



Decision Problems in Developing Proecological Transport System

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1. Introduction

Transport plays an important role for societies, economies and businesses. The functioning of these spheres of human activity is impossible without efficient and reliable transport systems for people and freights. At the same time, according to many studies, transport is one of the most significant sources of multifactorial environmental pollution, negatively affecting the health and lives of people and almost all elements of the ecosystems. The negative impact of transport, at the current level of its development, on the natural environment is related to (Merkisz et al. 2014):

- greenhouse gas emissions influencing climate change,
- emissions of air pollutants that adversely affect human health and natural environment,
- consuming valuable natural areas and cutting their continuity (fragmentation) with newly built technical infrastructure, contributing to the loss of biodiversity or anxiety of animals trapped in their locations,
- noise emission threatening human health,
- emission of water and soil pollution,
- emission of vibrations adversely affecting building substances and human health,
- traffic incidents,
- production of vehicles, exploitation materials and construction materials involving natural resources and human work.

In spite of actions constantly undertaken in designing, planning and organization, aimed at reducing the negative effects of transport (see Gołębiowski et al. 2013, Jachimowski et al. 2013), the continuous increase in transport volumes offsets desired proecological effects by increased transport work of both freight and passenger transport. Research (IOŚ 2011, Merkisz et al. 2014) show that road transport has the largest share in the overall emission of harmful compounds and noise to the environment (Jacyna et al. 2017). The continuing advantage of the road transport makes difficult achieving so much needed changes in the field of environmental protection. Switching between the modes will solve the problem until the right infrastructure is created and organized. Also, the European Commission pays particular attention to the need for sustainable development of environmentally friendly transport. Directive 2004/107/EC provides the framework for the control of ambient concentrations of air pollution in the EU. It also provides control of emissions from vehicles, improving fuel quality and promoting and integrating environmental protection requirements into the transport and energy sector.

Considering the above, it can be concluded that transport satisfying human needs is a "necessary evil" so the trade-off between social and economic development and natural environment protection needs new arguments on the environment side. In the consistency it is justified to search for new technical and organizational solutions for transport to limit its negative impact on the environment. In addition, due to the current economic conditions and forecasted growth, it is justified to develop legislative solutions affecting the attitude of transport service providers and transport users.

Simulation models seems to be the right tools to support the planning and developing proecological solutions in transport, but modelling the development of large and complex proecological transport systems is a multi-faceted issue including (Jacyna & Wasiak 2014, Jacyna et al. 2014b):

- the needs and preferences of transport services purchasers,
- the sensitivity to changes in the transport system of clients,
- technical potential of transport service providers, including the possibility and willingness of implementing environmentally friendly solutions,
- the condition of transport infrastructure and vehicles of different modes, as well as investment opportunities and needs in this respect,

- solutions in the field of traffic organization in individual regions,
- transport policy including ecological conditions of transport system development,
- negative impact of transport on the natural environment and quality of life (including health) and the possibility of its reduction.

Planning of the development of national transport systems with regard to the proecological aspects of different nature is usually referred as *shaping a sustainable transport system* (Ambroziak et al. 2013, Chi-queto & Mackett 1995, Colvile et al. 2001, Gołębiowski et al. 2013, Jacyna & Wasiak 2014, Jacyna et al. 2014a, Jacyna-Gołda et al. 2014, Vaitiekūnas & Banaitytė 2007). Therefore, shaping a sustainable transport system is associated not only with the implementation of operational objectives of the transport policy, but also with ecological goals concerning, among others, air, soil and water pollution, noise or vibrations emitted by means of transport and good of animals.

Considering the above, the main decision-making problems of shaping a pro-ecological transport system can be listed (Jacyna et al 2014a, Jacyna et al. 2015, Korzhenevych et al. 2014):

- selection of mechanisms for internalizing external costs that effectively affect the behaviour of transport services purchasers,
- creation of zero emission zones or low emission zones in urban agglomerations,
- introduction of emission limits for different classes of harmful compounds,
- introduction of low-emission means of transport and planning point emission sources (power plants),
- improvement of traffic flows.

Regardless of the type of decision problem in developing proecological transport system, the key issue remains the modelling of the impact of transport activity on the natural environment.

