Development of a sustainable road transport system

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Abstract

Significant progress has been made recently in reducing the negative impact of vehicles on the environment. The said progress mainly involves the reduction of exhaust emissions through the advancement of powertrains, the use of alternative fuels, preservation of natural resources and waste minimisation through recycling of end-of-life vehicles as well as reduction of noise emission. The greatest progress, however, can be achieved by the appropriate design of transport systems particularly since most of the vehicles in use are fitted with conventional drive systems.

Significant change in the level of environment pollution from automotive sources can be made through the application of traffic organisation solutions such as the design of road infrastructure hubs or traffic flow management in urban areas. In contrast to many other measures, the optimisation of traffic flow organisation has a huge advantage because it does not affect exclusively the selected but all vehicles involved in the traffic flow.

This paper describes steps and basic guidelines related to the creation of a sustainable transport systems model. The model may be used to design environmentally-friendly transport systems that reduce negative environmental impact from vehicles and guarantee the efficient use of the road transport network.

Keywords: transport system, sustainable transport.

1 Introduction

A properly developed transport infrastructure is of paramount importance for the development of the economy and living status of the society. The evolution of

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transport networks is tightly related to the overall economic level. Economic development translates to a growing demand for transport services and a developed transport infrastructure facilitates investment projects and conducting economic activity both in industry and services. Transport network allows the flow of passengers and goods, which has impact on the trade and human mobility. Modern, developed transport networks are a prerequisite for international integration of regions and the participation in the process of globalization.

2 Negative impact of transport on the environment

We need to remember that the development of transport networks, hence an increased transport in all branches of industry generates a negative impact on the natural environment including human health. Transport in general accounts for around a third of all final energy consumption in the EU member countries and for more than a fifth of greenhouse gas emissions [1]. It is also responsible for a large share of urban air pollution as well as noise nuisance.

An ideal solution would be to create a sustainable transport system of high level of safety, pro-ecological and energy-efficient while still accommodating different branches of industry. We need to remember that currently, road transport has an 83% share in passenger transportation in the EU (fig. 1) and a 46% share in the transportation of goods (fig. 2) [2]. Hence, in the short term, measurable effects can be achieved by introducing the principles of sustainable road transport.

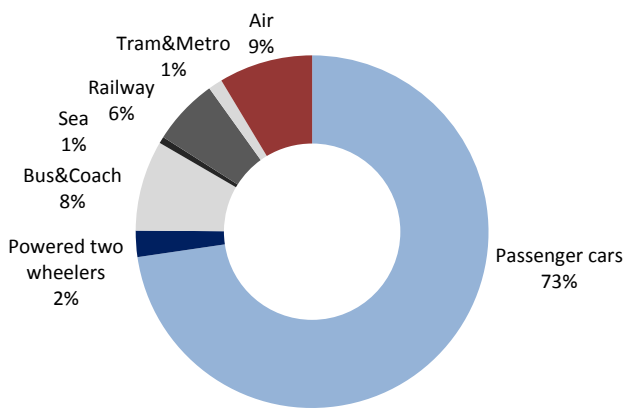
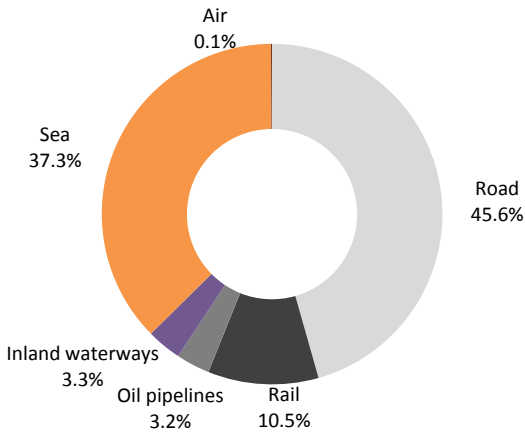


Figure 1: Modal distribution of passenger transport performance, EU-27 (% pkm) [2].



Road - national and international haulage by vehicles registered in the EU-27, Air and Sea - only domestic and intra-EU-27 transport

Figure 2: Modal distribution of goods transport performance, EU-27 (% tkm) [2].

