URBAN TRANSPORT INFRAESTRUCTURE: A STATE OF THE ART

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ABSTRACT

The urban transport infrastructure is one of the most important problems for the cities, and involves many aspects that concern to citizens, governments and the economical growth of the countries. The objective of this paper is to show how this issue has been studied in recent years, with emphasis in the new technologies, the use of simulation and optimization at the whole planning process. Some study cases are shown in order to clarify the concepts presented.

Key words: Urban transport, planning, simulation, geotechnologies

1. INTRODUCTION

Nowadays one of the bigger problems in cities is the transportation system and its infrastructure. There have been lots of studies and research in recent decades trying to find solutions. In general there is an economic impact when countries make an investment in this sector. Most of the studies on transport infrastructure, in particular, focus on its impact on growth. In the past two decades the analytical literature has grown enormously, with studies carried out using different approaches, such as a production function (or cost) and growth regressions, as well as different variants of these models (using different data, methods and methodologies), the majority of these studies found that transportation infrastructure has a positive effect on output, productivity or growth rate Calderon & Serven (2008). One of the pioneers was Aschauer (1991) who, in his empirical study, provided substantial evidence that transport is an important determinant of economic performance. Another example is the study of Alminas, Vasiliauskas and Jakubauskas (2009), who found that transport has contributed to growth in the Baltic region. Another study on the Spanish plan to extend roads and railways that connect Spain with other countries concludes that these have a positive impact in terms of Gross Domestic Product (GDP) Alvarez-Herranz & Martínez-Ruiz (2012). In a study of the railroad in the United States, it is mentioned that many economists believe that the project costs exceed the benefits Balaker (2006). However, the traditional model of cost-benefit assessment does not include the impact of development projects De Rus (2008). In these studies focused on growth, we see there is a bias towards economic rather than social goals. That is why it is important to emphasize the impact of transport infrastructure on development and not just growth.

In order to show the subject clearly, we will use a systems approach, dividing urban transport infrastructure according to The City of Calgary (2009)

Urban Transport infrastructure:

- Transportation Planning
- Transportation Optimization
- Intelligent Transportation Systems

According to this system paradigm, this paper is focused on the description of the research made in the last five years, mainly considering optimization, simulation and the intelligent systems. The structure of this paper is as follows. Section 2 shows the state of the art for the general transportation planning issue. Section 3 is devoted to transportation optimization techniques that have been used in different ways in accordance with the problems they are meant to solve. Section 4 is about intelligent transportation systems and how the development of new technologies interacts with the whole system and where they are being used. Section 5 is about some study cases. These cases are important because of the new technologies used and their successes and failures. Section 6 gives some conclusions and future research on this approach.

The impact that transport infrastructure has in increase of the quality of life can be seen in the next figure:

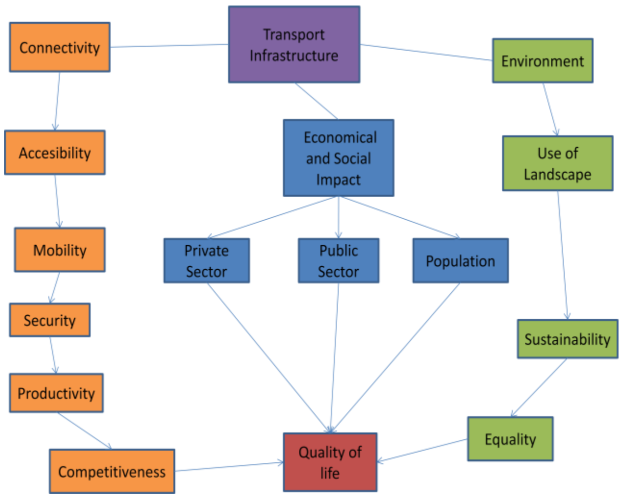


Figure 1 Impact of the transport infrastructure.

2. TRANSPORTATION PLANNING

Transportation planning covers a lot of different aspects and is an essential part of the system. According with Levy (2011), "Most regional transport planners employ what is called the rational model of planning. The model views planning as a logical and technical process that uses the analysis of quantitative data to decide how to best invest resources in new and existing transport infrastructure."

