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Efficient Solutions for Urban Mobility - Policies, Strategies and Measures

Alvaro Seco, Ana Bastos Silva
University of Coimbra
aseco@dec.uc.pt, abastos@dec.uc.pt
Portugal

1. Introduction: Formulation Processes of Mobility Policies

Over the past few decades, particularly in urban areas, mobility needs have significantly grown and changed as a result of the normal social and economic development. The mobility is nowadays a very diverse and complex reality, in reason of the tendency for a more disperse residential occupation and for a more decentralized location of most commercial and service activities, as well as of different population mobility habits resulting from their increased wealth. As a consequence urban mobility has been ever more dependent on the private car and, in many cases, by the existence of inefficient and costly public transport systems, with obvious negative impacts at the environmental, social and economic levels for the society as a all.

It is also relevant to refer that in some European Union (EU) countries transports use up to 30% of the energy used by the different human activity sectors and is responsible for 25-30% of the total of greenhouse gases (EEA, 2000; Civitas, 2006), with the car being responsible for as much as 50% of the emissions produced by passenger transport systems.

It is also important to notice the negative impacts that transport systems can, and often have, over several quality of life aspects. In many cases these systems invade many of the cities public spaces, which are otherwise used in many other activities such as leisure.

This situation has led to an increased emphasis being placed in the development of transport strategies and solutions within the Sustainable Development Global Agenda (Commission of the European Communities, 2006). The EU Green Paper over Urban Environment, the EU Treaty, the successive EU environment and transport action programs, the Rio de Janeiro UN Conference on Environment and Development or the different UN conferences culminating with HABITAT II, constitute some of the initiatives witch have been raising the sustainability issue and, in this context, have been discussing the future of urban mobility.

An urban strategic planning process, taking into consideration the urban area fundamental characteristics and its population needs, is thus an essential framework for the identification of adequate sustainable transport policies.

These planning processes can vary significantly but generally it can be said that they are evermore inter-disciplinary and focused mainly on two different but complementary areas.

One focus is on the identification of packages of measures directed at achieving an effective modal shift towards the most sustainable ones and the other directed at achieving a reduction of the need for transport.
In this context the formulation of a mobility policy applicable to complex urban environments and which can serve as a supporting basis for subsequent planning, implementation and management of transport schemes, is a complex process where many technical and political questions and decisions interact and which involve a very significant number of stakeholders. It is, however, possible to define a number of basic methodological principles, as well as some typical system intervention strategies and measures, which can work as a framework to this process.
The first step of the process (see Figure 1) deals with the identification of the existing problems and of the basic strategic objectives which are to be achieved with the implementation of the new mobility policy. At the same time the definition of a set of performance evaluation criteria, applicable both during the initial diagnosis phase and during the final evaluation and monitoring periods, is essential.

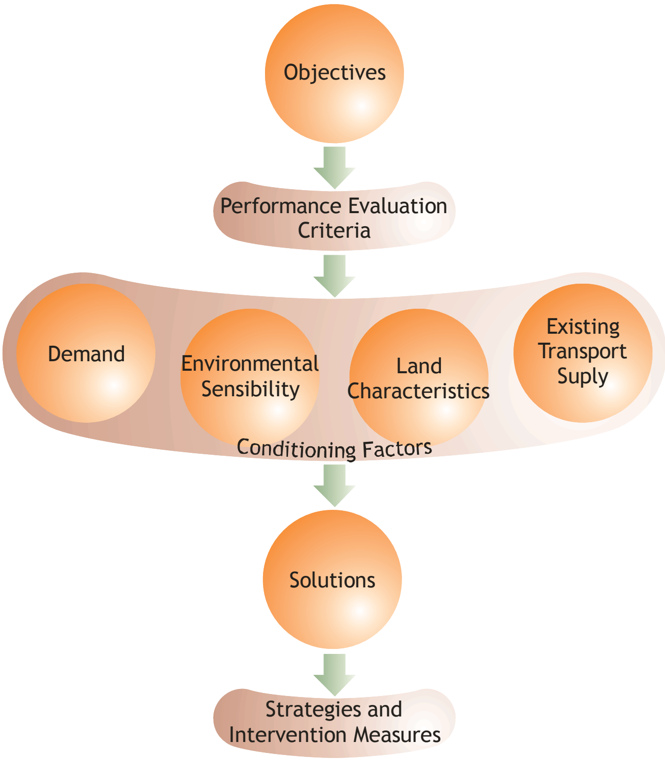

Fig. 1. The process to formulate a new transport policy

The second step focus on the identification and characterization of all the factors which, some how, limit the universe of ways in which the transport system can be structured.

A basic conditioning factor is in itself the way society view and value the concept of quality of life, namely in regard to the natural and historic heritage, and how it views environmental sustainability problems which result from the way society in general and the transport system in particular is organized.
Other important conditioning factors are, of course, the potential, weaknesses, and flexibility to change the existing transport systems have. Similarly important to be considered are the existing levels of transport demand and supply, and their predictable evolution in the foreseeable future. In fact the demand patterns, which result from the existing economic and social practices, as well as the specific characteristics of the existing transport supply systems, create a significant inertia and restriction to the eventual selection of new organizing and operational transport solutions.
In a similar way the specific natural and built land characteristics will be of paramount importance to the selection of efficient solutions and thus will need to be particularly well known and understood.
The understanding of the ways in which all these different conditioning factors interact enables the identification of the most efficient transport system organizing solutions, which will tend to be drawn and adapted from a number of "typical" ones.
In the present text reference is made to generally adequate organizing solutions applicable to different urban environments, namely those who were designated as "Historical Areas", "Traditional City Centers", "Modern, Medium-High Density Developments" and "Suburban, Low Density Developments". The "scale" of the problem is a topic which also needs to be taken into consideration in any process of this kind and, thus, will be briefly analyzed.
Having identified the adequate transport policy to be adopted, it will then be necessary to select a coherent set of basic intervention strategies and measures capable of guarantying its adequate implementation.
In the current text the different strategies and measures which are generally applicable are presented in a structured way, with reference being made not only to their potential but also to their applicability conditions.
In the final part of the text, a number of real life benchmark case studies are presented, in order to better demonstrate the potential that exists to implement efficient and sustainable transport policies.