2. EMITRANSYS simulation model

2.1. General characteristics

One of the tools supporting conceptualizing and shaping proecological transport system is the simulation model EMITRANSYS developed by the research team from the Faculty of Transport, Warsaw University of Technology in cooperation with Poznan University of Technology in Poland. The model covers territory of Poland as a whole and enables research on the national transport system in macro-perspective, including road and rail modes, which are decisive in servicing land passenger and freight flows. The characteristic feature of the model is the possibility to include emissions of harmful compounds of exhaust gas from various road spark- and self-ignited vehicles. Emission characteristics were obtained by testing in real road conditions.

Pollution emission testing is a complex process and requires specialized tools. There are different methods of conducting tests, but the most general classification divides them into laboratory and in real condition tests (Franco et al. 2013, Jehlik 2008). Proposed simulation model includes the results of tests of the emissivity of road transport carried out in real conditions. Series of tests allowed to identify functional dependencies between the emissions of harmful exhaust compounds and the traffic parameters like speed and type of vehicles (capacity, EURO emission standard, type of fuel).

The EMITRANSYS model was implemented in the VISUM modelling environment, which additionally enables conducting many (standard for this tool) analysis of the impact of transport on the natural environment, including (Jacyna & Wasiak 2014):

- emission of air pollutants in accordance with the HBEFA method (The Handbook Emission Factors for Road Transport),
 - noise emission in accordance with the RLS-90 method (guidelines of the Federal Minister for Transport regarding noise reduction for roads),
- or taking into account other original models regarding the impact of transport on the environment.

The EMITRANSYS model consists of transport network, private and public transport modes as well as demand for passenger travel and demand for freight transport.

2.2. Model of transport network

Model of transport network is the fundamental element of EMITRANSYS model. At this moment road transport has the largest share in freight transport (about 83%) and passenger transport (about 66%) in Polish transport market. Rail transport takes the second place in this respect (about 13% share in freight transport and about 32% share in passenger transport) (GUS [Central Statistical Office of Poland] 2014). In line with this fact developed model includes information on the actual course of national and provincial roads, railway lines as well as basic characteristics of their sections. In order to build the model of transport network in EMITRANSYS, it was necessary to map the nodal and line infrastructure of road and railway modes as well as the availability of individual types and means of transport for system users (Figure 1). The model consists of:

- road and rail road sections,
- nodes representing ends or beginnings of segments, or connecting elements,
- nodes mapping essential elements of network (eg places where the characteristics of road change, places where traffic appears and disappears or is transformed),
- transport regions as well as public transportation nodes and stops,
- connections linking transport regions to the transport network and indicating nodes in which traffic flow units appear and disappear,
- turn relations defining possible directions of movement of traffic units of different types in particular transport nodes,
- public transport sections and lines with timetables.

Data inputted into EMITRANSYS model included road routes broken down into sections and nodes, chainage and length of sections, speed limits, load capacity, number of carriageways and lanes, technical road classes, types and parameters of vehicles admitted for traffic, directions of winds and the presence of sound-absorbing screens. In addition, for the purposes of calibrating the traffic model, results of the General Traffic Measurement (Jacyna & Wasiak 2014) were taken into account including: average daily traffic (ADT) and nominal hourly traffic volumes. Subsequently, sections of the railway network were characterized

by: railway line class, number of tracks, electrification, maximum speed for passenger and freight traffic, maximum permissible axle load for the locomotive, wagon and electric traction unit, track gauge, destination (passenger, freight, mixed traffic), traffic protection (type of rail traffic control devices), track node capacity, track group capacity.

In addition to the parameterization of the road and rail network, the model implements data on bus timetables for over-distances public transport and data on train timetables.

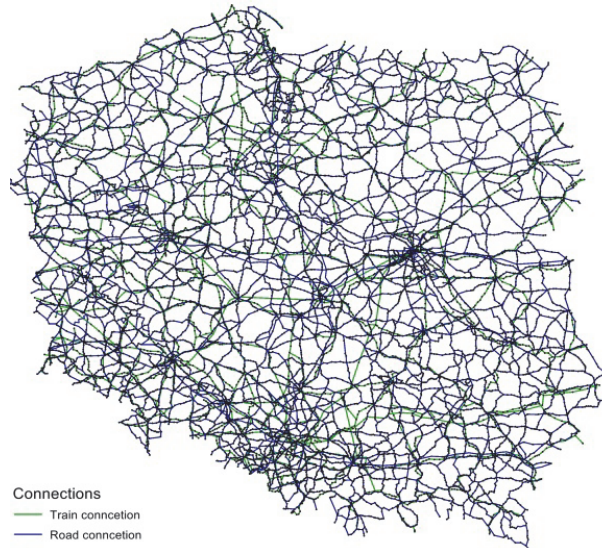


Fig. 1. Map of the transport network of Poland [Model EMITRANSYS in PTV Visum]