Phases for transportation planning

There are three phases: The first, preanalysis, considers what problems and issues the region faces and what goals and objectives it can set to help address those issues. The second phase is technical analysis. The process basically involves the development of the models that are going to be used later. The post-analysis phase involves plan evaluation, program, implementation and monitoring of the results, Johnston (2004).

Transportation planning involves the following steps:

- Monitoring existing conditions;
- Forecasting future population and employment growth, including assessing projected land uses in the region and identifying major growth corridors;
- Identifying current and projected future transportation problems and needs and analyzing, through detailed planning studies, various transportation improvement strategies to address those needs;
- Developing long-range plans and short-range programs of alternative capital improvement and operational strategies for moving people and goods;
- Estimating the impact of recommended future improvements to the transportation system on environmental issues, including air quality; and
- Developing a financial plan for securing sufficient revenues to cover the costs of implementing strategies.

Transportation planning process. Figure 2 shows the process briefly and clearly.

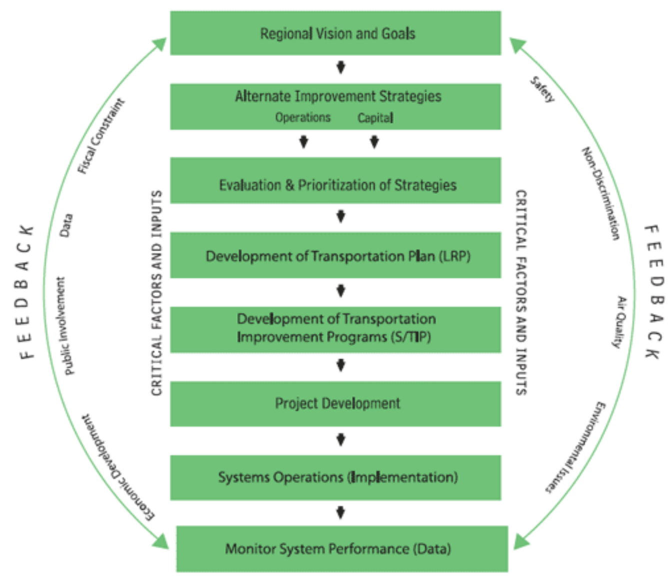


Figure 2 Transportation planning process. Source (FHWA, 2007)

Urban Infrastructure

Urban infrastructure, a human creation, is designed and directed by architects, civil engineers, urban planners among others. These professionals design, develop and implement projects (involved with the structural organization of cities and companies) for the proper operation of important sectors of society. When governments are responsible for construction, maintenance, operation and costs, the term "urban infrastructure" is a synonym for public works.

Road infrastructure is the set of facilities and equipment used for roads, including road networks, parking spaces, traffic lights, stop signs laybys, drainage systems, bridges and sidewalks.

Urban infrastructure includes transportation infrastructure, which can, in turn, be divided into three categories: land, sea, and air, that can found in the following modalities:

• Street networks, high or low-speed railway lines, together with such as bus stops, road signs, traffic lights, parking bays, and so forth. This applies to all the cases cited below:

• Infrastructure for mass transit or bike paths and footpaths

• Canals, bridges

• Ports, airports and lighthouses, etc.

Figure 3 shows a systemic approach to the relationships between transport infrastructures, considering the main elements that require analysis.