2. Transport Policies' Objectives

Although the specific solutions adequate for each urban space will decisively depend on their specific mobility problems and of its own population and their representatives perspectives, it is however possible to identify a set of strategic objectives which are relatively consensual and that can work as basic references in any urban mobility policy defining process. Three main strategic objectives which are increasingly consensual can be identified:

- To contribute to the improvement of the populations quality of life by guarantying the provision of good and equitable mobility conditions for all;
- To contribute to the economic development, through the provision of good accessibility by people and goods to the different spaces of the territory;

- To optimize the global efficiency of the transport system both in operational and energy and environmental terms.

This means that the transport system must also assume a social mission by guarantying mobility to every one, including people with special mobility needs, as well as adequate accessibility to all urban areas, including the ones with scarce occupancy, even when that is not economically sustainable. It is also important to notice that the efficiency of the system is based on the optimization of its operation, especially at the speed, reliability and safety of the offered services, as well as by minimizing of the financial effort associated with the implementation, operation and maintenance of the system. The minimization of the negative impacts that the functioning of the system inevitably have over the natural and urban environment, is also gaining significant importance, as is the option towards the adoption of more energy efficient, less dependent on hydrocarbon fuels solutions.

The set of general objectives identified above imply that any transport problem will inevitably be a multiple objective one. Furthermore the increasing importance of aspects like safety, minimization of energy dependency and, specially, minimization of environmental impacts has created the need for a more systematic identification, quantification and taking into consideration of all the costs and benefits involved in the operation of a transport system, namely through a process of internalization of the transport externalities.

3. Transport Policies' Conditioning Factors

As referred above the development of efficient and sustainable transport policies must take into consideration a number of technical and sociological conditioning factors namely: demand basic characteristics; type of land use and natural characteristics of the territory; existing and implementable transport modes and services; residents and stakeholders' environmental awareness.

The demand patterns are a consequence of the location and relative importance of the different land use types, but are also the result of their scale and concentration levels.

The scale and density of the land usage tend to decisively influence the eventual existence and typology of the public transport systems. Banister (2007), for example, states that some empirical studies suggest that some level of sustainability for quality public transport systems can only be achieved in cities with at least 25,000 (preferably 50,000) inhabitants, with occupancy densities of at least around 40 hab/ha.

Also the population social-economic basic characteristics can significantly influence the potential applicability of different transport solutions. Households' income is a major factor affecting private car ownership levels which tend to significantly influence private car mode share. Also the age distribution of the population might be an important factor, for example to determine the potential importance of school trips.

Land characteristics can also significantly condition the choice of transport supply solutions. The existence of a significantly consolidated urban area immediately imposes significant difficulties or costs to solutions which might imply the implementation of new infrastructure components. On the other hand, the existence of important historical or natural spaces will tend to force the adoption of less intrusive, more environmentally friendly solutions. Different natural barriers such as rivers or other significant physical terrain features can significantly influence transport networks shapes and characteristics.

Also the type, potential and performance of existing transport infrastructures is an obvious and decisive conditioning factor since seldom a transport problem occurs in an area with very little existing infrastructures and systems, leading to the option of optimizing those instead of introducing new ones, being very attractive. The basic characteristics of the different readily implementable new systems is also an important factor to be taken into consideration since, in most cases, the development of an entirely new system is not an option. The thorough knowledge of all applicable systems and services is thus of paramount importance when developing a structured transport policy and selecting the most adequate intervention strategies and measures. The basic characteristics, but also the potential and applicability conditions of some of the most common and interesting modes and services are presented below.

Finally, it is also important to make a reference to the conditioning factors associated with the different stakeholders' sensitivity in relation to different aspects connected to the concepts of quality of life in general and environmental quality and sustainability in particular. The fact that in many countries and societies the possession of a private car gives social status, while the usage of, for example a bicycle, is a sign of low social status, introduces significant difficulties to the consideration of more environmentally friendly solutions. Also the existence of a more or less intense environmental consciousness by the different stakeholders but, especially, by the potential users, can significantly affect the success prospects of policies where this aspect of the problem is important.

At this level the quantification of the externalities associated with the operation of the different modes and services is very important, since one of the potentially more important strategies to guaranty the successful implementation of more sustainable policies is the internalization by each system or service of their intrinsic externalities. This aspect of the problem if further analyzed below.

4. Transport Systems: Characteristics, Potential and Applicability

At the present many transport systems and services can be considered for application, ranging from the more traditional pedestrian, bicycle, private motorized vehicles, or road and rail based collective modes, to the more innovative ones such as car sharing or car pooling. There are also other more or less specialized solutions applicable to special problems such as the mechanical elevatory or maritime systems or, finally, those which involve the integrated use of more than one mode, such as Park-and-Ride or Bike-and-Ride.

Each of these systems and sub-systems presents specific intrinsic characteristics, both at their operational and performance potential levels, which decisively influence their applicability to the resolution of the different mobility problems which might exist in an urban area. Table 1 presents a brief characterization of some of the more relevant and common modes (see for example Vuchic, 2007).

The pedestrian and cyclist modes offer an excellent timing availability although, sometimes, this can be limited by adverse weather conditions. On the other hand, these modes' spatial range, particularly that of the pedestrian mode, are somehow limited, not only due to the limited distances which can be covered in view of their limited operational speeds, but also due to their difficulty in dealing with adverse orography.

	Pedestrian	Bicycle	Auto Taxi	P&R B&R	D. Ride BUS	Light Rail	Metro Rail
Service potential							
• Operational Speed(km/h)	3/5	10/20	20/70		12/25	20/45	25/70
• Coverage Range (km)	1	5/10	≈40		≈20	≈40	≈40
• Capacity (Pas./h)x10^3	4,5 (/meter)	2,0 (/lane 1,2m)	1,4/2,2		2,4/8	6/20	10/40
• Productive Cap. (Pas.xKm/h^2) x10^3			10/120		20/90	120/600	400/2000
• Availability/Frequency	Very Good	Very Good	Very Good	Good			
• Spacial Availability	Good	Good +	Very Good	Good +			
• Comfort			Very Good	Good +	Good	Good +	Good +
Implementation/operation							
• Adaptability/phasing possibility /Level of Investment	Very Good	Very Good	Very Good	Good	Good		
• Energy Efficiency/ environment/intrusion	Very Good	Very Good		Good	Good	Very Good	Very Good
Preferential application							
• Link type	Short distance	Level terrain	Low -Low density	Low - Med./high density	Med. - Med./high density	Med./high- Med./high density	High- High density

Table 1. Potential, implementation and operation conditions of some transport modes

In operational terms both the pedestrian and cyclist modes present interesting potential due to their implementation and operational easiness, since they can be implemented progressively and do not need sophisticated management and control systems.

They also present the highest energy and environmental efficiency levels and the smallest urban intrusion impacts.