The European Union has one of the most dense transport networks in the world, which results from the population density and the demand for transport services. According to the European Environment Agency approximately 25% of the EU population (except Romania and Bulgaria) live closer than 500 meters from a road with more than 3 million vehicles per year [3].

Road transport is the mode that consumes most energy, accounting for 26 % of the EU-27's total final energy consumption [2]. It remains also the mode that emits most greenhouse gases, contributing 93% of transport total, excluding extra-EU-27 aviation and maritime transport, as well as electrical traction for rail [2]. Furthermore, road transport has a serious impact on the landscape because it divides natural areas into small patches with serious consequences for animals and plants.

Despite the major progress that has been made in road safety, the death toll of transport accidents stands at upwards of 44 400 with the share of road transport of 97% in level of fatalities [2]. Noise from transport sources is also a significant environmental problem. World Health Organization indicates that at least 1 million healthy life years are lost every year in Europe as a result of noise from road traffic alone [4].

A significant progress has been made recently in reducing the negative impact of vehicles on the environment. This progress chiefly relates to the reduction of exhaust emissions through technological development of powertrains and the application of alternative fuels, reduction in the exploitation of natural resources, a reduction of the production of waste by recycling of end-of-life vehicles or a reduction of noise.

According to the European Automobile Manufacturers Association noise from passenger cars has been reduced by 90% since 1970 [5]. 85% of vehicle

components are recovered for use as spare parts, secondary raw materials or in energy production and from 2015 only 5% of end-of-life vehicle's weight will be landfilled. In road transport a greater reduction of exhaust emissions has been recorded than in other branches of transport. One car in the 1970s produced as many pollutant elements as 100 cars today [5]. The admissible limits of gaseous components and particulate matter set forth in the Euro 6 European standard are many times lower than the ones applicable to date. Nowadays particulate matter filters can reduce particulate emissions from diesel vehicles by over 99%. In 1995 80% of new cars emitted more than 161g/km of CO_2 and only 3% 140 g/km or less. In 2008 already 42% of new cars emitted less than 140g/km of CO_2 and only 31% more than 161 g/km (fig. 3). Due to stringent regulations, vehicle emissions are already cleaner than the surrounding air in some urban environments [5]. However, further efforts are planned to make emissions even cleaner, including the reduction of gases that contribute to the greenhouse effect.

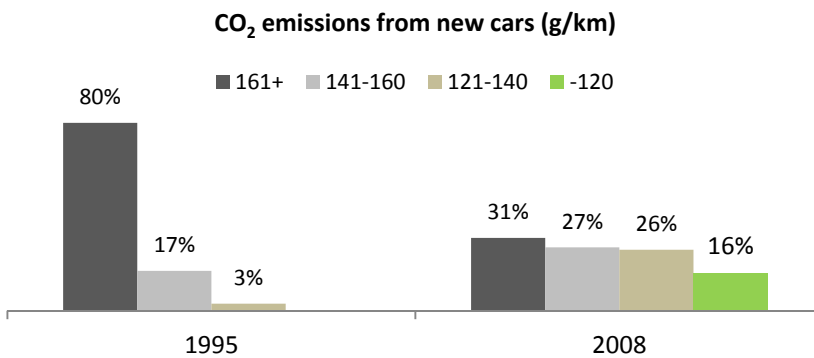


Figure 3: Trend in car CO_2 emissions [5].

Although new cars now emit significantly less CO2, road transport (passenger cars and commercial vehicles) remains one of the few sectors where emissions keep rising. This is due to the growth of freight transport, of vehicle ownership and of increased mileage [5]. Hence, the greatest progress can be achieved through an appropriate shaping of transport systems, particularly since more than 66% of the vehicles in use are vehicles of 5 years or more and the majority of all vehicles in use are fitted with conventional powertrains [6].

3 Design criteria of transport systems

By skilful traffic organization such as the application of design solutions for transport nodes in road infrastructure or management of the flow of vehicles in agglomerations we can generate significant changes in environment pollution from the automotive sources. Contrary to many other measures, optimal traffic organization has a great advantage as it influences not only the selected but all vehicles participating in the traffic.

