

# Scenario analyses for a sustainable transport system development

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**Abstract.** The paper presents selected aspects of developing sustainable transport system and provides the essential elements of scenario analysis procedure. The scenario analyse permits a background for setting approaches for the development of transport system. A major step towards reliable scenario analyses is establishing a system of criteria and indicators for evaluating the quality of analyse results. The appropriate system of criteria was proposed as a support for decision maker examining variants of transport system development. Scenario analyses require a tool for traffic distribution into transport network under different scenarios of its development. The large scale and detailed transport systems can be investigated with EMITRANSYS model – a new tool for multivariate distribution of traffic flow with regard to ecological, economic and technological criteria.

**Keywords:** ecology transport, scenario analysis, sustainable development of the transport system.

## 1. Introduction

Researchers exploring transport systems build variety of analytical models enabling examination of interaction between transport modes on different organizational levels and from different perspectives [7]. Selected models can be used to determine the priorities for national transport policy with regard to external costs off transport activity and costs of undesired effects of transport on the environment and human life. The external costs of transport and its harmful environmental impact are dependent not only on transport volumes and technical equipment, but also on the distribution of traffic into modes of transport within given network and expeditious switching it between the modes. Switching modes requires time, resources and appropriate regulations forcing or allowing it [7], [8]. Assessing plans of transport system development and elements of transport policy is a complex task that should have been solved at the level of greater detail.

As many authors point out, one of the key features of a modern approach to transport systems planning is the possibility of harmonious interaction or normal competition between different modes of transport [1], [4], [8], [12]. Since the transport system is based on graph structure it needs nodal elements for goods and passenger transition between modes and places to enter and leave the system like logistics hubs or freight handling facilities and passenger traffic centres. The infrastructure cannot be expanded endlessly not only because it is not environmentally friendly, but costs money, space and environmental degradation [4], [5], [7].

The quality of the offer of transport services provider's is related to the quality of transport system including network, infrastructure and organization. Transport system quality criteria are derived from transport policy strategies of individual operators, carriers and business entities which implement a specific transport processes under policy of the country [5], [7], [13].

Strategies of the development of transport system in a pro-ecological way must take into account the interests of all participants of transport process, as well as external bodies [8]. The first face is the level of harmful environmental impact (ecological aspect), and the second one is

the traffic safety (number of accidents and disasters) under planned costs and volumes. Thus, the development of transport modes is not only determined by new of better technologies and vehicles, but must take into account dynamic factors like just-in-time strategies, increasing need of mobility and ecological and safety constraints [7], [8], [13], [9], [11].

EMITRANSYS was prepared and tested as efficient support for multiobjective analyse of sustainable transport system development through scenario analysis.

## 2. Scenario analysis

### 2.1. Transport system development scenarios

Scenario analysis is the process of estimating the expected values of a criteria after a given period of time. Scenario analysis is commonly used in business analyses but when used to transport system development must be fitted to. The scenario method consists of a steps, first of which is a description of examined system and specifying factors affecting it, and then outlining the development possibilities and justification of given decision situation. As a result, many potential images of the future are obtained [16], [15], [17], [3], [14], [2].

Scenarios of the future situation in transport system include [16] overview of the state of system elements during established time under projected volumes of goods or passengers, interpretation of predicted phenomena, their consequences and planned investment expenditures.

The advantage of scenario analyse is possibility of examining effects of decisions in variable conditions and their risk characteristics. It is used for studies on effectiveness of the investment projects, changes in law regulations, behaviour of buyers and providers of transport services, changes in stock vehicles stock and volumes with different initial data [15].

Scenario planning of transport systems implemented into dedicated tool is an important help for identifying risk factors and areas of uncertainty related to the activity of a particular industries, organizations, enterprises or market segments.

### 2.2. Procedure for scenario analysis

The procedure for scenario analysis can be divided into three stages according to the systematic analysis: I – formulation of research objectives; II – building a model, III – evaluation of scenarios based on a multi-criterion evaluation. Especially the stage II is important and complex. Model must contain features of transport system common for all scenarios, be scalable and ensure a reasonable amount of certainty regarding the change in system elements.