All these characteristics imply that their competitiveness is highest in dense urban developments where trips will tend not to be very long. Furthermore, these modes are especially interesting in the implementation of aggressively sustainable policies.

The private car is characterized by its unbeatable timing and spatial flexibility and by its intrinsic comfort. In fact, no other mode can match the freedom that the car can offer to go almost anywhere at any time in completely private conditions and in complete comfort offered by, amongst others, their air conditioning and audiovisual systems.

However, at the present, it is also the most inefficient mode at not only the energy and environment levels, extremely important aspects in terms of achieving a sustainable mobility, but also at the intrusion of urban spaces level and in terms of efficiency of use of the road networks' capacity. If it is very likely that in time the first two aspects might be less conditioning factors due to the expected development of more efficient, less polluting, propulsion technologies, on the contrary it is very likely that the other two will maintain their importance.

An overall evaluation of all these characteristics leads to the conclusion that this mode of transport is especially competitive in not very environmentally sensitive urban contexts and where there is limited concentration of trips within the territory and, particularly, when

there are not only good road connections but particularly good parking conditions at the destination locations.
It is also worth nothing the existence of a number of related sub-modes as are the Taxi, or the Rent-a-Car, the Car-Sharing or Car-Pooling systems or, in a slightly different perspective, the Motorbike, which present slightly different characteristics and applicability potentials enabling the coverage of specific market niches.
In contrast with the private car, road based collective transport systems present the possibility of offering significant higher transport capacities and lower urban and environmental impacts while using similar infrastructures' space. On the other hand they offer less scheduling and geographical coverage.
This leads to them being considered potentially more efficient and sustainable if they are applied in medium-high demand concentration urban spaces and to serve trips which are simple, for example single destination ones, and repetitive in geographical and timing terms.
A number of different sub-systems and services are also present within this mode, as are the Dial-a-Ride and the Metro Bus (where there is a systematic use of segregated lanes), or even, although less distinctive, the services resulting from the use of different types of vehicles such as Mini Buses or Articulated ones. All these solutions enable a significant enlargement of the applicability field of this type of systems.
Rail based systems such as trams, tram-trains, metro or regional trains, all present some characteristics similar to those of the road based collective systems. However they present a potential for much higher capacity levels and for offering higher operational speeds, and have the potential for offering the highest performance in energy consumption and environmental terms. On the other hand, they need a special infrastructure, generally segregated from the other urban spaces (not determinant but very useful in the cases of Trams and, particularly, Tram-Trains), which is much more demanding in terms of initial financial and time investment and require more sophisticated management and control systems. Relative to the road based collective systems they also present less adaptability to significant shifts in demand patterns, thus requiring more sophisticated planning systems.
All these characteristics make these systems particularly competitive when serving links and networks which connect high occupation density areas (>50 hab/ha) where very high number of trips are generated.
In terms of range tram and metro based systems are particularly suited to serve short-medium distance, urban trips with high frequency of stops, while tram-train and regional train systems serve more medium-long distance suburban and regional trips, with less stops and higher commercial and operational speeds.
Within the more urban solutions the decisive difference is that while the complete segregation of the metro enables higher commercial speeds and capacity, the tram solutions enable a closer, less expensive service in smaller urban areas.
The more recent Tram-Train solutions use vehicles with special technical specifications which enable them to function basically like Trams within the city centers and as regional trains across the suburban environments.
Within the multimodal solutions it is worth a special reference to the Park&Ride/Metro/Tram or Bike&Ride/Metro/Train ones, since they are amongst the more common and with more potential.

In these solutions an individual mode is intertwined with a collective mode of transport at a certain interface where, generally, there exists a long term parking area and a collective transport station.
In some cases, when the bike mode is involved, instead of parking the bike near the station, it is carried in the collective mode of transport, transforming the system in a Bike&Ride/Metro/Train&Bike one.
The combined usage of two very different transport modes enables the implementation of services with special characteristics where, basically, on one hand one takes advantage of the greater timing and spatial flexibility of the individual modes to serve the part of the trips which takes place in low-medium density demand areas, and of the higher transport capacity and efficiency in using urban space or higher range provided by the collective modes to serve the high urban occupancy areas.
These types of solutions are, thus, particularly competitive when connecting low density, suburban areas with high density, urban ones and, in particular, to serve more stable, repetitive home-to-work and home-to-school trips.

5. The Problem of Transport Externalities

Associated with transport systems operations one can identify different costs which can be classified either as internal or external. The internal ones are those which are directly beard by the users, while the others, more of a social type, are generally supported by the society as an all either at a local or at a global scale.
The justification for the adoption of a strategy of internalization of all the externalities is basically one of adopting a user-payer logic or, perhaps more appropriately, beneficiary-payer, meaning that who benefits from the provided service should bear all the associated costs, so that everyone is encouraged to adopt travel behaviors taking in consideration all the associated costs, including the social ones.
This strategy is off course essential in order to make the competition between all modes of transport "fairer" and in order to be able to create competitive conditions for the more environmentally friendly modes which are essential in the creation of a more sustainable mobility system.
However, external cost quantification processes present significant technical and political difficulties. At the technical level a basic difficulty is the choice of the most adequate type of analysis. One alternative is based on the quantification of induced costs, "damaged costs methodologies", which is normally carried out using declared preferences techniques, with which a quantification is made of the amount of money users are willing to pay to avoid the damage or willing to receive to accept it (WTP or WTA). The alternative methodologies, designated "avoidance costs methodologies", are based on the quantification of the costs associated with avoiding the occurrence of the external costs expected to occur if nothing is done to avoid them.
It should be noticed that this choice of methodology has significant implications on the obtained results (see Table 2) since the "avoidance costs methodologies" tend to produce much higher estimates than those based on "damage costs" (Austroads, 2003).
Still at the technical level there exist significant difficulties, on one hand, to identify all involved costs and, on the other hand, to accurately predict the future evolution not only of the phenomena that are responsible for the costs, but also of the exact values of these ones.

