CONTEMPORARY TRAFFIC MANAGEMENT TECHNOLOGIES IN SUPPORT OF ENVIRONMENTAL PROTECTION

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ABSTRACT:

As the population grows, so does the need for efficient transport, which is essential for the functioning of society. Quality and effective transport systems play a key role in providing access to markets, employment, education, and basic services, which are essential to reducing dependence on motor vehicles. The goal of this comprehensive review of relevant literature and analysis of world experiences is to identify technologies that can significantly contribute to reducing negative impacts on the environment and to recognize opportunities for their application in different traffic conditions.

KEYWORDS:

traffic management, techology, environmental protection, emissions, energy

1 INTRODUCTION

Movement is generally an indispensable need, while transport represents one of the existential functions of people. Transport is essential for the economic and social development of all countries, as well as for supporting regional and global cooperation. Historically, the development of a country's transport sector has been an indicator of its economic well-being and success, as well as its development capacity. The direct value added by the transport sector to global gross domestic product (GDP) is 3-5% and transport typically provides 5-8% of average total paid employment at the national level [1]. In addition to all the positive effects of transport, its accelerated development brought negative effects both on the living environment, including human beings and their communities, flora, and fauna, and on the non-living environment - soil, water, air, and climate. Primarily, the negative impact relates to emissions of polluting gases, energy consumption and traffic accidents.

Boltze and Tuan [2] point out that mobility is extremely important for the population of each country because it is crucial for the development of activities and social well-being. People consider it one of the most important benefits of their life because they can move freely, safely, quickly and at a reasonable cost. The authors emphasize that it is widely accepted and recognized as an asset of human civilization that mobility should be unlimited, while at the same time noting that the demand for travel or mobility under normal conditions continues to grow over time.

When it comes to solving transport problems, it is crucial to provide adequate infrastructure of a high standard. However, securing the infrastructure alone cannot completely solve the problem - the need to be aware that no country in the world can expand its transport infrastructure to such an extent to meet the growth in demand is emphasized [2].

With the development of the automobile industry, people began to use motor vehicles more and more to get around. Between 1950 and 1990, the number of motor vehicles in the world increased by about nine times, from about 75 million to about 675 million [1]. Adequate, efficient, and effective transport systems are important for access to markets, employment, education, and basic services that are critical to poverty reduction [1]. At the same time, the transport sector is responsible for about one third of energy consumption in the European Union (EU) (Figure 7 and Figure 8) [3]. Most of that consumption is related to the use of petroleum products, which means that transport is responsible for around a quarter of greenhouse gas (GHG) emissions in the EU [3]. For example, in the case of Portugal the transport sector accounted for around 24% of GHG emissions in 2017 [4]. The transport industry is one of the three main sources of carbon dioxide (CO_2) emissions in the world. According to data from the Ministry of Communications of the People's Republic of China [5], annual economic losses caused by traffic congestions amount to as much as 20% of the disposable income of the urban population. In 2020, China's CO_2 emissions in transport accounted for 15% of the total national CO_2 emissions, while for the entire transport field, the carbon emissions from road transport accounted for 90% [6]. Consequently, to reduce the negative effects of transport, less polluting and more efficient forms of transport have been promoted for the past twenty years, using alternative technologies, energy sources and business models.

Figure 7: Development of gas emissions in the EU by activity [7]

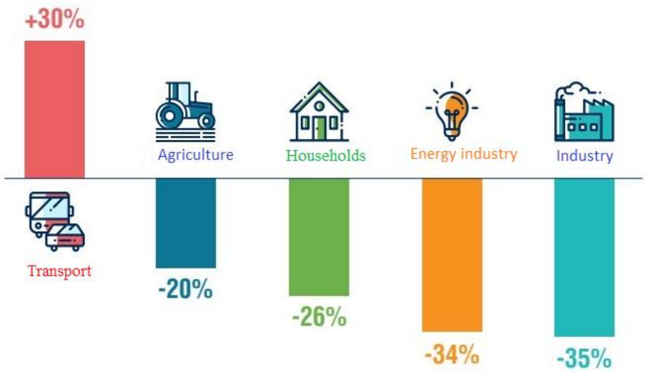

Figure 8: Emission of gases in the EU depending on the activity [7]

Traffic accidents also lead to significant social and economic losses for families and society. In order to assess traffic safety, especially in the road sector, the current situation, trends and controlling factors of traffic accidents (e.g. speeding and drunk driving, infrastructure condition, etc.) should be determined.