Zanon and Verones [7] and Huang [8] draw our attention to proper planning and transport infrastructure management being a response to climatic changes. There is a necessity to create proper infrastructure capable of satisfying high demand, but the development of infrastructure and transport system in general must take into account the environmental and social factors. Chen *et al*. [9] stress that today no unified standards exist related to sustainable traffic development, and in the design of networks the most frequently used indexes (as sustainable development parameters) are related to traffic congestion, flow density and sometimes time fleet retention time. Szeto *et al*. [10] emphasize that the environmental sustainability is closely related to transportation, especially to the road network, and it is, therefore, important to take vehicle emissions into account when designing and managing road networks.

Sustainable development of transport network occurs in the following cases:

- Building of a transport network,
- Redesigning of a transport network, i.e. adaptation of transport nodes to the demand for transport services and integration with other branches of transport.

Decision problems related to the modeling of transport networks have already been widely discussed in literature. It should be noted however that the most frequently proposed criterion for the creation of a transport system is cost minimization. The cost of transport systems covers the costs of moving vehicles (fuel costs, costs of congestion related to excess traffic flow, road tolls), the costs of the construction of road infrastructure and the costs of maintenance of the elements of this infrastructure.

The function of cost minimization is most often understood as minimization of expenditure necessary to realize the transport task on the existing road network (costs of carriage related to the realization of the task) or the costs of construction of the infrastructure ensuring a given flow of vehicles. The selection of the function of cost minimization leads to a mono criterion optimization task. In literature we encounter works that propose multi-criteria approach to modeling of transport systems [11]. As partial criteria the following are assumed:

- Minimization of transport cost,
- Minimization of time of delivery,
- Maximization of amount of goods delivered,
- Maximization of the system reliability,
- Maximization of the transport service safety,
- Minimization of unsatisfied demand.

A very fundamental, yet frequently neglected aspect of modeling of transport systems are the external costs of transport that should constitute an obligatory criterion in both the construction of infrastructure, its modernization and designing of vehicle traffic. The tools for modeling and evaluation of transport systems must consider such influence as toxic emissions, noise emission or landscape use.

The model taking the environmental aspects into account has been presented by Yin *et al*. [12]. The Authors established a bi-level model describing the relationships among housing allocation, traffic volume, and CO_2 emissions. At the lower level, the model achieves the user equilibrium condition of a transport system. At the upper level, it optimizes housing allocation to achieve minimum CO_2 emissions. Model relates to the optimization of transport demand, traffic density, and CO_2 emissions with an optimized housing development pattern in the city area.

4 A model of development of sustainable road transport

Due to legal, organizational, economic and now also environmental regulations the development of transport systems is a complex decision making problem. The complexity of this problem forces us to equip the decision makers with appropriate decision-support tools that will facilitate a diagnosis of the current state and allow taking an optimal decision according to the selected evaluation criterion with the existing limitations and boundary conditions.

The sequence of actions leading to the creation of a transport system can be as follows [13]:

1. Analysis of the existing transport system;
2. Determination of requirements for the new transport system;
3. Selection of transport combination.

The analysis of the existing system is the starting point for actions aiming at an improvement of the current situation. The analysis must include the current flows in the transport system, future demand for carriage of passengers and goods and the consequences of the functioning of the current system such as road congestion; noise emission; toxic emissions; accident statistics. In the next step we need to identify the objective that we intend to achieve e.g. by determining the level of admissible exhaust emissions at a given flow density of vehicles.

The selection of the transport combination covers the identification of admissible solutions for example such related to the modification of the traffic organization (new traffic nodes, modification of the traffic signaling, limits in vehicle flow of a given type on given roads) and the evaluation of the consequences of their implementation. At the final stage of the process a decision is made as to which solution is the best in terms of the decision maker expectations, i.e. maximizes the function of benefit at assumed limitations (for example financial).