		Average cost per Passenger PT1995 (Euros/1000pkm)		Average cost per Passenger EU1995 (Euros/1000pkm)		Average cost per Passenger EU2000 (Euros/1000pkm)		Average cost per Passenger EU2010 (Euros/1000pkm)	
		Vehicle	Bus	Vehicle	Bus	Vehicle	Bus	Vehicle	Bus
Road Accidents		35,0	2,7	35,7	3,1	30,9	2,4	41,9	3,6
Noise		2,0	8,0	3,7	1,3	5,2	1,3	6,0	1,6
Atmosferic polution		8,0	6,1	17,3	19,6	12,7	20,7	13,9	19,4
Climatic changes	High	10,0	4,5	15,9	8,9	17,6	8,3	17,8	12,0
	Low	± 1.4	± 0.7	± 2.3	± 1.3	2,5	1,2		
Nature and Landscape		1,0	0,2	2,3	0,8	2,9	0,7	3,0	1,0
Urban impact		0,0	0,1	1,3	0,5	1,6	0,4	1,6	0,5
Before and after processes		5,0	1,8	3,6	4,3	5,2	3,9	8,3	5,1
Traffic jams		1,2	1,3	5,8	3,1			± 3.4	± 2.9
Total without traffic jams and Climate changes-High		61,0	16,0	87,0	38,5	76,0	37,7	92,7	43,1

Notes - References

Ref: INFRAS/IWW (2000/2004)

Values adapted from the study

Notes – Climatic changes scenarios

Method "Damage Cost - Willingness to Pay" less restrictive than "Control Cost - Avoidance Cost"

Used method "Control Cost" - scenario "High" - 140 €/ton CO2 (50% reduction of CO2 from 1997 to 2030)

Used method "Control Cost" - scenario "Low" - 20 €/ton CO2 (8% reduction of CO2, 1990 to 2010 - Kyoto)

Table 2. Transport external costs according to Infras and IWW (2004)

The political level, on the other hand, leads to a strong subjectivity in this type of process since, for example, when one uses "avoidance costs", the final results depend strongly on the adopted targets relatively to the reduction of the phenomena which produce the costs.
For example, according to Infras and IWW (Infras/IWW, 2000/2004) in order to achieve the Kyoto targets, which aim for a CO2 reduction between 1990 and 2010 of 5% at the world level and of 8% at the European Union level, it implies the assumption of a 20 Euros/tonCO2. If, on the other hand, the adopted objectives are those proposed by the UNFCC, "UN Framework on Climate Change", which aim for a 50% reduction at the World level and an 80% reduction at the OECD level in 2030 in relation to 1997, then it results in an estimated cost of around 140 Euros/tonCO2.
Also, when a methodology based on the WTP or WTA principles is used, the estimated costs will depend significantly on several factors. For example, the income levels of the population being questioned will probably be a relevant factor since, normally, the population willingness to assume costs will tend to be greater the greater their incomes are.

6. Sustainable Mobility Policies: Reference Solutions

6.1 Efficient versus Optimal Solutions

In multiple objectives, complex, problems it is usually impossible to identify optimal solutions, since conflicting objectives tend to coexist and it is not always possible to refer them all to the same measuring unit. In the transport field this tends to result in complex performance evaluation processes to access alternative transport systems organizing solutions. For example, objectives like minimization of the investment effort or performance optimization, on one hand, and minimization of the environmental impact and energy consumption reduction on the other hand, are conflicting and not easily reduced to a single monetary unit.

This leads to the search for "efficient" rather than "optimal" solutions where one identifies which, amongst the solutions which are the best regarding one or more partial objectives, are also the most efficient regarding all the remaining objectives. This concept can be visualized on the example represented on Figure 2 where one can say that the solution represented by the continuous red line is "better" and thus more efficient than the one represented by the dotted red line, but one cannot necessarily conclude the same when comparing it with the solution represented by the continuous blue line.

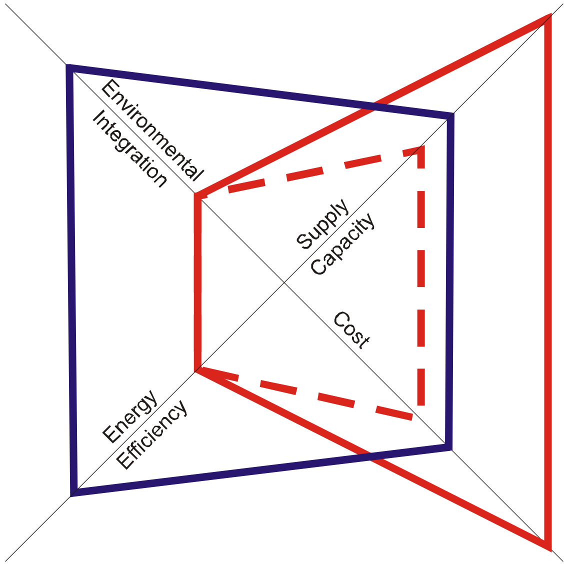

Fig. 2. Efficient versus Optimal Solutions

In complex transport problems this means that in many cases it is not possible to identify truly optimal solutions. However, from the identification of integrated solutions which are very efficient in regard to a significant number of objectives and which fulfil at least minimum requirements in relation to all the other objectives, it is normally possible to identify a reduced number of alternative "efficient" solutions. In particular for a number of characteristic transport problems occurring in certain representative urban environments, using adequate benchmarking it is possible to identify "efficient" integrated policies, intervention strategies and measures, which can confidently be applied.

In the current section four different and representative urban environments are analyzed and, for each of them, a set of basic options and solutions is identified as capable of creating efficient accessibility and internal mobility conditions. The urban environments object of

analysis were "Historical Areas", "Traditional City Centers", "Modern, Medium-High Density, Developments" and "Suburban, Low Density Developments".
It is however worth noticing that the variability of the characteristics and potential presented by the different transport modes and services which can be applied is such that, although the types of policies which are considered adequate for a certain type of environment are reasonably similar, on the contrary the specific solutions to be applied can vary significantly and are particularly dependent on the "scale" of the problem at hand. In fact, for example, the mobility problems and consequent applicable solutions related to small urban developments with 15/20.000 inhabitants are necessarily different from those with 100/150.000 inhabitants ones and, obviously, even more from those of big metropolitan areas.

6.2 Efficient and Sustainable Solutions for Historical Areas

Any solution to be selected for application in an Historical Area must have as basic reference the nobility and intrinsic quality of the urban space. On the other hand, from a transport infrastructure point of view the main reference tends to be their extreme irregularity and limited potential (see examples in figures 3 and 4).