All this significantly affects people's quality of life. In addition to having an immediate negative effect, transport leaves consequences for generations to come. In this connection, the concept of sustainable development appeared in the mid-eighties of the last century. Sustainability in transport is related to many different factors. According to the United Nations Economic Commission for Europe (UNECE), the sustainability of transport is based on the so-called capital base consisting of the following three elements [8]:

- Social capital, which is associated with institutions, relationships and norms that shape the quality and quantity of social interactions in society. Transport connects people and provides access to basic social services, and is a necessary condition for social sustainability;

- Economic capital refers to (tangible and intangible) financial capital. Transport provides access, connects people and businesses and is therefore essential to economic sustainability;
- Environmental capital comprises natural capacities, including stocks of natural resources, land, and ecosystems. Transport negatively affects ecological capital through pollution, GHG emissions, energy use, waste generation and loss of natural habitats. Mitigating these impacts is critical to the sustainability of transport.

At the current stage of development, while looking at the current situation and considering the recommendations of experts, it is necessary to accept the fact that the majority of transport work in the region, as well as in most countries of Central and Eastern Europe [9], takes place on roads. It is predicted that the growth trend in this sector will remain very high for the next (at least) ten years. For this reason, it is important to provide the necessary infrastructure for such needs, while at the same time maximally respecting the human right to a quality environment. Trends in road transport point towards even greater inefficiency, congestion, pollution, harm to health and dangers to life, with the long operational life of existing vehicles contributing to these problems.

On the other hand, the accelerated development of technology represents a great opportunity for the development of transport management systems and provides the capacity to bring transport and transport infrastructure closer to the concept of sustainability.

Real-time monitoring of traffic flows, congestion index, delay index, etc., through intelligent transportation systems (ITS) can reduce traffic congestions, improve transport efficiency, and reduce carbon emissions [10]. According to Wand et al. [11], accelerating the establishment of a low-carbon road transport system and changing the extensive way of industrial development is the main strategic task for the development of road transport in the present and future.

The aim of this paper is to, based on a comprehensive review of the literature and analysis of world experiences, select technologies that can help reduce negative impacts on the environment and identify opportunities for their use in different traffic conditions. The review method used in this paper represents a critical analysis of information from numerous sources which resulted in a selection of the relevant literature systematized into different groups that provided the most significant findings related to the topic of the paper. The most significant findings are presented and summarized in this paper.

2 LITERATURE REVIEW

Boltze and Tuan [2] provided an overview of ten management measures aimed at establishing sustainable transport. It is particularly emphasized that the expansion of infrastructure alone cannot solve traffic problems, and that efficient traffic management is a key strategy for solving those problems, while contributing to the achievement of sustainable development.

Transport demand control is mentioned as the first approach. Worldwide experience has shown that the capacity of transport systems cannot be expanded to meet all requirements, nor would it make sense. In addition to financial resources, the expansion of infrastructure is also limited by surrounding conditions. To avoid unnecessary transport demand, one of the key aspects is land use control. Land use planning should be oriented towards short journeys connecting places of human activity and must reflect the characteristics of different modes of transport or systems, including their capacity. Transit-oriented development is certainly one of the most effective and long-term strategies in this context. An example of successfully adopted transit and land use planning to achieve desired settlement patterns is the city of Curitiba in Brazil. By improving the public transport system, the city created a linear structure. The density of housing and jobs is higher in the zones of transport corridors influence, with exclusive bus lines in the center and high-speed urban roads used by both cars and express buses. It was found that around 1.3 million passengers use Curitiba's public transport every day, and 28% of them switched from cars [12].