Particularly difficult is the development of transport systems where the fundamental requirements for the new systems are environment related. Taking the environmental aspects into account limits the development of the road transport systems that somewhat naturally generate negative environmental impacts. The priority of the investors and decision makers is most often the maximization of the throughput of the new system at given limitations (related to the investment expenditure) or, possibly, building infrastructure at a minimum cost for a given network efficiency. Reducing negative impact of transport on the

environment either increases the capital expenditure for the construction of the system or limits the traffic, thus the system throughput. The complexity of such a decision problem requires a development of a decision-support tool for the best decision in terms of the configuration of a transport system meeting the assumed traffic throughput requirements but taking the environmental aspects into account at an acceptable level of capital expenditure. The decision-support tool in the said area may constitute a model of development of a pro-ecological transport system. Modeling plays an important role in the cognitive process enabling the exploration of the relations and processes in complex systems. Besides, modeling enables a simulation of the functioning of a system depending on the implemented modifications and system organization.

Currently, in Poznań and Warsaw Universities of Technology works have been carried out on the implementation of the model of development of a sustainable road transport for Polish transport network.

The model aims at performing the above-described actions related to the development of transport systems, particularly allowing an analysis of the existing state and providing a possibility of selecting of such transport organization that would reduce the environmental impacts at assumed economic effects.

The fundamental feature of the model is the reflection of the relations between the structure of the transport network with its parameters and the level of exhaust emissions generated by the means of transport. The implementation of the model will allow a simulation research of the assessment of the influence of decisions related to the development of road transport and legislation related to the functioning of road transport on the level of emissions (GHGs and toxic emission) and, at the same time on the congestion level and use of natural resources.

The effect of the model implementation will be the possibility of determination of the influence of transport node solutions and traffic organization on the actual level of exhaust emissions in road transport. The application of the model will lead to conclusions as to how the structure of the road transport flow in connection with the road transport infrastructure influence the environment pollution level. The measurable benefits will include in particular:

- The evaluation of the toxic emissions from road transport and emission dispersion on a local, regional and global (the whole system e.g. countrywide) scale;
- Optimization of the distribution of the traffic flow in the network (traffic organization models);
- Adaptation of the transport infrastructure models to the transport demand. That includes the problem of distribution of finances for modernization of the infrastructure elements necessary for the realization of tasks and a selection of the least environmentally impactful variant of the modernization of the transport infrastructure elements.

The creation of a model of sustainable road transport includes the following steps (fig. 4):

1. Mapping of the existing transport network

   The mapping of the existing transport network includes the mapping of the existing transport infrastructure on a selected area. The geographical area for the discussed model will cover the area of Poland in particular.

2. Determination of demand for transport services

   That includes the measurement of the traffic density and extrapolation of trends considering the social economic development as well as description of carriage tasks for both the carriage of goods and passengers.

3. Modeling of the traffic flow depending on the method of traffic organization (type of traffic signaling, types of intersections)

4. Measurement of actual exhaust gas emissions

   At this stage occurs the reflecting of the characteristics of the means of transport based on the exhaust emissions (CO_2, CO, HC, NO_x, PM). This reflection will take place based on research under actual traffic conditions of different means of transport, different ranges of average speeds and considering such factors as traffic intensity, method of traffic organization, road types (urban, extra urban, expressway) and technical infrastructure solutions.

5. Identification of the functional relations between the exhaust emissions and traffic parameters with the structure of the vehicle flows

6. Development of the mathematical model

   The mathematical model will contain a description of the relations between the parameters of the transport network, characteristics of the means of transport and the level of exhaust emissions (GHGs and toxic emission) resulting from the realization of transport needs. The model will include both the mono and multi criteria optimizations depending on the decision maker preference.

7. Computer implementation

   Following the implementation of the model in PTV VISUM computer software a practical use of the model as a decision making tool will become possible.

8. Simulation of the influences within the system and analysis of the results

Depending on the objective of the modeling at this stage an evaluation takes place of the existing pollution level from road transport in the analyzed transport system or a selection of the traffic organization that is the least nuisance to the natural environment.

The first five stages of the works are the preparation for proper modeling i.e. developing of a mathematical model and its computer implementation. Yet, the quality of the simulation results will directly depend on the quality of the collected data related to the distribution of traffic flow and toxic emissions as well as on identification of the functional relations.