Fig. 3 and 4. Details of the historic areas of Coimbra and Viseu in Portugal

From these two basic factors it results that the existing and potential motorized capacity is very limited since, on one hand, there tends to be inadmissible any significant change in the infrastructure and, on the other hand, even when the potential operational capacity is significant, the real operational usable capacity will tend to be quite moderate due to the application to the road network of the concept of "environmentally sustainable capacity".
From this it results that both the accessibility to and mobility within historical areas must essentially be guaranteed by public transport, by special mechanized modes whenever appropriate, and by other environmentally friendly modes such as pedestrian and bike ones.
In fact, an efficient and sustainable usage of the very limited available road capacity implies that the essential of the access to these areas must be guaranteed by public transport, if possible completely ecological, with private motorized vehicles' usage being reserved and even so in a restricted way to priority users (residents, load and unload activities, priority and emergency vehicles, and people with special disabilities).

Special attention must of course be given to an adequate interconnection between internal transport modes and those that serve the surrounding areas. A relevant example is the possible interconnection between surrounding car parking areas and the internal pedestrian network complemented where relevant by mechanical elevatory systems or other internal public transport services. The same modes and services will of course constitute the backbone of the internal mobility system.

6.3 Efficient and Sustainable Solutions for Traditional City Centers

Most traditional city centers are characterized by the significant importance of commerce and services, which involve significant numbers of trips towards and from these areas with significant concentration during rush hours. At the transport infrastructure level it is common to exist road networks with limited capacity in relation to the potential demand, due to the fact that, in many cases, they were designed and built at a time when the private car did not have the dominant role it now tends to have. At the same time, because normally these are consolidated areas, there is very limited space to significantly expand the transport infrastructure unless underground solutions are assumed (see figures 5 and 6).

Fig. 5 and 6. Areas of the City Center of Coimbra in Portugal

Besides, having in consideration the desirable existence of quality public spaces, for which it is always negative the existence of high levels of motorized traffic, it will often be justified also to apply the concept of environmentally acceptable road capacities, although with significantly higher acceptable levels than those normally assumed in historical areas.

As a result of all these factors it is normally virtually impossible to serve most of the home to work movements by private car with any quality and without major impacts over the environment and the city quality of life. Within this context it is clear that the access to this type of urban areas, particularly by home to work type of movements, must be served by traditional public transport or by P&R services, with the exact mix of allocated services mainly dependent on the geographical pattern and intensity of the corresponding flows of each specific situation. On the other hand accessibility by commerce and services users, as well as by residents, should usually be served by all the available modes and services in "loyal" competition. To enable this it is necessary that the users bear all the costs for which each mode or service is responsible including those relating with "invasion of the urban

space" and with the environment. In what it concerns residents, within coherent strategies against the desertification of the city centers, in many cases it might be advisable to implement positive discrimination solutions such as priority given in the access to public car parking.
The internal trips should be mainly served by the more environmentally friendly modes, particularly pedestrian, for which it is essential that this mode is provided with dense, comfortable and safe infrastructure networks directly connecting all the important trip generation equipments.
Finally, in what concerns the best use of the road networks maximum usable capacity, all efforts should be made to eliminate through road traffic since it does not bring any value to these areas. At the same time, it will normally be justifiable to manage the existing road network capacity giving priority to the most efficient modes (collective and or more environmentally friendly), namely using a logic of maximization of the number of people rather than the number of vehicles susceptible of being served.

6.4 Efficient and Sustainable Solutions for Modern, Medium-High Density Urban Areas

The more recent, medium-high density, urban areas in many cases present residential occupancy levels in the order of 60/100 hab/ha and, in most cases, have already been designed, although sometimes inadequately, with the road networks and accesses needed for a more car oriented way of life (see examples in figures 7 and 8). In these cases it is normally acceptable to serve most accessibility needs using all the modes available, providing that all the corresponding costs, direct and indirect, are internalized and supported by the respective users.


Fig. 7 and 8. Examples of Medium Density Neighborhoods in Coimbra, Portugal

In order to give competitive conditions to the public transport and bicycle modes it is essential that inside these areas adequate infrastructures are created along the full length of the trips, so that real door to door services can be provided. Public transport modes need not only comfortable and well localized stops but also a coherent interconnection with the pedestrian and cycling networks. These environmentally friendly modes should also be the main support for the internal trips for which it is essential that there exist dense, comfortable and safe networks, where one of the main aspects to be taken care of is the adequate management of the conflicts between these and the road networks, where the control of the vehicles' speeds tend to be very important.

6.5 Efficient and Sustainable Solutions for Suburban, Low Density Developments

Suburban residential areas are usually characterized by land uses with densities in the order of 10/25 hab/ha resulting from a mix of fundamentally rural areas and small urban agglomerates (see figures 9 and 10).

Fig. 9 and 10. Examples of suburban agglomerates in Coimbra, Portugal

Generally private transport modes, normally motorized but sometimes cyclist, by themselves or integrated in a multimodal solution, will tend to have a dominant role in the service of the accessibility to these spaces. Public transport systems will tend to be reserved to the more specific, but not less important, roles related with guaranteeing minimum accessibility conditions to everyone, thus fulfilling what is normally considered to be public service. When the problem is the connection of these zones with urban city centers, then standard public transport solutions can be competitive although, when lower density areas are concerned, multi-model solutions like P&R tend to be a better choice.
Inside the different agglomerates mobility should be well served by pedestrian networks which must also guarantee good access conditions into public transport stops. The quality of service provided by these pedestrian networks is very much dependent on the way conflicts with the road network are dealt with, with the control of the trough motorized traffic speeds, eventually using traffic calming solutions, being an important aspect.

7. Integrated Strategies and Measures for an Efficient Urban Mobility

7.1 The Need for integrated Strategies

The urban transport systems' possible intervention strategies are quite varied and require a coordinated development and implementation.
Generally, as seen before, the general aims of a transport policy are to better serve a reduced number of private car users, while at the same time more people is convinced to use interesting, more sustainable modes, like public transport, bike or foot.
The different relevant strategies generally involve:

- The optimization of the road network performance;
- The introduction of car usage restrictions, particularly in the most sensitive areas;
- The creation or improvement of competitive, sustainable alternatives (public transport, bike or pedestrian systems) and their promotion;
- The intervention at the land use level in order to change the urban mobility patterns so that the more sustainable modes can be more competitive.

