TECHNICAL AND ENVIRONMENTAL LIMITATIONS OF PRO-ECOLOGICAL TRANSPORT SYSTEM DESIGNING

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Abstract

Transport is one of the most environmentally destructive branches of economy. It contributes to environmental degradation and influences negatively on human live. It should therefore seek to reduce the negative impact on the environment. The paper presents many aspects of development of the national transport system. In article characterized technical constraints and environmental issues, which are applicable to the designing of pro-ecological transport system. Presented in it also indicators of the proposed design solution quality.

In shaping the pro-ecological system the special role plays environmental restrictions, because they mainly determine the quality of solutions in terms of minimizing the negative impact of transport on the environment. Technical factors are equally important, because they allow, among others, reducing the external costs of congestions and allow on the creation of transport tasks on the appropriate level. In particularly, EU requirements for sustainable development of the transport system, the components of the external costs arising from the sphere of transport, indicators and ecological limitations in designing of pro-ecological transport system, ecological limitations, technical limitations, indicators for assessing pro-ecological transport system are presented in the paper.

Keywords: *pro-ecological transport system, transport, air pollution, emission of exhaust fumes, EMITRANSYS*

1. Introduction

One of the commonly discussed problems on the world is environmental paradigms. One of them stating that environment is not a part of economy, but economy is a part of environment. On this basis can be concluded that it is necessary to apply environmentally friendly technological and organizational solutions. Due to the fact that transport is a branch of the national economy, the same must happen with its.

Analysing the transport system of the country it should be included all aspects influencing on its functioning. Complexity of the problem result from technological and financial limitations, ecological forcing and different perspectives of transport process participants maximizing their own profit. Analysing decision process in infrastructural investments it can be concluded that decision-maker uses to make an optimal decision not one, but many criteria simultaneously. Therefore, it is necessary to search for multicriteria and multiobjective methods supporting decision making in transport organization, in transport network modernization or in expansion.

It can be concluded that not only by demand for transport, technical condition of carriers, including the ability to carry out changes and technical condition of transport infrastructure and superstructure, but also development of the transport system is determined by traffic organization in particular sections, transport policy of a country or region and of course by environmental conditions.

Designing of European countries national transport systems is a consequence of transport needs forecasts and adaptation of transport infrastructure to the standards and requirements of European Union. The European Commission pays particular attention to the sustainable and

environmentally friendly transport [4]. Transport activities generate significant costs – external costs. A part of it is paid by the users, and the remaining charged to all taxpayers. This means that the external cost is not paid by subjects producing it (costs of means of transport utilization to provide transport services, which are not incurred by the buyer or the carrier).

Socio-economic development and international cooperation implies the increase of transport needs engaging different modes of transport, which are integral elements of transport system, so their development has certain effects in the rest. Transport policies of all EU countries pay special attention to the relationship between the road transport and other modes of transport especially with the rail transport. The research on the designing environmentally friendly transport system must be compatible with the recommendations of the EU Commission and international organizations like World Health Organization [21].

2. EU requirements for sustainable development of the transport system

Transport is one of the most environmentally destructive branches of economy except of some types of heavy industry or agriculture. It contributes to environmental degradation and impacts negatively on human live. In addition to this transport contributes to climate change, high congestion, accidents, air pollution and noxious noise. More than half of the air pollution comes from the sphere of transport. Transport is the only one of economy sector in EU which emission of greenhouse gases consequently increases since 1990. Until 2005 emission of greenhouse gases related to national transport in EU-15 countries increased by 26%. About 90% of that amount was produced by road transport.

Using fossil fuels in road transport to power vehicles generates air pollutants like: carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (including polycyclic aromatic hydrocarbons), particulate matter (PM) and heavy metals. According to Central Statistical Office in Poland road transport is responsible for more than 28% of total emission of nitrogen oxides (NO_x), more than 27% of carbon monoxide (CO) emissions and over 15% of dust matter (Fig. 1). In large urban areas, especially with well-developed and in centre heavily loaded by traffic, the share of road transport and public communication in emission is much larger. Statistics for European Union are (Fig. 2): 39% NO_x, almost 36% of CO, 17% of non-methane volatile organic compounds (NMVOCs), more than 17% of PM_{2.5} and almost 15% PM₁₀ come from the sphere of transport.

Fig. 1. The share of road transport in total emission of nitrogen oxides, carbon monoxide and dust matter in Poland source: own work based on [23]

Fig. 2. The share of transport in total emission of nitrogen oxides, carbon monoxide, non-methane volatile organic compounds and particulate matter in EU source: own work based on [22]

All other modes of transport have significantly smaller proportion of such emissions. On the other hand railway is considered generally as less harmful to the environment than other modes of land transport [7]. It also generates organic and inorganic pollution [15, 17] resulting mainly from

utilizing oils and coolants, using petroleum, metal ores, fertilizers and other chemicals. According to [2] railway areas are considered to be place of heavy metals high emission. The impact of rail transport on the environment is mostly from the noise and vibration (from locomotives), specific types of pollution, emission of dust, land consumption and partitioning natural environment. Harmful emission from railway transport in European Union is of the 1 to 3% of total emission [15], [20]. European Environment Agency reports that railway transport in EU is responsible for 1.2% of total emission of NO_x and 0.13% of NMVOCs [6]. Depending on the EU-member total national NO_x emission varies between 0.3% to 7.2% (more than 1% in Poland), and total NMVOCs emission varies between 0.04% to 0.93% (0.24% in Poland). Fig. 3 shows share of rail transport in total emission of nitrogen oxides and non-methane volatile organic compounds in European Union (EU) and in Poland (PL).