An important step in the procedure is establishing a system of criteria in relation to decision maker goals. Assessing the positive and negative effects of each scenario with regard to uncertainty factors, boils down to formal comparative analysis of different scenarios of development according to the values of defined criteria. The course of research led to the aggregated criterion used for the evaluation of the variant of development scenario of the transport system of number  $sc$  defined as follows:

$$\forall sc \in SC,$$

$$W(v(sc)) = \sum_{crs \in CRS(sc)} q(crs) \left( \sum_{f(csr) \in F(csr)} q(csr, f(csr)) \cdot n(v(sc), csr, f(csr)) \right), \quad (1)$$

where:  $n(sc, csr, f(csr))$  – standardized assessment of the variant of design solution in  $sc$ th development scenario according to criterion  $f(csr)$  for  $csr$ th purpose;  $q(csr, f(csr))$  – validity of  $f(csr)$  criterion for  $csr$  purpose;  $q(crs)$  – validity of  $crs$  purpose.

### 3. Application of scenario analysis to develop a sustainable transport system - case study

The analyse of the development of a transport system of Poland was provided to demonstrate the method. The experiments were carried out in EMITRANSYS model [6] developed on the base of VISUM environment [10]. The model consists of the model of network and the model of demand for transport services. 4 035 nodes and 4 437 connections of railway network were mapped together with 14 863 nodes and 16 666 connections of road network. The demand was forecasted for the needs of freight transport and passenger transport. Both models were calibrated up to districts or significant municipalities.

Three scenarios of system development were analysed in EMITRANSYS:

$sc = 1$  – realistic, for which stable economic development is assumed, investment in transport infrastructure is moderated but stays on average level, number of vehicles with high EURO standards increases in the structure of rolling stock while low EURO standard vehicles withdraw.

$sc = 2$  – optimistic, for which a strong economic development is assumed, investments in transport infrastructure are high, a number of high EURO standard vehicles grows significantly together with a significant fall in the number of vehicles with lower EURO standards.

$sc = 3$  – pessimistic, for which a slow economic development is assumed, investments in transport infrastructure are far below what is really required, the number of vehicles with high EURO standards increases slowly while low EURO standard vehicles dominate in rolling stock.

The study was carried out for the year 2020. Mode switching possibilities are related to the accessibility and quality of nodal infrastructure. The analysis was based on the multifaceted forecast of the goods and passengers volumes. Demand for services in the passenger segment was divided into business trips, trips to school and work, and other trips. Demand for freight segment was determined for fourteen basic cargo groups [10]. Vehicles used for the transport were aggregated into five categories (buses, passenger cars with compression ignition and spark ignition, and trucks with compression ignition and spark ignition) and seven types of EURO norms (EURO 0 - EURO 6). The railway rolling stock was limited to diesel and electric traction with appropriate cars. The structure of vehicles was defined for each scenario.

The distribution of cargo and passenger traffic for 2020 made in EMITRANSYS model implemented in VISUM, as shown in Fig. 1. The transport work passenger transport was amounted to 715 466 582,5 pkm, while the transport work in freight transport is amounted to 264 294 491 tkm.

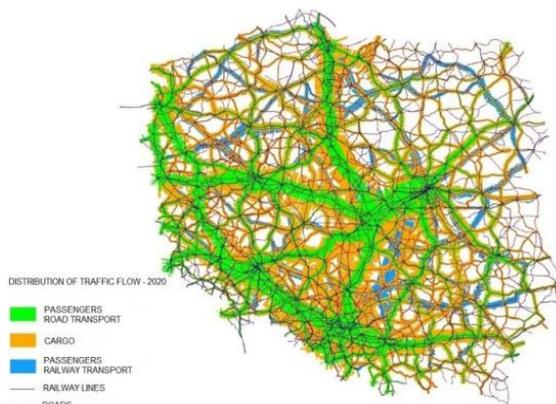


Fig. 1. Distribution of traffic flow for 2020. Source: [10]

The appropriate analyses of harmful emission were done on the base of own studies of exhaust emission in real traffic conditions. The emission of carbon monoxide (CO – red in figures), nitrogen oxides (NO<sub>x</sub> – green in figures) and hydrocarbons (HC - blue in figures) was estimated.