7.2 Optimization and Restriction of Private Car Usage

As was referred before the private car, within the urban mobility context, tends to be the most inefficient mode of transport at both the energy and environment levels.
The intervention strategies in relation with this mode tend to include three different focus areas: first, improvement of the infrastructure operational efficiency so that more vehicles can better use the available infrastructure or, preferably, that the same or even less number of vehicles is better served by a smaller infrastructure; second, improvement of the usage of the available transport capacity by improving the vehicles' occupancy; third, promoting the shift to other, more efficient, modes by introducing a coherent set of restrictions towards the movement and parking of private cars, particularly in the most sensitive urban areas.
In the first group of measures one can identify several ITS based ones, such as the implementation of Centralized Real Time Traffic Control and Traffic Information Systems, through which it is possible not only to optimize available capacity but also to influence the way in which the users use the infrastructure.
The second group includes interventions not only at the infrastructure operation level but also through information and promotion actions.
At the infrastructure level the basic measure relates with the implementation of an integrated network of High Occupancy Vehicles (HOV) lanes which are to be used only by cars with 2, or eventually 3 or more occupants, thus optimizing the use of the existing road capacity.
This kind of measure should be complemented with the implementation of Car Pooling solutions, where two or more persons, who have similar mobility needs, choose to use the same vehicle, normally sharing their costs, and thus reducing the number of vehicles circulating. This can be done by simple promoting actions or by the creation or support of structured car pooling systems and companies which try to speed up and optimize the trip matching processes.
The promotion of a less intense use of the private car can be done by physically restricting the access, the movement or the parking in the most sensitive areas, for example by reducing the capacity or speeds provided by the road network or by reducing the parking offer or by introducing timing restrictions.
The intervention can also be done by increasing the cost of using the private car either by increasing the parking tariffs or by the implementation of urban tolls. This last type of solution has been gaining popularity and proved to significantly contribute to control access levels and conditions to sensitive areas (Commission of the European Communities, 2006).
Other interesting instruments are Car-Sharing schemes, where people give up the ownership of the car and is encouraged to use cars, rented in some kind of pool system, just

when that is absolutely necessary. This kind of scheme is particularly attractive in areas where parking is very difficult or expensive.

7.3 Promotion of the Pedestrian and Bike Modes

The pedestrian system is of central importance in the implementation of any integrated sustainable transport policy. In fact the pedestrian mode has all the potential to be the main mode in city centers, in residential ones or, in any sensitive locations in general.
Intervention on the infrastructure must be designed in a coordinated way in all its components (circulation links, intersections with other sub-systems and mode interfaces), with the clear perception that its quality of service and competitiveness depends decisively of the existence of direct, continuous, effortless, comfortable and safe circuits connecting all the important trip generators. For that to be possible a number of infrastructure intervention methodological principles should be considered:

- Separation of the road and pedestrian networks particularly at the major road links, in order to guaranty high levels of pedestrian safety and to contribute to create attractive circuits;
- Creation of a dense pedestrian network connecting not only the trip generators but also connecting all the existing modal interfaces;
- To attend with special care the specific needs of the most vulnerable pedestrians such as children, old people and people with reduced mobility.

In what concerns the promotion of the bicycle transport mode it should be noticed that it depends in first place on the existence of a quality bicycle specialized supporting infrastructure, which includes not only a network of bicycle paths, but also involves parking areas located near the major trip destinations and public transport interfaces, as well as other complementary equipments such as specialized maintenance service companies and, desirably, sanitary installations with showers in the working places and schools.
In what concerns the implementation of a quality bike network the design principles have a lot in common with those presented in relation to the pedestrian networks (dense networks providing direct, continuous, comfortable and safe connections between all major trip generators and mode interfaces), although consideration must be given to the bicycle mode special needs relating mainly with the difficulty it has to deal with particularly steep gradients.
The promotion of the pedestrian and bike modes should go beyond the investment in the infrastructure, with the implementation of awarness campaigns, aiming to change the negative stereotyped image that, in many countries and communities, still is associated with these modes. In particular, special campaigns, focused on the promotion of the bicycle use, with family involvement but particularly directed at small children and teenagers, are promising avenues. Also innovative initiatives developed at important working places and schools have also shown to have some potential (Commission of the European Communities, 2006).

7.5 Promotion of Public Transport Modes

Public Transport (PT) promotion involves the creation of higher density services, particularly those with no vehicle interchanges within the same trips, along extended periods of time of every day, and with a good quality of service which involves reliability, speed, comfort and competitive pricing.

Competitive PT also implies the adoption of a door-to-door service approach as opposed to a stop-to-stop approach.

A basic element of the intervention strategy must be the creation of an efficient circulation supporting infrastructure where the existence of reserved segregated paths is essential to guaranty reliability and good commercial speeds. These segregated paths should be as continuous as possible with that being an obligation for the heaviest rail based systems.

For the non-completely segregated solutions the assumption of priority awarded at the crossings with other modes' networks is also very important and the highest capacity the specific PT mode has, the more this priority should be given in a systematic way. This can be made through the implementation of Automatic Vehicle Location and Identification (AVL) integrated with Real Life Traffic Control (UTC) Systems.

Another potentially interesting measure is the creation of more direct circuits than those allowed to the private car mode in order to create a positive discrimination for the PT. This can, for example, be achieved by the implementation of counter-flow Bus lanes.

The competitiveness of the Public Transport systems also depends very much on the quality of the location and intrinsic quality of their stops, on the existence of very good connections, particularly with the pedestrian paths, and on the existence of good accesses for users with reduced mobility.

One other important system element is the existence of a good information system, capable of providing information over schedules and service connections both remotely, in the stops and inside the vehicles, and whenever possible, providing it in real time.

7.6 Promotion of Multimodal Solutions

As explained before multimodal solutions present the potential to capture a significant number of important types of urban trips.

For that to be possible adequately designed and located modal interfaces are essential components in order to counterbalance the inevitable shock which results from the need to change mode and or service in the middle of the trip. In these points a panoply of different components, not only directly linked to the transport systems but even complementary ones like sanitary installations, media centers or fast food outlets, are of relevance.

Other decisive components are the multi modal integration not only of the existing information systems, dealing with door-to-door information, but also of the ticketing systems.

Finally it is also important to notice that the creation of really competitive multi modal solutions implies the complete integration of the services not only in terms of scheduling but also in what concerns tariffs.

7.7 Land Use Planning Complementary Intervention Areas

The urban structure, namely its type and concentration, influences the mobility patterns, particularly in what concerns the geographical distribution and concentration of the trips.