Rys. 1. Sieć transportowa w Polsce [Model EMITRANSYS w PTV Visum]

2.3. Representation of vehicles

The means of road transport for the carriage of passengers are divided into: mopeds and motorcycles ($st = 1$), passenger cars ($st = 2$), minibuses with 6 to 9 seats ($st = 3$) and buses with 16 to 45 seats ($st = 4$) and with more than 45 seats ($st = 5$). Vehicles for cargo transport include trucks with a wide range of capacities, ranging from delivery vans with a permissible gross weight (PGW) of 3.5 tones to heavy duty vehicles with a PGW up to 24 tonnes ($st = 6, \dots, st_d$).

In case of passenger rail transport, passenger carriages are classified according to the length of the wagon and class of compartments for travelers to those with a number of seats from 54 to 88. Carriers are pulled by electric and diesel locomotives or are organized into electric traction units. On other hand cargo is transported by wagons with a capacity of 20 to 65 tons were ($st = st_d + 1, \dots, ST$), depending on the transport form and the susceptibility of natural loads as well as the load class of the railway line.

Due to the different impact of particular transport means on the environment, the model additionally takes into account structure of transport means due to:

- type of engine and fuel: engines powered by gasoline, ON diesel oil, LPG propane-butane liquid gas, CNG compressed natural gas and a hybrid engines, $RS = \{1, 2, 3, 4, 5\}$
- European emission standard EURO, $NE = \{0, 1, 2, 3, 4, 5, 6\}$.

The model also includes functional relationships describing the emission levels of the following types of harmful substances:

- carbon oxide CO, $s = 1$,
- hydrocarbons HC, $s = 2$,
- nitric oxide NO, $s = 3$,
- nitrogen dioxide NO₂, $s = 4$,
- particle matters PM, $s = 5$,
- carbon dioxide CO₂, $s = 6$.

The unit emission factors for listed harmful substances were set on the basis of extensive research in real traffic conditions with on-board test equipment for different road segments, vehicle speeds and loads and engine heating characteristics. Emission characteristics were developed at Poznan University of Technology (Merkisz et al. (2014) [0]).

2.4. Demand model

The demand model for EMITRANSYS covers demand for passenger travels and freight transport between the areas of the network.

The traffic volume in transport network results from the demand for transport services. It is expressed in the amount of goods and number of passengers that in the given period are subjected to deliberate move-

ment. Taking into account the structure of transport means and their average occupancy rates, traffic volume is converted into the number of vehicles of particular types used for carriage. Therefore, the nature of transport tasks in EMITRANSYS simulation model is determined by: the type of transport (cargo or passenger), features or requirements of the transport subject, transport relations, as well as the type of vehicle.

Because the tool was developed in PTV Visum environment, freight transport was modelled in characteristic for this environment way – as s.c. *private transport* (timetables are not required). The segments of demand for freight transport are related to NST 2007 classification (Table 1).

Table 1. Relations between transport systems and segments of demand in freight transport in the EMITRANSYS

Tabela 1. Relacje uwzględniające popyt na poszczególne formy transportu towarowego w EMITRANSYS

System of transport	Mode	Demand segment	Demand matrix
Private transport	Freight transport: cargo trains, Trucks and lorries	Products of agriculture, hunting, forestry and fishing	ŁaRR
		Hard coal and lignite, oil and natural gas	ŁaWR
		Metal ores and other mining and quarrying products	ŁaRM
		Food products, beverages and tobacco products	ŁaPS
		Textiles and clothing, leather and leather products	ŁaWW
		Wood and paper, cork, paper and straw products	ŁaDP
		Coke, briquettes and refined petroleum products	ŁaKB
		Chemicals, synthetic fibers, rubber and plastic products	ŁaCS
		Products from other non-metallic raw materials	ŁaNm
		Metals, metal products without machinery and equipment	ŁaMW
		Machines, devices, electrical and electronic equipment	ŁaMU
		Transport equipment	ŁaST
		Furniture, other finished products	ŁaMP
Secondary raw materials, municipal waste	ŁaSW		

Source: Jachimowski et al. (2013)

Because the cargos can be carried out both by road and rail, the model mapped the possibility of trans-shipments between these modes. Specified places (existing road-railway transshipment infrastructure) are

adapted to pass the freight traffic (tons) from the road network to the railway network and vice versa.