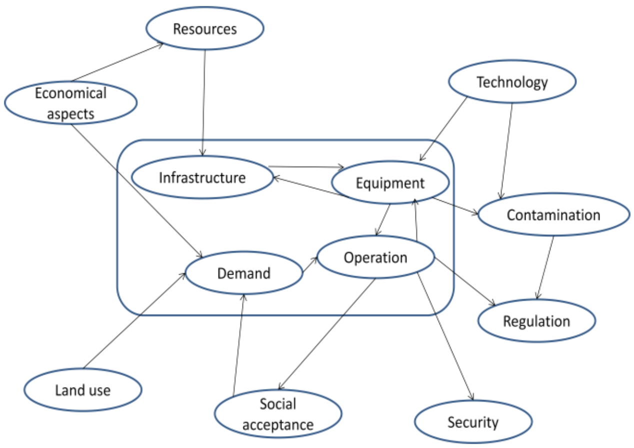


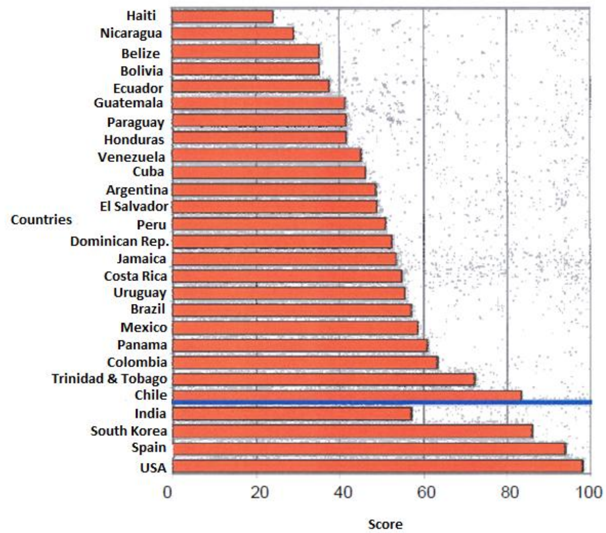
Figure 3 A systemic approach to transport infrastructure

3. TRANSPORTATION OPTIMIZATION

The goal of transportation optimization is to identify, evaluate and plan enhancements that optimize the operation of a transportation system. With this in mind many countries have specific policies for this and a lot of research has been developed over recent years to this end. Optimization deals mainly with the maintenance costs and management of the infrastructure that requires a balance between the performance of the structure and the total cost accrued over the entire life-cycle. There are a series of new technologies that, using GIS, GPS, sensors and cameras, have been used in visual inspections.

The proper and efficient management of urban transport infrastructure includes many technological, political, and social aspects. So it is necessary to use an interdisciplinary approach such as geotechnology, with which digital technologies can be integrated for a spatial analysis of reality.

The maintenance of urban infrastructure consists of a series of actions that require knowledge and experience about the needs of different types of infrastructure (bus stops, signage, benches etc.) to be done in the optimum manner. To achieve this, infrastructure can be changed, expanded and/or replaced in an efficient manner in order to meet the needs of the users of a city.
Urban transport infrastructure has a direct impact on people's daily lives, which can, in a positive or negative way (depending on its condition), affect the competitiveness of people in general and the country at large (depending on the competitiveness of its urban infrastructure on a global level), as can be seen in the following figure 4:



Source: Division of Sustainable Development and Human Settlements (2007) with data of American Economics, January 2007 according to the http://www.cg-la.com database.

Figure 4 Worldwide competitiveness of urban infrastructure

There are many factors that lead to the growth of urban transportation, but we must not forget other important factors such as rural development, use of the countryside or urban development.
Mexico, in particular, has changed from a predominantly rural country to a being mainly urban culture, so the term urban development has a very important role to play in Mexico's sustainability, where urban development involves the growth and quality of new housing, bringing greater wellbeing, as a result of urban expansion, planning and access to credit for housing.

That is why forecasting and transportation data are two other important topics in this section, considering forecasting as an important tool for designing, building, operating, and maintaining models for forecasting the demand for transport. These models are built using optimization algorithms as well as simulation software.

Following with the systemic approach, the transport issue can be seen as a transportation network, and in this way the relationships among the main elements to analyze and study, figure 5 shows these ideas.

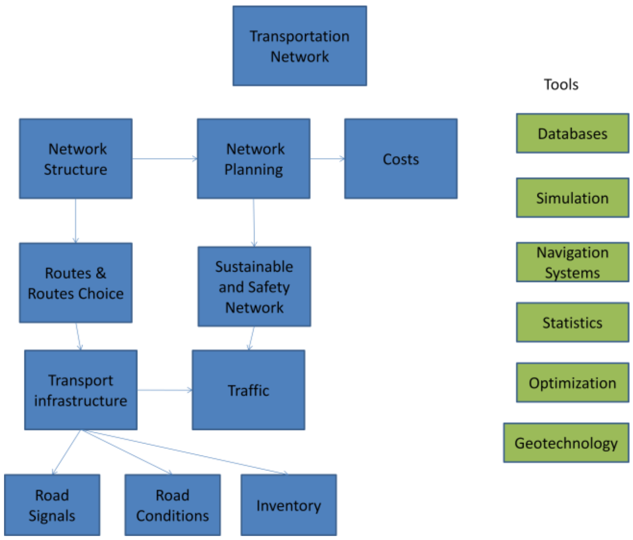


Figure 5 Transportation network

Some of the tools used to diagnose, analyze and solve problems relating to urban transport infrastructure are shown in table 1

