)
17. Mulley, C., Nelson, J.: Flexible transport services: a new market opportunity for public transport. *Research in Transportation Economics* 25, 39–45 (2009)