Passenger transport has been modelled as private transport (for passenger cars) and public transport (inter-regional bus and train connections). Public transport requires specified timetables and communication lines. The model firstly distributes demand to communication lines and next pass the resulted traffic into networks. A passenger demand in the model was segmented according to travel motivations characteristics for transport feasibility studies (Table 2).

Table 2. Relations between transport systems and segments of demand in passenger transport in the EMITRANSYS model

Tabela 2. Relacje uwzględniające popyt na poszczególne formy transportu pasażerskiego w EMITRANSYS

System of transport	Mode		Demand segment	Demand matrix
Private transport	Passenger transport: cars		Traveling to work and school	PrPS
			Business purposes	PrBI
			Other purposes	PrIN
Public transport	Passenger transport: – EC, IC trains – IR trains – Regional trains (R) – Buses	Collective transport of people	Traveling to work and school	PuPS
			Business purposes	PuBI
			Other purposes	PuIN

Source: Jachimowski et al. (2013)

2.5. Selected criteria for distribution the traffic and assessment of the environmental impact of transport

For the purpose of distributing the traffic resulting from demand for transport to the transport network in PTV Visum, it is necessary to specify the distribution criteria. The criterion function is used to determine the resistance against the traffic motion in sections and nodes of transport network, turn relations and regions connections. Resistance can be equated with the distance travelled, time of movement and the cost of movement. For the sought-after distribution of traffic value of the resistance function in the transport network reaches the extreme (maximum or minimum) value.

EMITRANSYS uses emission of selected pollutants to the environment and the resulting external costs and/or noise emission as criteria for traffic distribution. The emission characteristics measured in real conditions were implemented as functional relations, in which the intensity of harmful compounds emission by types of vehicles depends on traffic velocity. Results of exemplary measurement tests are presented in Fig. 2 in the form of graph of changes in CO₂ emission intensity as a function of vehicle speed and acceleration

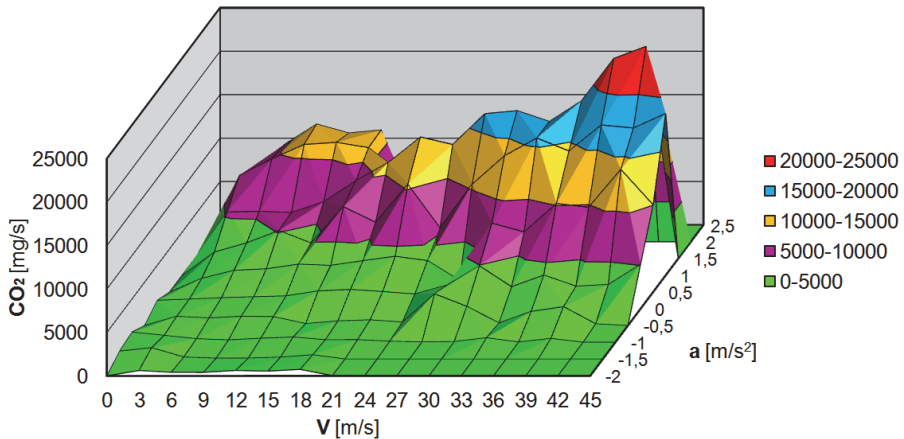


Fig. 2. CO₂ emissions as a function of instantaneous speed and acceleration of the vehicle (Jacyna et al. 2014a)