Table 1 Methodologies used for urban transport problems

Issues	Methodologies				
	Simulation	Optimization	Statistics	Geotechnologies	Databases
Crashes	✓		✓		✓
Traffic for a future network	✓		✓	✓	✓
Traffic for a modified network	✓		✓	✓	✓
Routes design	✓	✓		✓	✓
Routes selection	✓	✓		✓	✓
Regional accessibility	✓			✓	✓
Level of service	✓	✓	✓	✓	✓
Cost	✓	✓			✓
Supply and demand	✓	✓		✓	✓
Physical condition of the streets, avenues and roads	✓		✓	✓	✓

As can be seen in table 1, simulation is one of several methodologies that can be used for a transportation network, when we want to plan and optimize transportation problems in the all aspects that are open to being solved. There are general-purpose discrete simulation software packages such as SIMIO, Promodel or Flexim, as well as other more specific packages, such as S Paramics, or Simleader.

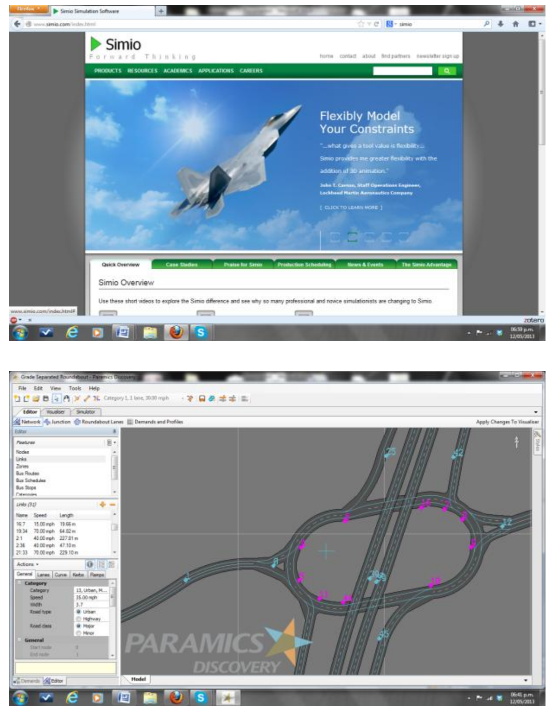


Figure 6 SIMIO and S-Paramics simulation software

However, there is also the need to optimize an entire transportation network. There are two main methods for this, the exact and heuristics, though a hybrid that that combines them both can also be used. In most cases, though, some heuristic algorithms are used because of the size of the problems involved. This subject, according to the vast amount of literature Laporte (2007) Laporte (2009), Toth (2002), Daskin (2008) focuses particularly on optimization from the perspective of logistics and distribution, and most especially on route optimization.
This is largely because distribution is one of the functions that has evolved the most over the last few years in organizations. And this evolution has inevitably resulted in increasingly complex transport and distribution operations that, combined with factors such as the need to lower production costs, constantly rising transport costs or the increasing demands in customer-supplier relations, have made logistics management as a key element of companies' strategies.

In this scenario, the capacity of companies for optimizing their transport and distribution routes appears as a key element of logistics management; however, not all companies approach this problem in a suitable and systematic way.

Therefore companies are interested in route optimization, which, in general, can be understood to mean all those actions that contribute to improving the distribution function, either in terms of level of service, the improvement of quality, lowering costs, etc.

One of the tools that have been proposed for the optimization is the use of the Design of Distribution Networks to include a set of highly combinatory problems, Chekuri (2007), Vishv (2009) and Ambrosino(2009).

Related problems are the inventory distribution problem as well as the vehicle routing problem Cohelo et al (2012) that, in turn, has as a precedent the vendor management inventory problems and the traveling salesman problem. These problems respond to optimization decisions such as: inventory, location and routing. Each one of these problems has its own origin and solution methodologies, all of great complexity, that enable the optimization in matters to do with transport, particularly route optimization. Laporte (2007), Laporte (2009), Toth (2002) and Wu (2002).