Total emission of particular compounds for the realistic scenario is shown in Fig. 2(a). Total

emission of HC was 80 998 641 g, of CO was 402 946 593 g, and of NO<sub>x</sub> was 1 413 797 760 g. Total emission for optimistic scenario is shown in Fig. 2(b). Total emission of HC was 77 617 900 g, of CO was 394 469 119 g, and of NO<sub>x</sub> was 1 382 488 645 g. The emission for pessimistic scenario is shown in Fig. 3. Total amount of emission of HC was 82 444 260 g, of CO was 404 924 785 g, and of NO<sub>x</sub> was 1 424 592 543 g.

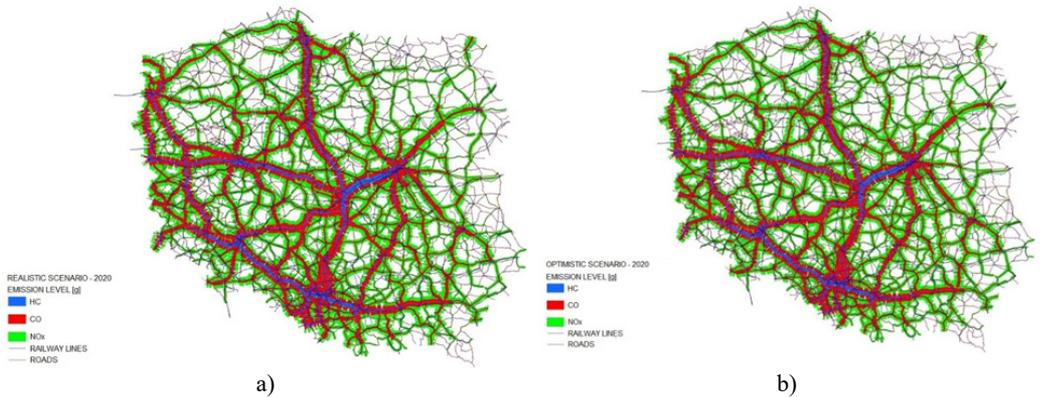


Fig. 2. Emission of harmful compounds for scenarios a) realistic b) optimistic. Source: [10]

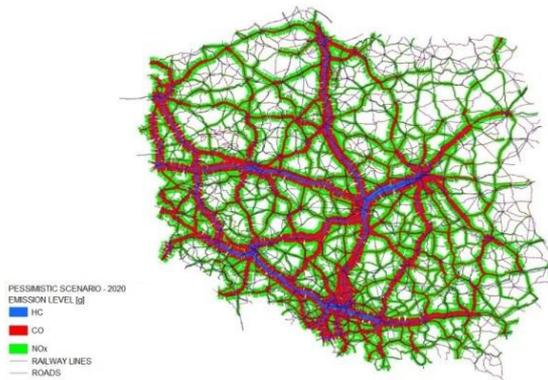


Fig. 3. Emission of harmful compounds for pessimistic scenario. Source: [10]

As it was expected, the smallest emission of harmful compounds was obtained for optimistic scenario, even under significant growth of demand for freight and passenger transport. High economic growth, more infrastructural investment and switching high-emission vehicles to low-emission foster better organization, higher traffic velocity and better access to the transport network. Better planning and high volumes justify using high capacity, low emission vehicles.

#### 4. Conclusions

EMITRANSYS model offers a possibility to perform multifaceted analyses of material and passengers flow in transport network. It is a complex tool set for analysing scenarios of transport system development under different economic, technological and environmental criteria. Alternative traffic distributions according to different development scenarios can be analysed and evaluated on the required level of detail. Investment expenditures can change infrastructure and stock, while economic projections show the indicate the direction of changes in demand for transport services.

The model uses a set of partial criteria functions related to different aspects of transport activity. Each variant requires individual set of functions to reveal the objectives of decision maker.

Due to the diverse nature of the partial criteria functions represented by each participant in the decision-making process, it is difficult to obtain a satisfactory solution for each transport system user. Multi-criterion methods are used to assess the decision from the point of view of contrary criteria representing different expectations of users. The basic difficulty in the practical implementation of the multi-criteria objective function is that only in exceptional cases a mutual conformity of the partial functions of the criteria appears. In general, the inclusion into the multi-criteria mathematical programming model more than one criterion does not lead to the unequivocally best solution, i.e. one that would provide the optimum for all criteria at the same time.

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