Rys. 2. Emisja CO₂ w zależności od prędkości i przyspieszenia pojazdu

The emission of noxious exhaust gases depends on the type of vehicle, its technical and ecological characteristics, age, condition and driving patterns. In addition, emission level depends on the traffic velocity resulting from traffic intensity and technical condition of infrastructure. Therefore, the formula for emission levels of harmful exhaust gases take into account cofactors depending on the section on which vehicles move and speed. In this perspective, the formula takes the following form (Jacyna et al., 2014):

$$\begin{aligned}
 & \forall s \in \mathbf{S} \quad \forall k \in \mathbf{K} \quad ES(s, k) = \\
 = & 3600 \cdot 10^{-6} \cdot \sum_{(a,b) \in \mathbf{E}} \sum_{p \in \mathbf{P}^{ab}} \sum_{st \in \mathbf{ST}(k)} \sum_{ne \in \mathbf{NE}} \sum_{rs \in \mathbf{RS}} xp(p, a, b, st, ne, rs) \cdot \text{(kg)} \quad (1) \\
 & \cdot \sum_{(i,i') \in \mathbf{LE}: st \in \mathbf{ST}(i, i') \wedge p \in \mathbf{P}_{ij}^{ab}} \frac{l(i, i')}{v(i, i')} \cdot em(s, st, ne, rs, i, i')
 \end{aligned}$$

where:

$ES(s, k)$ – total emission of harmful component of exhaust gas through the k -th transport subsystem (in kg);
 $xp(p, a, b, st, ne, rs)$ – number of s -th type vehicles moving on p -th road in relation (a, b) , which meet ne -th emission standard and are equipped with an engine of rs -th type (in vehicles),
 $l(i, i')$ – length of section (i, i') of transport network (in km),
 $v(i, i')$ – traffic flow velocity on section (i, i') (in km/h),
 $em(s, st, ne, rs, i, i')$ – unit emission of s -th harmful compound identified for st -th vehicle equipped with rs -th type of engine that meets ne -th emission standard and moves on section (i, i') of transport network determined per unit of distance (in mg/s/vehicle).

Including the dependence of emissions levels on the distance of transport (the shortest trips generate the largest unit emission), the emission is reformulated as follows:

$$\begin{aligned}
 & \forall s \in \mathbf{S} \quad \forall k \in \mathbf{K} \quad ES(s, k) = \\
 = & 3600 \cdot 10^{-6} \cdot \sum_{(a,b) \in \mathbf{E}} \sum_{p \in \mathbf{P}^{ab}} \sum_{st \in \mathbf{ST}(k)} \sum_{ne \in \mathbf{NE}} \sum_{rs \in \mathbf{RS}} xp(p, a, b, st, ne, rs) \cdot \text{(kg)} \quad (2) \\
 & \cdot \sum_{(i,i') \in \mathbf{LE}: st \in \mathbf{ST}(i, i') \wedge p \in \mathbf{P}_{ij}^{ab}} em(s, st, ne, rs, i, i') \frac{l(i, i')}{v(i, i')} \psi(s, st, ne, rs, p, a, b)
 \end{aligned}$$

where:

$\psi(s, st, ne, rs, p, a, b)$ – the influence of distance on unit volume of emission of s -th compound identified for vehicle of st -th type with rs -th type of engine meeting ne -th standard of emission and traveling in (a, b) relation on the p -th route,
 other symbols as in formula (1).

Formulas (1) or (2) combined with the volume of transport carried out by all transport subsystems allow to determine the rate of emission efficiency of transport work:

$$\forall s \in \mathbf{S} \quad \forall k \in \mathbf{K} \quad \varepsilon(s, k) = \frac{\sum_{rt \in \mathbf{RT}} q(rt, k) \cdot L(rt, k)}{ES(s, k)} \quad (\text{tkm/kg, paskm/kg}) \quad (3)$$

where:

$\varepsilon(s, k)$ – emission efficiency of transport work performed by k -th transport subsystem in respect of s -th compound (in tkm/t, paskm/t),

$q(rt, k)$ – the volume of transport carried out by k -th transport subsystem by rt -th type of transport (in tones or passengers),

$L(rt, k)$ – average transport distance under the k -th transport subsystem for rt -th transport type (in km),

other symbols as in formula (1).

3. An example of a model application

EMITRANSYS has been used for finding the emissions volumes from passenger and freight transport in Poland in respect of carbon oxides (CO), nitrogen oxides (NO_x) and hydrocarbons (HC). The time of transport was assumed as a criterion for traffic distribution to the transport network of Poland. Research was based on demand and structure of vehicles from 2015 as well as the demand and structure of vehicles according to forecasts for 2025. Due to the available data to calibrate the model, 2015 was considered as a base year.