It has been argued that the “compact city” is the most efficient form of organization from an energy perspective, also presenting some potential social and economic advantages.
Other urban structures, such as that of “decentralized concentration” or that of the “linear city” are also considered efficient from a mobility perspective (Stead, 2001).
As it is understandable the basic characteristic common to all these types of structures is the existence of high urban concentrations around the points with high accessibility (Banister, 2007). This gives a significant potential for public transport competitiveness since it enables significant efficiency gains which, for example at the energy consumption level can represent 10-15% reductions of transport fuel usage by comparison with other less efficient urban structures (Ecotec, 1993).
In parallel, the wider implementation of mixed-use urban developments pursuing a local self-sufficiency logic, which tends to reduce the need for long, complex trips, is considered to be an interesting urban planning option.
From what was presented here it is apparent that, in the medium-long term, the assumption of land-use planning options consistent with sustainable mobility models, can have a significant impact and thus contribute towards reducing the current private car mode over dependency.
In parallel, the recent technological developments relating with information and communication technologies (ICT) are creating opportunities to improve urban mobility conditions by impacting on people mobility needs and behavior.
In fact their use presents the potential for greater human activities’ scheduling flexibility, with reduction of peak hours travelling, and even trips’ elimination. However, these kinds of impacts are complex and not yet completely quantifiable (Banister and Stead, 2004).

8. Sustainable Mobility Benchmarking Case Studies

In the following points a structured, but resumed presentation is made of a number of international benchmarking real life examples, representing different integrated and efficient intervention strategies.
In the presentations an effort is made to identify the basic intervention principles associated with each of the basic options, while at the same time some attention is given to the actions and measures used to implement the policies.

8.1 Public Transport Systems’ Promotion

(a) KARLSRUHE – Germany (implementation of Tram-Train system)

Karlsruhe, is a city with around 273,000 inhabitants which is surrounded by a 1.3 million inhabitants region.
Since 1961 the urban and sub-urban rail based systems have been jointly organized and managed, covering a network with over 600Km. The objective of this merger was to better integrate both systems (Lehmbrok et al, 2007), with the final objective of creating a more competitive public transport system capable of attracting previously private car trips.
Over time the adopted management model assumed a number of basic strategic options:

- Integration of the tram and train lines avoiding unnecessary transfers between the services provided by the two networks;

- Construction of new stretches of lines connecting both networks, adaptation of the interfaces and acquisition of new rolling stock capable of using the two different electrical propulsion systems;
- Introduction of a number of new urban and sub-urban stations taking advantage of the higher acceleration and deceleration capability of the rolling stock;
- Integration of the two services scheduling and increase of the services' frequency as well as better coordination with the road based public transport services and with the private car and the bicycle through new Park&Metro and Bike&Metro systems;
- Integration and development of the information, ticketing and tariffs systems;

In parallel the densification of the urban developments served by the tram-train system was pursued in this way increasing the potential number of users.
The population has been always informed and involved in the project through newspapers, magazines and pamphlets based campaigns.
The results from this project have been extremely interesting with the system demand growing 400% from 1992 to 2000 to around 150 million passengers per year of which 40% were previous private car trips.

(b) STRASBOURG – France (integrated transport system)

Strasbourg is a medium size French city with around 250,000 inhabitants. Since the nineties the sub-urban areas quick development associated with an accelerated concentration of the commerce and services in the city center have aggravated significantly the mobility problems.
It was then decided to assume a more sustainable transport policy through the promotion of the more environmentally friendly modes in detriment to the private car mode, coordinated with a land use policy directed at the development of a compact city guarantying short distances between the major traffic generating and attraction areas.
The transport system restructuring was based on the implementation of a new urban tram system associated with its efficient coordination and integration with a restructured road based public transport system (Lehmbrock et al., 2007; Difu, 2007).
In parallel, new multimodal Park&Ride and Bike&Ride solutions were developed near the more suburban tram stations, particularly the terminal ones, and bicycle use promoting campaigns were developed.
Special care was given to the urban integration and image of the new tram system having in consideration the special needs of the nobler city center spaces (see Figures 11 and 12), as well as to the accessibility needs of people with reduced mobility. Taking advantage of the opportunity given by the implementation of the new tram system, significant city center spaces were made pedestrian areas.
At present the tram network is constituted by four lines totaling 31.5Km and directly serving 70,000 inhabitants. This network offers high service frequencies throughout the day. The tram network is complemented by a bus network with a total length of 310Km in the urban areas and 280Km in the suburban ones.


Fig. 11 and 12. Areas of the City Center of Strasbourg in France

It should be noticed that the all project was initially received with some scepticism by residents and commerce. In order to overcome it the local authorities have developed a comprehensive information and promotion campaign based namely in public information events.

Following the implementation period and with the beginning of the new tram operation, the scepticism has disappeared and the system became a significant success resulting in a 32% public transport passenger increase from 1992 to 1995, with a parallel reduction of private car use of 17%, with the total number of annually transported passengers in 1996 being 41.9 million (Lehmbrock et al., 2007).

Amongst the residents the creation of the new pedestrian areas in the city center, made possible by the implementation of the new transport system, was viewed as a major contribution to the local urban quality of life.

8.2 Pedestrian and bicycle promotion

Many cities around the world have over the last few decades assumed a coherent strategy of systematic promotion of the bike and pedestrian modes as real alternatives to the use of the private car. Good examples are amongst other Odense and Copenhagen in Denmark, Munster and Berlin in Germany, Bolzano in Italy, Amsterdam in The Netherlands, Sandnes in Norway, Barcelona in Spain, Basel in Switzerland or Davis in the USA.

(a) ODENSE – Denmark (bike promotion)

The Danish city of Odense, which has 145,000 inhabitants, in 1999 has received the "National Cycle City of Denmark" awarded by the Danish Transport Ministry (Adonis, 1998) as a recognition to the systematic and coherent implementation of actions and measures to increase bicycle use.

The city has developed a large scale implementation which have involved 60 case studies financed at the national and local level and involving investments of over 3.5 million Euros.

The city has assumed the objective of obtaining a dominant use of the bicycle in the access and mobility in both the city center and its surrounding areas, in order to preserve the traditional urban space quality and attractiveness, while at the same time the city accessibility should be improved.

A 512Km long bicycle network has been built representing the basic infrastructure component of the system, while at the same time complementary actions such as safety promotion (intersection priority measures, speed controlled corridors, traffic calming measures), adaptation of the transport regulatory system, creation of new specialized services and information systems, were also carried out.
Special attention was also given to the development of promotion and information actions directed not only to the population in general but, at the same time, electing school children as a basic target in relation to home-to-school trips.
All these actions were supported by a strong marketing campaign, in which a special logo and an informative magazine were created.
All the implementation was also subjected to systematic monitoring procedures, in order to guaranty the quality of the solution with immediate correction of any identified deficiencies and regular maintenance of the infrastructure.
The population has assumed the project in an extremely positive way, so that by 2002 the bicycle was already the most important mode used (43.1%), followed by the pedestrian (23.2%), the private car (21%) and public transport (14%) modes.