After transport demand control, modal choice is very important in many aspects, e.g. traffic safety and efficiency can be improved by shifting passengers from "dangerous" low-capacity vehicles (e.g. car and motorcycle) to "safer" high-capacity vehicles (e.g. train and bus). To achieve this, it is necessary to apply "push and pull" type measures with the principle of "making lower preferred transport modes less attractive and preferred modes more attractive". The implementation of "push and pull" measures must be coordinated for the combined effects to produce a result. In parallel, attractive alternatives for users must always be provided. Full measures can, for example, include pedestrian zones, safe bike tracks/lanes, bus signal priority, separate bus lanes, bus rapid transit and a subway system. To attract large numbers of passengers, public transport must provide shorter journey times, reliable timetables and/or significantly lower costs compared to individual motorized modes of transport. In Denmark, the government has provided financial grants for the integration of rail and regional bus services, allowing passengers across the region to use one ticket to transfer from one mode of transport to another, and providing free tickets for children under 12 years of age. This pulling policy has contributed to a significant increase in the number of passengers on public transport in the country. Preferred modes must be prioritized according to location and situation as the best modes are highly location dependent. While individual transportation is compatible and efficient in less densely populated areas, it is impossible to manage traffic if all cars go downtown. Therefore, the concept of intermodal travel must be supported through the provision of park-and-ride, bike-and-ride, bicycle transportation in buses and trains, etc.

The choice of mode and the spatial distribution of movement, as well as the distribution of departure times, are affected by the road usage fee. In some developing cities, there are plans to implement simple charging systems, such as paying a flat rate per day or even annually. Such a simple payment scheme cannot help much in controlling demand. Singapore has shown great success in implementing road user charges [2]. As early as 1975, the city introduced an area permit scheme with the aim of reducing traffic during peak periods in the central business district (CBD) and the system proved to be very successful. Then, in 1998, an electronic road charging system was introduced covering the CBD and several city expressways. In this way, there was a huge reduction in the number of vehicles entering toll zones at certain times of the day, which reduced congestion and improved travel speeds on the entire network, and at the same time enabled conditions for active forms of traffic (cycling and walking).

Transport demand changes over time and depends on location, but the capacity of transport infrastructure and transport systems is usually the same. This fact has led to situations where demand exceeds supply, leading to congestion and environmental degradation. Therefore, it is important that transport infrastructure and transport systems function more dynamically in response to changes in transport demand and other conditions. Available resources in public and private transport should be used in a flexible way, depending on the time and situation, as well as on the priority of the current mode [2]. Good examples are "tidal flow" systems: signal control activated by the volume of traffic, dynamic speed limits, dynamic route signs, on-demand public transport services, etc. It is obvious that detecting problematic traffic situations and devising effective control methods are feasible only with the application of advanced technologies. Congestion can be avoided or reduced if countermeasures are taken quickly. Therefore, dynamic transport management strategies must be pre-planned, evaluated and agreed between all stakeholders.

In addition, individual value systems and behavior are also changing, especially among younger generations. Recently, in developed countries, it can be observed that the interest in private ownership and use of cars is significantly decreasing. Meanwhile, new technologies are emerging rapidly and enabling changes in individual values, lifestyles, and travel behaviour. The Internet, smartphones, satellite navigation and new applications play a major role in the changes. These new technologies enable easy and spontaneous access to personalized information and services, not only in public transport, but also in other modes of transport. Some examples include traffic information services, multimodal routing services, car rental, car sharing, bike rental, ride sharing, taxi sharing, pedestrian navigation, etc.