Analyses included passenger cars (private vehicles), buses, delivery trucks and lorries and rail transport vehicles (used for passenger and cargo traffic distribution, but omitted in estimation of harmful compounds emission due to the different nature of energy production). On account of different emissivity from vehicles of various types data on the structure of vehicles in terms of emission standards (Euro 0 – Euro 6) and type of fuel were included. In this way, data on the emission of harmful exhaust gases from road vehicles used to transport cargo and passengers in the Polish transport system were obtained.

Functional relationships integrated in EMITRANSYS model enabled estimation of CO, NO_x and HC emission volumes by particular vehicle types, with a given emission standard and with a specific engine

type. After decomposing passenger and cargo streams onto transport network segments, the emission level of harmful exhaust compounds was estimated on particular sections of road network in Poland. Results obtained for 2015 and 2025 are shown in Figures 3-4.

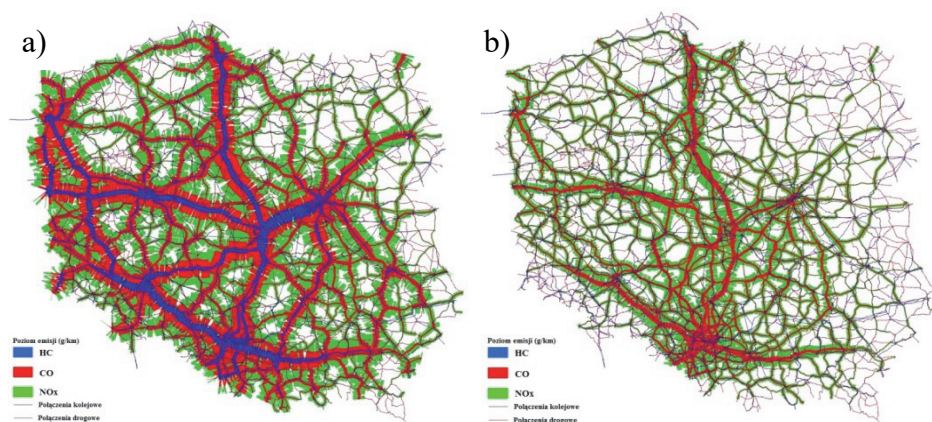


Fig. 3. The volume of emissions of subsequent compounds in 2015 by: a) passenger transport, b) freight transport [Model EMITRANSYS]

Rys. 3. Poziom emisja substancji szkodliwych w 2015 roku generowanych przez: a) transport pasażerski, b) transport towarowy

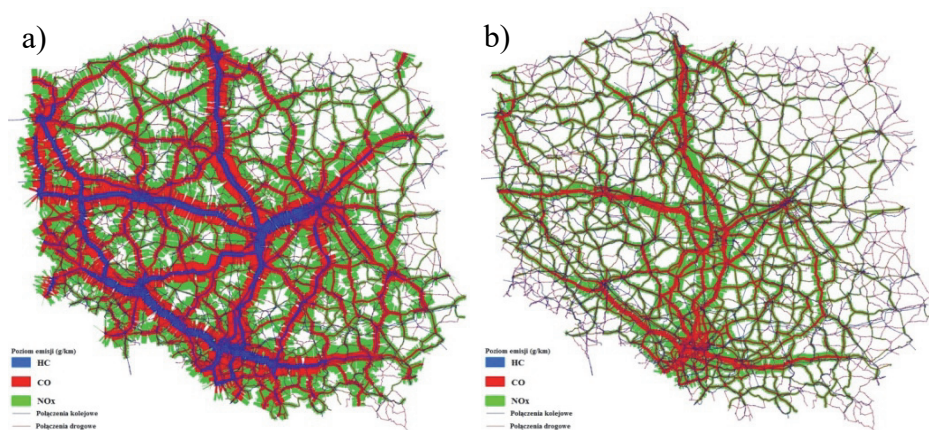


Fig. 4. The volume of emissions of subsequent compounds in 2025 by: a) passenger transport, b) freight transport [Model EMITRANSYS]

Rys. 4. Poziom emisja substancji szkodliwych w 2025 roku generowanych przez: a) transport pasażerski, b) transport towarowy

The projected increase in transport system emissivity for selected exhaust gas compounds in 2025 is presented in Table 3. These changes were estimated on the base of emissions expressed in g/km in relation to the base year 2015.