The key to approaching a route optimization problem lies in understanding that you deal with it depending on the particularities of each organization and, as such, there are no global solutions capable of solving all the existing distribution models.

The objective of the optimization must be clearly defined: i.e., the scope of the problem you want to solve must be clearly defined as must be the variables that are most critical when measuring the success of the optimization (level of service, cost, etc.)

Clearly demarcating the current service in terms of the characteristics of the product, characteristics of the routes and characteristics of the organization (processes and means it has)

The type of result desired for the project has to be established. That is to say whether one is looking for a system that makes it possible to control numerous routes even at the cost of losing flexibility or, on the contrary, if one wants a more flexible system with more limited scope.

Once all these questions have been analyzed, one is then in a position to tackle the project; its scope and the complexity shall determine how this is done.
Logistics in general and transport in particular has progressively undergone a transformation over the last few years that is directly related to a massive growth in trade that has meant the traders in the supply chain to need to be constantly adapting. This transformation is based on two major trends:

- The growing integration of logistics chains**.**
- Growing attention to **intermodality** and **multimodality** in the distribution chain.

As it was mentioned before according to the solution methods some routing studies have been developed using either genetic algorithm hybridized with Dijkstra algorithms to find the shortest routes, or just some advanced label algorithms as the one shown in Klunder, (2006).

As has already been mentioned, metaheuristics are used because they provide very good solutions in a short time, like the neural networks that are used by Yu et al (2011)
The exact methods we are referring to include branch and bound, branch and cut, dynamic programming. The location and routing problem presented by Belenguer et al (2011) uses branch and cut for the design of logistic networks. In this case the overall distribution cost may be excessive if routing decisions are ignored when locating depots. In order to overcome this problem they propose a branch and cut algorithm for solving it. The proposed method is based on a zero-one linear model reinforced by valid inequalities.
Berman et al (2011) gives us an example of search paths for service. In this paper an optimal search path is found for a service problem that is stated as follows: "A customer residing at a node of a network needs to obtain service from one of the facilities; facility locations are known and fixed. Facilities may become inoperational with certain probability; the state of the facility only becomes known when the facility is visited. Customer travel stops when the first operational facility is found. The objective is to minimize the expected total travel distance". This problem is NP-hard and a forward dynamic programming procedure is developed.
Communications technologies and IT have been successfully used for years in this scenario, thus permitting the development of freight transport management. However, its growing development under the global umbrella of ITS (Intelligent Transport Systems) has made it possible to more efficiently mold transport operations that, in intermodality environments, are getting ever more complex to manage.
The most significant of these different technologies are:

- Geographic Information Systems.
- Geolocation Systems (GPS, for example)
- Computer applications capable of calculating mathematical route optimization models based on a series of intrinsic constraints on the logistic process (fleet availability, geographic location of the distribution and delivery points, loading, reception and delivery time slots, variable distribution cost, etc).

Nowadays these technologies tend to form part of global solutions that have given rise to a multitude of IT programs offering companies the possibility of managing their transport operations more efficiently and effectively.

In this sense, the IT programs include simulation programs with built-in optimization for the construction of scenarios that, apart from solving the problems already mentioned, are used for aspects such as:

- Measuring the traffic on main streets and how it can be solved by constructing scenarios that make it possible to look for alternatives to lighten it at certain peak hours.
- Measuring traffic when streets have to be closed for repairs, in which case scenarios are also constructed to assess alternatives and alternate routes
- Assessing routes in transport networks to find the safest routes with less traffic.
- Distributing transport in critical routes, taking into account safety, sustainability and efficiency.

4. INTELLIGENT TRANSPORTATION SYSTEMS.

The issue of the proper and efficient administration of urban transport infrastructure contains many technological, political, and social aspects. So it is necessary to use an interdisciplinary approach such as geotechnology, whereby digital technologies can be integrated for a spatial analysis of reality.

Geotechnology, in other words, is presented as a new vision of geographic space that enhances the field of computer systems using cybernetic human and electronic systems for the analysis of physical and social Buzai (2012) and its scope is ever expanding geoBlog (2007).

Some geotechnological tools are:

- Geographic Information systems (GIS).
- Global Positioning System (GPS).
- Aerial Photos.