2.1 DEVELOPMENT OF INTELLIGENT TRANSPORTATION SYSTEMS

As mentioned, new technologies enable changes in movement behavior and support safe, efficient, and environmentally compatible operations of transport and transport systems. ITS and their application play an important role in transportation because they can help improve traffic flow, road safety, security and crime reduction, improve public transportation, freight efficiency, and reduce environmental impact. In developing countries, a high-quality, high-capacity public transport system is an efficient and long-term solution to solving transport problems. ITS applications play an irreplaceable role in improving the quality of services and integrating different public transport systems and services. Receiving the right information at the right time and in the right place is crucial for successful urban public transportation, especially in a multimodal transportation system. It is difficult to imagine the existence of a flexible and high-quality public urban transport without the introduction of ITS. Applications of ITS in urban public transport include:

- Information services before and during the trip via the Internet and smartphone;

- Electronic displays about the remaining time until the vehicle arrives at the station;
- Ticket machines;
- Electronic tickets;
- Security cameras;
- Electronic informative signs;
- Other passenger information services, such as displaying vehicle location, walking distance between stationks and parking information.

Many ITS applications have already been implemented by different stakeholders and for different purposes. However, it is usually not possible to take full advantage of the system because information and data cannot be seamlessly exchanged between different systems. Also, Aldegheishem et al. [13] state that there is a large gap between the total level of urban traffic in different countries and the ideal situation due to illogical and uneven urban road network structures, imperfect road function, imperfect system, lack of transport management facilities and low level of governance. The acceleration of urbanization and the sudden increase in the number of cars have led to increasingly serious problems of city congestion, frequent traffic accidents and worsening noise pollution, as well as air pollution.

The advantages of ITS are reflected in several aspects [13]:

- Integration of information technologies such as the Internet, cloud computing, big data technologies and mobile Internet to build ITS;
- Traffic management in real time is ensured through the collection and processing of traffic information using information technologies;
- Strengthening connections and cooperation between people, vehicles, roads and the environment while improving road capacity, reducing the number and severity of traffic accidents and improving the efficiency and safety of traffic by easing traffic jams, reducing pollution;
- ITS fully uses traffic information as an application service, which can improve the efficiency of existing transport facilities.

The contradiction between cities, population and traffic has become more pronounced, creating the ground for the development and use of ITS [5]. Lv and Shang [5] also stated that the whole ITS industry is in a growth phase, and the demand for intelligent transportation is clearly growing and has a wide application area. Many governments are trying to become active in promoting the implementation of ITS. The same authors state that China’s strategy for building a strong transport country clearly indicated the necessity to vigorously develop intelligent transport, promote the deep integration of new technologies, such as artificial intelligence (AI), the Internet and all other technologies that contribute to the development of ITS.

Two basic (classic) ways to collect traffic data are vehicle detection using an inductive loop and using a pneumatic tube. In both cases, the systems identify the passage of the vehicle through an inductive loop or through a pneumatic tube that records the change in pressure. Although these systems effectively collect data such as speed, flow, and vehicle category, due to the high cost of implementation and the impact on traffic in the implementation process, these techniques have been overcome, especially at locations with high traffic volumes [5].

A big shift in the field of data collection, which is gaining momentum in the region, is cameras for video surveillance of traffic. Cameras are placed at various points on the transport network to record traffic, and then special image processing software analyzes the collected video to determine traffic flow, speeds, vehicle types, and other information [5]. Automatic license plate recognition (ALPR) is also widespread [14]. Combining traffic data obtained through radio frequency identification (RFID), enables determination of different characteristics of the flow, selection of characteristic situations and automatic selection of predetermined management actions or possible manual action from the traffic management center [5].

Video surveillance contributes to making traffic data significantly cheaper and more convenient. Traffic image processing is widely used to determine traffic conditions and determine traffic control strategies in ITS [5]. A major drawback of this technology, which has not yet been completely overcome, is that traffic images always contain data important to privacy, such as vehicle registration numbers, faces of drivers and passengers, pedestrians, and location of traffic participants. Misuse of this data threatens the privacy of vehicle drivers, passengers, and pedestrians [5].