Fig. 3. The share of rail transport in total emission of nitrogen oxides and non-methane volatile organic compounds in European Union (EU) and in Poland (PL), source: own work based on [22] and [23]

The EU Directives imply the reduction of harmful emissions by 80-95% until 2050 (in comparison with 1990). While referring directly to the restrictions imposed on the transport sector, greenhouse gases emissions should be reduced by 20% until 2030 (in comparison with 2008).

One of the major trends in sustainable development pointed by OECD (Organization for Economic Co-operation and Development) and EU is to take over the flow of passengers by environmentally friendly modes of transport, like railways. Ecological and energetic advantages of railway transport give potential competitive advantage on transport market, but unfortunately at the moment there is no real possibility for taking over the part of the flow from road transport by railways because particular users decide about usefulness of transport service, which is primarily perceived by time of realization, price, comfort conditions and reliability of service [14].

European Union provides many regulations allowing for transport modernization to make it less harmful for the environment. The White Paper of European Commission (2001) presents a plan of creating unified European transport area to gain competitive and resource efficient transport system [5]. One of the ways to achieve pro-ecological transport system by reduction of carbon dioxide emission by 60%. This is one of the UE Transport Policy objective, that will be realized by shifting long and average passenger travel distance from road transport to other modes (especially rail), and reduction of external costs associated with road accidents.

Another document regulating pro-ecological trends in transport systems is Green Paper of UE (2007) about mobility in urban areas [9]. In 2008 European Commission presented a Communication about internalization of external costs of transport [8]. Internalization is the element contributing to sustainable development. Because external costs are incurred by not only transport users but also society together, Commission invite users to changes in their behaviour that which should contribute into reduction external costs.

Taking into account above sustainable development of pro-ecological transport system can:

- ensure safe access to transportation, not endangering human health and environment in equal

manner to the current and next generation,

- allow on effective operation with access to different means of transport for supporting economy and regional development,
- reduce emission and wastes that could be absorbed by grounds and
- use renewable resources in amounts that could be recreated.

In addition, we can say that very also is possibility of using non-renewable resources in amounts that could be replaced by renewable substitutes with minimal land consumption and noise.

3. The components of the external costs arising from the sphere of transport

The negative impact of transport on the environment is expressed in external costs, i.e. costs incurred by the surroundings as a result of the activities of some factor. External costs connected to transport, as was mentioned in points 1 and 2, result mostly from:

- accidents (i.e. costs of material damages, administrative proceedings, treatment and rehabilitation or production losses),
- air pollutions (i.e. costs of treatment and rehabilitation, property damage or losses in crops),
- climate change (i.e. costs of prevention and mitigation of climate change, the damage caused by the greenhouse effect),
- congestion (i.e. congestion costs, the costs of delays, losses of lost opportunities),
- noise (i.e. costs of nuisance, treatment and rehabilitation),
- nature and landscape (i.e. costs of the loss and fragmentation of habitats, reforestation and reclamation costs).

Through the traffic accident it should be understood unexpected external event, occurring at a specific time and place, without clear or intentional cause, but with a clear result. External costs of transport accidents are partly borne by the users of vehicles, but also by people not participating in the movement (i.e. pedestrians). This cost may be indirect (impossible to assign for a specific person) or direct (imputable to the specific person), and related to the health or life of persons who are involved in an accident or in connection with property damage caused by the same accident.

The costs of accidents consist of expenditures incurred by the operational services (police, fire brigade) and medical services granting aid at the accident scene, and then in hospitals where patients injuries were treated. Other costs relate to burials of victims, conducting criminal trials, maintenance of the convicts in prisons, and from payments of pensions and compensation to victims of accidents and their families. To the global costs of road accidents are also included losses incurred by the employer of the victims and the whole national economy because the victim of an accident also hide defects in the state budget resulting from the decrease in production and a decline in consumption. The last component in this kind of external cost is repairs of damage in the vehicles involved in accidents. In the case of accidents part of the cost is borne by the insurer. Because of that only part of the cost (not covered by insurance) shall be considered as external costs.

External costs relating to air pollution were analysed using bottom-up approach. Bottom-up approach consist of the analysis the physical route that is done by particular vehicle which allows on the assessment of various types of negative effects and risks associated with them. The basic components of the cost of air pollution caused by transport activities are:

- costs related to loss of health, there are negative effects on human health (mortality and morbidity) resulting from the inhalation of polluted air,
- material damages, there are negative effects on buildings associated with the degradation of structural materials from which these buildings were made,
- losses of crops, there are negative effects on ecosystems (crops, soil, forests, waterways, groundwater, etc.). caused by pollution, acidification and eutrophication of heavy metals.