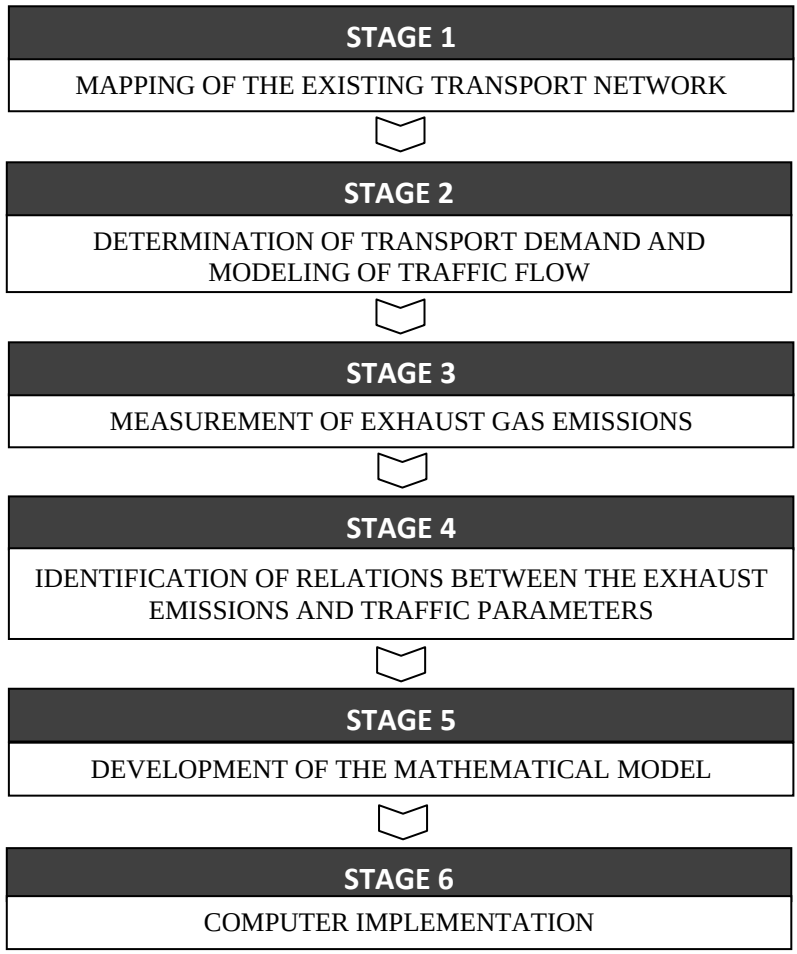


Figure 4: Stages of the works on the model of sustainable road transport.

At the stage of development of the mathematical model an important step will be the formalization of the notation of the criterion function (mono and multi criteria) and limitations including mutual relations and connections of the elements, requirements set for the transport network and the throughput (actual and planned) of the infrastructure. In mono criterion optimization the criterion function will be the minimization of the toxic emissions at assumed requirements related to the realization of transport tasks in the network. In multi criteria optimization partial optimization criteria will be distinguished. Apart from the environment related criterion, economic criterion will be taken into account of the cost of realization of the transport demand and, optionally, the criterion of time of realization of the carriage.

The model of development of a pro-ecological transport system will be implemented in PTV VISUM software and it will be possible to conduct research and simulation on the system in the macro scale e.g. covering a given region or even the whole country. The research to date focused mostly on the simulation and optimization of the transport systems in the micro scale i.e. selected intersections, nodes or transport routes, mostly within agglomerations.

5 Conclusions

Due to the influence of the transport sector on the quality of natural environment when designing transport systems we cannot neglect this negative impact. The model and results of the research based on the model presented in the paper are to serve as a decision-making tool in the development of a pro-ecological transport system accommodating the principles of sustainable transport development. Under current conditions, strategic decisions related to the development of transport networks are made chiefly based on the economic efficiency while the assessment of the environmental impact is largely intuitive. Contrary to other existing tools, this model will find its application in research on the relations between road transport and environment pollution countrywide (Poland in particular) and not only for individual subsystems such as individual intersections or selected agglomerations.

Hence, the currently conducted research on new solutions in vehicle technologies will be extended by the promotion of pro-ecological technical solutions of the infrastructure and organizational solutions of transport systems.

Acknowledgement

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