Modern smartphone technologies such as GPS [15], media access control addresses, Bluetooth and WiFi components [16] and data from mobile phones can be used to analyze traffic conditions and even driver and passenger behavior during travel. An example is the identification of mobile phone use while driving. The concept of developing smart cities based on ITS systems is rapidly developing in the world (Figure 9). Modern ITS combines computers, big data, fifth generation technology (5G) and information systems. Additionally, sensor technology, electronic control systems, fuzzy control mechanisms and AI are comprehensively applied to transportation, management, control, and production of vehicles [5]. This combination of technologies helps to form a safe, efficient, and energy-efficient integrated transport system, as well as to solve the problems that exist in traditional transport, reduce the pressure on existing roads and improve the construction of road infrastructure.

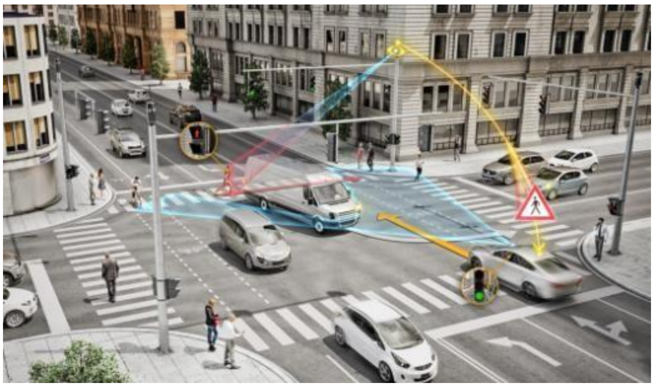

Figure 9: ITS in the urban environment [17]

In addition, deep learning (DL) and big data tools (BDT) can further improve the personalization of transportation applications. They can meet data-based requirements from the amount and availability of data in ITS. BDT and DL algorithms have found wide applications. DL technology has a wide range of applications in the field of transport. As mentioned above, DL algorithms are often used to improve data transmission and vehicle scheduling schemes to alleviate traffic congestion. In addition, intelligent traffic control has an important impact on the efficiency of urban traffic flow planning.

It can be seen that ITS is an inherent element of forming a smart city to achieve the energy conservation and emission reduction (ECER) goals for the transportation system. In ITS, road network optimization and vehicle flow monitoring led by AI and DL algorithms will become the research focus. In the future, in addition to data obtained from sensors and cameras in the transport network, public and opinions collected online (e.g. on social networks) can help to understand the situation and performance of the urban transport system. The severity of traffic problems can be comprehensively assessed through time- and space-tagged social media data, combined with actual traffic conditions, which is of great help to ECER in urban traffic.

2.2 ENERGY CONSERVATION AND EMISSION REDUCTION

Accelerating the establishment of a low-carbon road transport system and changing the extensive way of industrial development are the main strategic tasks of transport development in the present and future. The objectives of ECER can be summarized in three types:

- technical reduction of emissions;
- organizational management of emissions reduction;
- energy upgrade and replacement of means of travel.

When it comes to reducing emissions in the field of transport, it is primarily based on improving the efficiency of energy use. Technical measures to reduce emissions mainly include: the development of energy-saving and environmentally friendly vehicles, the promotion of public transport, the adoption of new energy-saving processes, new technologies, new equipment and new materials in the transport industry, the forced elimination of high-consumption and low-efficiency means of transport [5]. It is interesting to emphasize the difference in the progress of rail transport compared to road transport. Road transport is still running through the stages that rail transport went through during the evolution of steam locomotives, diesel locomotives and electric locomotives, which corresponds to the consumption of coal, diesel, and electricity [5]. At the same time, fuel consumption for rail transport is replaced by energy production from coal and oil, while in the case of road motor vehicles, the consumption of oil derivatives is replaced by electricity and other alternative fuels.