Table 3. Changes in emission of harmful exhaust gases from road transport in 2025 in relation to 2015

Tabela 3. Poziom emisji substancji szkodliwych w 2025 w odniesieniu do 2015

Exhaust gas compound	Increase in emissions compared to 2015
CO	29.277%
HC	26.062%
NO _x	27.405%

Obtained results indicate an increase in emissions of all harmful compounds from investigated transport system in 2025. This is due to the forecasted increase in demand for transport services, with assumed positive (pro-ecological), but not significant change in the structure of vehicles (emission standards) at once.

Importantly, the structure of vehicle stock adopted in studies did not assumed plausible introduction of future emission standards and significant development of zero-emission vehicle market (electric and hybrid drive). The last included standard was EURO 6 staying in force from 2014. It becomes clear that implementation of these changes is indispensable so that forecasted development of individual motorization and collective transport as well as freight transport was not coming along with the significantly increase of air pollution by road transport.

4. Conclusion

Due to some shortages in transport infrastructure development, and law issues, still a lot of potential is in the area of pro-ecological improvement of national transport system in Poland. As a consequence, apart from searching for low-emission drives, it is necessary to research the impact of construction and modernization of transport infrastructure elements as well as organizational changes in transport (including legislative solutions) on emissivity of harmful exhaust. One of the important conditions for the reliability of these researches is mapping the emissivity

of harmful exhaust gas compounds, so that it is close to the real situation noted on the road under operating conditions.

The EMITRANSYS simulation model described in the paper is an attempt to answer the questions posed by transport decision makers that deal with pro-ecological solutions. Both the mathematical model and its implementation in PTV VISUM are tools supporting decisions on the development of a pro-ecological transport system at the operational and strategic level. These decisions may concern, modernization of infrastructure, traffic reorganization or legislative constrains. Thanks to the implementation of a model, the simulative assessment of the impact of development decisions and legislative conditions on the pollution of the environment is possible. It takes also into account functional dependencies between technical and organizational consequences of these decisions and the level of emission of harmful exhaust gases.

At the same time, taking into account expected changes in the generic structure of vehicle stock in terms of their importance in meeting current and forecasted transport needs, the developed model enables identification of expected impact of road transport on the environment for various scenarios of the development of the transport system. It can be also used to identification noise issues – especially in smaller scale and support city logistics in steering traffic in city condition.

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Problemy decyzyjne kształtowania proekologicznego systemu transportowego

Streszczenie

Systemy transportowe mają kluczowe znaczenie dla funkcjonowania gospodarki oraz rozwoju społeczeństwa. Ze względu na stały wzrost skali przewozów, krytyczny stał się także sposób oddziaływania transportu na środowisko naturalne oraz zdrowie człowieka. Aspekty proekologiczne są więc niezbędnymi czynnikami projektowymi, które mają swoje odzwierciedlenie w konstrukcji pojazdów i infrastruktury transportowej, a także w mechanizmach planowania, organizacji i regulacji prawnej przewozów.

Szczególnie istotne jest zanieczyszczenie środowiska wynikające z wykorzystania mobilnych źródeł emisji szkodliwych związków spalin takich jak samochody ciężarowe i pasażerskie z silnikami spalinowymi wszystkich rodzajów, a także środki transportu kolejowego oraz innych gałęzi transportu. Zanieczyszczenie wynikające z wykorzystania silników spalinowych przekłada się na emisję szkodliwych składników spalin, a w szczególności tlenku węgla CO, węglowodorów HC, tlenku azotu NO, dwutlenku azotu, NO₂, cząstek stałych o różnych rozmiarach PM_x i dwutlenku węgla CO₂. Do tego dochodzi hałas i wibracje, zanieczyszczenie gleby i wód oraz fragmentacja środowiska.

Zmniejszanie tych negatywnych czynników przy jednoczesnym wzroście wielkości przewozów pasażerskich oraz towarowych wymaga opracowania nowych rodzajów środków transportu i metod organizacji transportu, które są przedmiotem tego artykułu.

W artykule podjęto tematykę proekologicznego kształtowania systemów transportowych kolejowo-drogowych realizujących przewozy pasażerskie oraz przewozy towarowe w skali kraju. Przedstawiono podstawowe czynniki wpływające na rozwój systemu transportowego i jego wpływu na środowisko, omówiono ich wpływ oraz sposoby modelowania.