GIS integrates hardware, software and data for capturing, managing, analyzing and displaying geographically referenced information. GIS allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns and trends in the form of maps, globes, reports, and charts. A GIS helps us to answer questions and solve problems by looking at all the available data in a way that is quickly understood and easily shared. Some of the top 5 benefits that GIS has to offer are the following:

- Cost saving and increased efficiency
- Better decision making
- Improved communication
- Better record keeping
- Geographical management

A GIS system can help its users, by mapping out where things are, allowing them to find places with the particular features they are looking for and letting them see patterns. GIS also allows users to map quantities and by mapping quantities people can find places that meet their criteria and take the necessary actions. Public health officials might want to map the numbers of physicians per 1,000 people in each census tract to identify which areas are adequately served, and which are not. In the case of map quantities, the user can, with a density map, measure the number of features using a uniform areal unit so the distribution can be clearly seen. This is especially useful when mapping areas, such as census tracts or counties that vary greatly in size. On maps showing the number of people per census tract, the larger tracts might have more people than smaller ones. But some smaller tracts might have more people per square mile—a higher density. To find what is inside this way, a person can use GIS to monitor what is happening and take specific action by mapping what is inside a specific area and then, finally map the change in an area to anticipate future conditions, decide on a course of action, or to evaluate the results of an action or policy. By mapping where and how things move over a period of time, you can gain insight into how they behave.

Nowadays we are living in an era characterized by technological advances, mobile devices are much stronger, more efficient and capable than they used to be and for this reason a new type of commerce has been created, called Mobile Commerce, where people can make transactions through their mobile device. A subcategory of Mobile Commerce is Location Based Commerce whereby a mobile device can inform its user through a GPS system certain information that can make the user's life easier; for example a user can be informed whether he is near a gas station, hospital or restaurant. Thus we can see that geography and the technologies associated with it are connected with humans to such a degree that they can help us in our daily round. Location based m-commerce, according to Turban et al. (2008), can be divided into the following 5 categories:

i. **Location**: the service that can determine the place of a person.
ii. **Mapping**: the service relating to the creation of maps for specific locations.
iii. **Tracking:** the surveillance of a person through his/her route.
iv. **Navigation:** the creation of the ideal route between two locations.
v. **Timing:** the calculation of the time that a vehicle needs to cover a specific route.

One system that is well known nowadays is the GPS (Global Positioning System). This was first used by the United States Department of Defense but its applicability to civilian life was recognized from the first moment. Its working principle, according to Turban et al. (2008), is based on satellites (originally 24 satellites). Each satellite's position is identified by a signal sent by the satellite from its highly sensitive and accurate onboard clock. According to Pike (2009), GPS consists of three segments: the space segment, the control segment and the user segment. The space segment consists of the satellites. The second GPS segment consists of the equipment on land (antennas, monitoring stations etc). The third segment of GPS consists of the receivers the users need in order to know their location. GPS receivers can be stand-alone devices or built into mobile devices. The receivers receive information (position) from the satellites in terms of latitude and longitude but use the GIS (Geographical Information System) software to change this information into a form that the average user can recognize (addresses), according to Turban et al. (2008). GIS is an electronic system that processes location-related data. Thus GPS/GIS can provide drivers with valuable information about how to get to their destination, such as how to take the shortest route. Moreover the head office of a company will be able, at any one time, to know the position of each of its vehicles. This provides transport companies with a higher level of security as they can immediately inform the police if a vehicle changes leaves its designated route. The connection to the GPS is something simple nowadays, because everybody with mobile device will be able to connect and to depict the geographical form of the route that he is going to follow and the vehicle on it, moreover the device will be able to provide the user with several statistical elements. Every request the user makes (for example, the shortest alternative route because the ideal route is closed for some reason) is received by the company's server, which will give the user the best solution.

Another type of geotechnology is the use of aerial photos (Orthophotography). These photos were made for the first time in 1960 Smith (1995). The technology of the early 1970s brought to this data source a good commercial application and its use began to expand. This technique has the advantages of a conventional map, but in contrast to this, is able to display the up-to-date details of the land, rather than a cartographic representation. There is software (GIS) that allows you to display the aerial photo and lets the user process it with annotations or geographic symbols such as schools, hospitals, police departments and stations, gas stations, etc. An example of an aerial photo can be seen in the following figure.