The organization and management of emissions reduction represent the area with the greatest potential for achieving energy savings and provide the most opportunities among all modern options for reducing emissions. Urban transport issues worldwide, such as management systems, policies and regulations, planning, technology, work practices and management mechanisms, provide the most significant potential for energy savings. Improving any of these aspects has a positive impact on road transport and emissions.

Improvements in energy consumption and replacement are promoting such technologies as "clean" vehicles. In relation to the development of technology, test results and the availability of different fuels, the main alternative fuels are natural gas, liquid petroleum gas, alcohol fuels (methanol, ethanol), electricity (fuel cell), hydrogen.

When considering the replacement of the means of travel, active travel has a huge potential to replace short-distance car trips, which significantly affects the emissions of personal travel. To influence daily travel decisions, change the spatial and temporal distribution of total emissions from motorized travel, it is necessary to provide high-quality infrastructure for walking and cycling [18]. One of the newer, alternative means that appeared relatively recently in cities is the electric scooter. They are mainly aimed at micro-mobility, i.e. short trips, but at the same time they create conflicts in urban areas and threaten security, which requires adequate policies to support their introduction [14].

Several analyzes have looked at the life cycle of electric vehicles, starting with motorcycles, bicycles, and light vehicles, showing that electric vehicles have a lower impact on emissions during use, but their production has at least the same impact as a conventional vehicle [19]. In addition, the end-of-life of electric vehicles can have a greater impact due to the complexity of the process of dismantling and recycling batteries. The use of electric vehicles can also lead to increased energy consumption and environmental burden if they largely replace the use of conventional bicycles or public transport [19].

Finally, a successful transition from traditional to renewable energy sources can help mitigate climate change and regional development. Yang et al. [19] established a long-term energy replacement planning system to study the environmental and socio-economic impacts of renewable energy development by forecasting energy consumption and associated GHG emissions in all industries in the period 2016-2050. year. The research results showed that city emissions would peak in 2030 under the integrated scenario, with a 13.23% reduction in energy consumption compared to the traditional energy scenario. Compared to traditional energy sources, renewable energy sources have shown a competitive advantage in terms of GHG emission reduction, employment opportunities and economic costs.

3 DISCUSSION AND CONCLUSION

The implementation of measures related to the control of transport demand must basically include the control of the construction of new infrastructure facilities. So, in other words, it is not enough to build even more infrastructure and thus solve traffic problems. Many practical examples and analyzes in the world have shown that the traffic problem was not solved in such a way. It is necessary to harmonize the mode of transport with the existing infrastructure. On the other hand, a different choice of modes of transportation significantly contributes to increasing the sustainability of transport. In this sense, it is necessary to make inefficient modes of transportation less attractive, and to give priority to more efficient and sustainable modes of transportation.

Charging for the use of roads, especially in large cities, i.e. in their central parts, is also one of the measures that has proven to be very useful when it comes to encouraging sustainable traffic and transport. Furthermore, ITS applications play an indispensable role in improving the quality of services and integrating different public transport systems and services. ITS includes a wide range of different technologies and their application in terms of sustainable development is practically necessary, especially considering the development of new technologies for more efficient traffic data collection.

The organization and management of emissions reduction is the area with the greatest potential for energy savings and the greatest opportunities among all modern ways of reducing emissions. Technical measures to reduce emissions mainly include: the development of energy-saving and environmentally friendly vehicles, the adoption of new energy-saving processes, new technologies, new equipment and new materials in the transport industry, or the forced elimination of high-consumption and low-efficiency means of transport.

The development of electric vehicles can also contribute to the sustainable development of transport, although previous research has not fully confirmed such a thesis, and this is primarily reflected in the problems of pollution and consumption of non-renewable resources during the production of energy for electric vehicles, as well as problems related to the storage of waste materials.