Przedstawiono autorski model EMITRANSYS zbudowany w środowisku PTV VISUM, służący do modelowania działania i rozwoju systemów transportowych w dużej skali z uwzględnieniem emisji szkodliwych związków

spalin oraz hałasu. Omówiono cechy narzędzia i możliwość jego wykorzystania. Następnie przedstawiono składowe modelu: model sieci transportowej (drogowej i kolejowej) wraz z charakterystyką odcinków sieci i punktów węzłowych umożliwiających zmianę rodzaju transportu (komodalność) oraz rejonów, model popytu na przewozy towarowe oraz model popytu na przewozy pasażerskie. Model popytu na przewozy towarowe został przygotowany w oparciu o klasyfikację NST ładunków, zaś model popytu na przewozy pasażerskie został oparty o typowe dla studiów wykonalności w transporcie podziały motywacji podróży.

Siec transportowa kolejowa i drogowa działają równolegle i obciążane są tymi samymi potokami ruchu. Decyzja o wyborze rodzaju transportu oraz drogi w sieci (rozłożenie potoku ruchu) jest symulowana w PTV VISUM zgodnie z zadanym kryterium. W tym przypadku kryterium wielkości emisji przy jednoczesnej realizacji zadanych zadań przewozowych.

Następnie omówiono tabor realizujący przewozy w transporcie drogowym pasażerskim i towarowym oraz w transporcie kolejowym wraz z rodzajami silników, stosowanym paliwa i norm emisji EURO. Na tej podstawie omówiono formalny model matematyczny minimalizujący emisję szkodliwych związków spalin w funkcji rozłożenia potoku ruchu na sieć. Do kalibracji modelu wykorzystano wyniki Generalnego Pomiaru Ruchu (2015), aproksymowane na rok 2020.

Artykuł kończy się analizą przypadku dla sieci transportowej Polski oraz wnioskami.

Abstract

Transport systems are of key importance for functioning of the economy and development of society. Due to the constant increase in transport volumes, the impact of transport on the natural environment and human health has also become critical. The pro-ecological aspects are therefore indispensable design factors that reflected in the construction of vehicles and transport infrastructure as well as in the planning, organization and legal regulation of transport.

The environmental pollution resulting from mobile sources of harmful compounds of exhaust gases such as trucks and passenger cars with combustion engines of all kinds, as well as means of railway transport and other modes of transport are of particular importance. The pollution resulting from internal combustion engines use translates into the emission of harmful exhaust components, in particular carbon monoxide CO, hydrocarbons HC, nitrogen oxide NO, nitrogen dioxide, NO₂, particulates of various sizes PM_x and carbon dioxide CO₂. Additionally, the noise and vibration, soil and water pollution, and environmental fragmentation must be considered.

Reducing these negative factors while increasing the volume of passenger and freight transport requires development of new types of vehicles and methods of organization, which are the subject of this paper.

The paper discusses pro-ecological shaping of rail and road transport systems for passenger and freight transport in the scale of country. The basic factors influencing the development of transport system, their impact on the environment and way of modelling are discussed.

The original model EMITRANSYS developed in the PTV VISUM environment was presented. The model is used for modeling of operation and development of large-scale transport systems with regard to emission of harmful exhaust compounds and noise. The features of the tool and application possibilities are discussed. Next, the components of the model are presented: model of transport network (road and rail) along with the characteristics of network sections and nodal points enabling changing the type of transport (commodality) and regions, the demand model for freight transport and demand model for passenger transport. The demand model for freight transport was based on the NST classification of loads, and the demand model for passenger transport was based on the divisions of travel motivation typical for transport feasibility studies.

The railway and road transport network operate in parallel and are loaded with the same traffic flows. The decision about choosing the type of transport and the route in the network (distribution of the traffic flow) is simulated in PTV VISUM according to the given criterion. In this case, the criterion is the emission volume and simultaneous implementation of the set transport tasks.

Then, the rolling stock in passenger and freight road transport and rail transport, the types of engines, fuel used and EURO emission standards were discussed. On this basis, a formal mathematical model that minimizes the emission of harmful exhaust compounds as a function of the distribution of traffic flow to the network is discussed. The results of the General Movement Measurement (2015), approximated for 2020, were used to calibrate the model.

The article ends with an analysis of the case for the transport network of Poland and conclusions.

Słowa kluczowe:

Model EMITRANSYS, system transportowy, transport a środowisko, symulacja, emisja szkodliwych związków spalin

Keywords:

EMITRANSYS model, transport system, transport and environment, simulation, emission of harmful exhaust compounds