Figure 7 Example of aerial photo.

In today's world, the role of official agencies and departments of transport has evolved significantly; the main job of these agencies has expanded over and above the mere construction and maintenance of transport infrastructure. The agencies also have to be responsible for the operation of networks, to achieve improvements in safety, fluidity, reliability, comfort and efficiency. Improving mobility and safety, lowering fuel consumption and the emission of pollutants, and providing travelers with dynamic and effective information, are the main goals on the market today.

The need for efficient transport networks means that their operation has become a primary focus, so intelligent transport systems have been used as tools to make this efficiency possible. ITS systems apply transport systems technology to solve problems and achieve optimum performance.

Some example of ITS are given below:
- Video cameras to detect accidents
- Dynamic message boards of road information boards
- Vehicle detectors to calculate travel times
- Electronic payment of collection systems
- Traffic management centers
- Systems integration software
- Intelligent traffic lights

The iRAP project uses technologies such as GIS and GPS with cameras in vans for the purpose of preventing road accidents and, when combined with ITS, can prove to be a really useful tool in the hands of the agencies responsible for the urban infrastructure, helping them to obtain in-depth knowledge of the state of the urban infrastructure in order to be able to meet future needs through a well-defined planning strategy. The International Road Assessment Programme (iRAP) is a registered charity dedicated to preventing the more than 3,500 road deaths that occur every day worldwide.

As they say "Our vision is a world free of high risk roads."
iRAP works in partnership with government and non-government organizations to:

- Inspect high-risk roads and develop Star Ratings and Safer Roads Investment Plans

- Provide training, technology and support that will build and sustain national, regional and local capability
- Track road safety performance so that funding agencies can assess the benefits of their investments

So, for the intelligent transportation system, it is important to use all these tools in order to support the provision of a safe, efficient and environmentally-friendly multi-modal transportation system through the application of the best technologies, practices, and partnerships. The City of Calgary (2009)

This section shall present and discuss how ITS are used and, more precisely, the next section shall examine the case studies.

5. EXAMPLES AND CASE STUDIES

This section gives some examples to illustrate the importance this issue has around the world. Some of them are taken from the report, *Integrating Australia's Transport Systems: A Strategy For An Efficient Transport Future* Booz Allen (2012) that describes cities with integrated transport planning and the use of ITS.

London

London's overall public transport network is characterized by a well-established rail network complemented by an extensive bus network together with a ferry network. These networks are integrated by multi-modal stations designed for ease of interchange for high volumes of passengers. At major stations, purpose-built bus interchanges have been developed to be within walking distance of the railway and underground stations, often manned by bus station staff and furbished with real time information systems (e.g. Countdown – which shows the number of minutes until the next bus is due to arrive).

Hong Kong

Hong Kong public transport services include railways, trams, buses, minibuses, taxis and ferries. This results in very high public transit mode share (90%) and very low vehicle ownership rates (50 vehicles per 1000 population). Hong Kong transport services are provided by several operators.

Singapore

Singapore is considered an international leader in integrated multi-modal transport planning. It established the world's first area licensing and electronic road pricing systems, and uses a quota system to limit vehicle ownership. The government makes continued investments in transport infrastructure.

Colombia

In 2011 in Colombia, an attempt was made to create an inventory of the streets and roads Quintero (2011) in terms of an inventory that includes: road infrastructure, infrastructure, signaling and control devices, parking infrastructure, the whereabouts infrastructure, and the infrastructure of public transport, routes and urban passenger transport. The case of the *Transmilenio* buses system was also studied.

6. CONCLUSIONS AND FURTHER RESEARCH

Big cities are experiencing and will continue to experience significant growth, so it is very important to be able to deliver the urban transportation infrastructure in a successful and sustainable manner. Experience with cases and projects in the past have given us insight into the failures, and, according to KPMG (2010), these experiences show that we need to take some points into consideration if we want to succeed

- Project environment and turbulence
- Political control and sponsorship
- Role of national government
- Effectiveness of planning
- Effectiveness of procurement and financing
- Organizing for operations

The next step is to consider each one of these factors and to analyze projects from this point of view.

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