(b) COPENHAGEN - Denmark (bike and pedestrian modes promotion)

Copenhagen is a 1.15 million inhabitants city with a very densely populated (5,700 hab/Km2) city center.
Before the implementation of the new integrated transport policy the city, which possesses a limited road network capacity, presented significant levels of congestion which were severely affecting the public transport level of service.
To address these problems local authorities decided to promote the bike and pedestrian modes and, at the same time, to introduce private car restrictive measures. This was carried out accompanied by permanent involvement and sensitization of the local population.
Many roads were intervened with the objective of creating shared quality public spaces, where priority was given to pedestrians and bicycles over cars. Others were completely devolved to pedestrians and bicycles.
All these places were object of urban renewable processes where, in parallel with the implementation of traffic calming measures, other interventions were carried out based on the substitution of bituminous pavements by other aesthetically more appealing, and placement of new urban furniture.
In parallel, a comprehensive set of bike supporting actions and measures were implemented ranging from explanatory campaigns, focused on particular segments of the population (immigrants, women, elderly, children, …), to physical measures (lengthening of the bicycle network, implementation of intersection bike priority, introduction of counter-flow bicycle lanes, …), to the implementation of a free availability of bicycles in city scheme.
New bicycle acquisition financing programs were also implemented, particularly directed at private companies, who then would devise their own logos and imaging on the bikes not only with marketing but also theft prevention purposes.
All the intervention was implemented progressively with the permanent participation of the residents and other stake holders, namely during the development of the relevant projects, in order to guaranty their acceptance off all the program.

Significant improvements at the quality of life level were obtained, reflected namely in the improvement of the noise and pollution levels and making the intervened spaces attractive and safe (Adonis, 1998).
The population has adopted the policy and that is reflected in a 2004 modal split that was already clearly dominated by the soft modes and by public transport with the private car reduced to less than 30% of the modal share.

8.3 Intervention at the Land Use Level

BOCHOLT – Germany (compact city)

Bochold is a very compact city where the basic mobility controlling intervention strategy has been the maintenance of small trip lengths, compatible with the bicycle and, specially, the pedestrian mode. The basic objective of the different actions is to maintain a situation where 90% of the population lives within less than 3Km of the city center.
This is achieved based on strict local regulations concerning land use rules, specially directed to the location of new commercial developments, where licensing is awarded only when the essential of the respective accessibility can be guaranteed on foot or bicycle.
Also a strong emphasis is put on the achievement of significant diversity of land use types in the different city neighborhoods in order to reinforce each area functional autonomy and thus contributing to contain and even reduce average trip lengths.
In parallel, car usage restrictions were imposed, ranging from the limitation of circulating speeds in residential areas by implementation of 30 Km/h zones, to the reinforcing of parking restrictions with the imposition of parking fees covering the entire city center.
As a result the city adopted the use of the bicycle, being at present one of the German cities where bicycle mobility is more important with a 35% modal share, and justifying the qualification of a "cycling city". This has been accompanied with the maintenance of a very high local quality of life for its citizens.

8.4 Sustainable Mobility in Developing Countries

Poorer countries, although possessing much lower motorization levels, are a significant cause for concern because of the potentially catastrophic environmental and energy impacts of their mobility conditions not only at the present, but particularly in the near future, due to their aging and outdated present motorized vehicles' fleets and, specially, to the potential for a very quick grow of their numbers.
In this context the World Bank has been developing new grant programs to help these countries to fight the climatic changes causes through the adoption of solutions capable of reducing pollution emissions while at the same time creating more efficient mobility conditions.
Within this line of action it is worth referring to a set of measures which, for some time already, have been under development in the Brazilian city of Curitiba.
This intervention program involves the transformation of the major federal highway (BR-116/476), which crosses through Curitiba, in an urban avenue served by a new high capacity Train Line ("Trem Urbano"), which will be closely interconnected with the city extensive public transport network. Furthermore this project contemplates other interventions such as the construction of new leisure parks and cycle paths as well as

remedial interventions directed at road traffic safety. It also involves intervention at the land use intervention level.

This program should enable the reduction of average trip duration, in parallel with improvements in the population accessibility to an improved transport system and, potentially, enabling a reduction of the metropolitan area mobility operational costs.

In general one of the main rules which might be defined for the implementation of new more sustainable mobility policies in developing countries cities is the need for the selection of low cost solutions which can be progressively implemented and evolve through time.

In first place, due to its importance, it is worth referring to the need for the progressive and systematic implementation of quality and dense pedestrian networks. In this respect particularly relevance assumes not only the construction of pedestrian paths but, specially, the improvement of their intersections with the road network.

A strong effort in creating good conditions to the use of the bicycle also seems to present significant potential due to the reduced costs involved, not only in the construction and maintenance of the infrastructure but, particularly, on the costs of the vehicles. A coherent and systematic investment in the creation of bicycle paths along the major traffic corridors tends to be very important.

Finally, particularly in the bigger cities and metropolitan areas, it is essential to progressively create dense networks of public transport services' supporting infra-structures. A specially promising strategy might be the identification and progressive implementation of exclusive "Busways", which at first can be used by the more traditional forms of public transport (as are for example the "Chapas" from Maputo in Mozambique), and which later on can be used to implement real Rapid Transit networks, which can be permanently road or rail based or can evolve from one type to another over time as demand and wealth grows.

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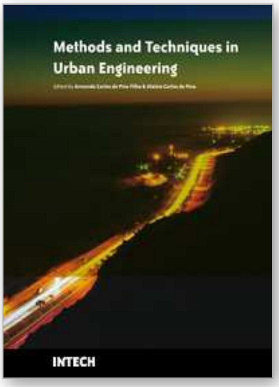

Methods and Techniques in Urban Engineering

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A series of urban problems such as dwelling deficit, infrastructure problems, inefficient services, environmental pollution, etc. can be observed in many countries. Urban Engineering searches solutions for these problems using a conjoined system of planning, management and technology. A great deal of research is devoted to application of instruments, methodologies and tools for monitoring and acquisition of data, based on the factual experience and computational modeling. The objective of the book was to present works related to urban automation, geographic information systems (GIS), analysis, monitoring and management of urban noise, floods and transports, information technology applied to the cities, tools for urban simulation, social monitoring and control of urban policies, sustainability, etc., demonstrating methods and techniques applied in Urban Engineering. Considering all the interesting information presented, the book can offer some aid in creating new research, as well as incite the interest of people for this area of study, since Urban Engineering is fundamental for city development.