Finally, based on a comprehensive analysis, it is possible to summarize the measures that have the greatest potential for achieving the best results when it comes to supporting the realization of the concept of sustainable transport:

- Control of transport demand;
- Promotion of sustainable modes of transport;
- Charging for the use of central city zones;
- Integration of ITS.

Based on the literature analysis, three large groups were singled out, i.e. types of measures that can significantly influence the establishment of sustainable mobility. The following Table 1 shows the types of technologies with their advantages and disadvantages, as well as possible areas of application.

According to the European Commission, i.e. the Strategy for sustainable and smart mobility - directing European transport towards the future [20], several strategic goals have been recognized that must be achieved. The strategy estimates that by 2050, gas emissions from transport can be reduced by 90%. In this regard, the European Commission has defined the key stages of this strategy for achieving the goals:

By 2030

- At least 30 million vehicles with zero emissions will be in use on European roads
- 100 European cities will be climate neutral
- High-speed rail traffic will double
- Group transport of passengers on distances shorter than 500 km will be climate neutral
- Automated mobility will be widely used
- Vessels with zero emissions will be ready for the market by 2035
- Large passenger and transport aircrafts with zero emissions will be ready for use;

By 2050

- Almost all cars, vans, buses and heavy goods vehicles will be emission-free
- Rail transport will double
- High-speed rail traffic will triple
- The TEN-T network will be fully equipped for sustainable transport.

The previously described goals can be achieved with the help of precisely defined 10 key strategic directions, namely:

- Encouraging wider use of vehicles with zero emissions, renewable fuels and related infrastructure;
- Airports with zero emissions;
- Sustainable and healthier city and intercity mobility;
- Greening of cargo transportation;
- Determining the price of carbon;
- Realization of connected and automated multimodal mobility;
- Innovations, data and AI in transport;
- Strengthening the single market;
- Fair mobility for all;
- Increasing traffic safety.

As can be seen, the identified advantageous technologies are fully in line with the strategic goals defined by the European Commission, and their application can quite logically be aligned with the key stages of achieving the goals. This is a particularly important fact for the less powerful EU states, as well as for the countries of Eastern and South-Eastern Europe, which are quite lagging in formulating goals and implementing measures and are mostly in the “waiting line” for admission to the EU.

Transportation shapes our lifestyles and underpins everything we do - the way people travel to work or for leisure, how businesses send employees to contact customers or partners, and how businesses deliver their products to distribution centers. Our lives and livelihoods depend on mobility. Access to mobility, like access to financial services, can be treated as a public good that helps organize other markets. Therefore, mobility is perceived as a critical factor of development, thus justifying large allocations for the transport sector. However, the prevailing system of global mobility is clearly unsustainable. The path to sustainability is a complex and long-term process because it requires a change in the thinking and behavior of all social actors, i.e. the understanding that the impact of development on environmental protection is as important as the economic one, whereby the attitude towards the environment should be set in such a way as to go ahead of regulatory norms, because it is the only way to meet future regulations, standards and requirements, with the least costs.

Table 1: A summary of potentially good technologies

Type of technology	Advantages	Disadvantages	Area of implementation
Control of transport demand	By reducing the capacity, the number of vehicles that travel every day is also reduced, and thus the emission of harmful gases is also reduced. Land use planning successfully directs flows along desired paths.	A reduction in capacity has the effect of reducing throughput and service levels.	Roads with high traffic load, i.e. high flow. Constant traffic jams can discourage car driving.
Modal choice	By choosing means of transport such as buses, trains, bicycles or scooters, current pollution is reduced.	A lower level of comfort when traveling by bus or train. Higher levels of pollution in the production of electric vehicles, consumption of resources in the production of energy and problems in recycling.	Large cities and city centers with heavy traffic during peak hours.
Road user charging	By charging for the use of roads, especially in the central areas of cities, drivers can be disincentivized when it comes to the daily use of cars in the city center.	Difficult or impossible access for less affluent users and abuse by more affluent users.	Central zones of big cities.

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