Assessment of the effects of air pollution depends on:

- locations including population density,
- the sensitivity of the land (naturally valuable areas),
- emission levels (according to various modes of transport).

Currently, the most dangerous to health and life are considered pollution by particles $PM_{2.5}$ and PM_{10} .

Congestions as defined in [12] are called situations causing losses journey time. They arise from the shared use of infrastructure elements by many vehicles, which reduce the capacity of the road infrastructure with a higher volume of traffic. In the case of air and rail transport congestion costs resulting from losses of use of space by another operator (another train). Congestion negatively effects on the operation of the transport system:

- generating travel delays,
- reducing the quality of travel,
- worsening driving conditions.

External costs associated with the congestions are the sum of the costs of delays.

External costs related to traffic noise are difficult to determine. The differences in noise level, both in terms of geographical coverage and in terms of time of day, greatly hinder the unambiguous determination of the level of noise, for which is exposed population in a given area. Traffic noise, its range includes a place to live, work and moves several million of Polish citizens.

The noise has a negative impact on human health (i.e. hearing damage and hyperactivity, nervousness) and even their lives (one of the reasons causing a heart attack). External effects of noise are losses of productivity of people because of distraction, fatigue, lack of sleep, rest - lower productivity, deterioration of the quality of work and treatment and rehabilitation.

4. Indicators and ecological limitations in designing of pro-ecological transport system

4.1. Ecological limitations

Designing the transport system in terms of pro-ecological need to consider a number of limitations, including the ecological aspect. There are restrictions compatible with sustainable development strategy and objectives of both transport policy and other documents regulating the environmental aspects [5, 7-10, 18, 19, 21].

One of the ecological constraints used in the construction of pro-ecological transport system is the prohibition of entry to designated areas of vehicles that do not meet applicable emission standards EURO. In some countries (i.e., Germany) introduced environmental zones in city centres - so called. „Green Zone.” Vehicles are divided into categories according to the standards of emissions of harmful exhaust gases, and only those that meet the relevant standard shall have the right to enter the designated zone.

Other restriction, which can be identified, is access to the section of road by vehicle having the engine meets the specified standard exhaust. Assigns for each section of the transport network (car and train) the value of EURO standards, which vehicles equipped with suitable engines that meet them, can move.

4.2. Technical limitations

An important group of constraints in the construction of the national transport system are technical limitations. They include:

- used to perform the tasks of transport only the number of vehicles that is available,
- capacity of transport links should not be exceeded,
- ability to drive of vehicles on the appropriate links,
- total mass of the vehicle shall not exceed the permissible total weight applicable on a particular link,

- axle load of a vehicle shall not exceed the permissible axle load on a particular link,
- height of the vehicle shall not exceed the allowable height for the particular link,
- width of the vehicle shall not exceed the allowable width for the particular link,
- means of transport must be equal to the size of passenger / cargo flow to carry on particular link.

In addition to these constraints also are important limitations connected with the transport of traffic flow.

4.3. Indicators for assessing pro-ecological transport system

The quality of the solution is determined by the indicator of solution quality assessment. In the case of shaping pro-ecological transport system we could mention the following indicators:

- indicators concerning to the structure of transport,
- indicators for the evaluation of transport infrastructure in the aspect of pro-ecological.

In the first group of indicators can be distinguished two measures to assess the environmental friendliness of the transport. One of them is the participation rate of pro-ecological transport work in relation to the total transport work $\alpha^{PT}(r)$:

$$\forall k \in \mathbf{K} \quad \alpha^{PT}(r) = \frac{q(r, k)}{\sum_{r \in \mathbf{R}} q(r, k)} \cdot 100\%, \quad (1)$$

where:

r – mode of transport,

k – the type of transport,

$\alpha^{PT}(r)$ – the share of transport work mode of transport no. r in total transport work,

$q(r, k)$ – the volume of transport work mode of transport no. r in types of carriage no. k .

This indicator determines the share of transport work done by the transport which is environmentally friendly (mostly by rail) in transport work carried out by all modes of transport in general. On the basis of this indicator we will assess involvement of rail transport in the implementation of transport tasks in the transport system.

The second indicator allowing assessing whether the transport is pro-ecological is a participation rate of pro-ecological transport work in relation to the total transport work in the selected area $\alpha^{PTO}(r, ob)$:

$$\forall k \in \mathbf{K} \quad \forall ob \in \mathbf{OB} \quad \alpha^{PTO}(r, ob) = \frac{q(r, k, ob)}{\sum_{r \in \mathbf{R}} q(r, k, ob)} \cdot 100\%, \quad (2)$$

where:

ob – the type of area,

$\alpha^{PTO}(r, ob)$ – the share of transport work mode of transport no. r on the area no. ob in total transport work,

$q(r, k, ob)$ – the volume of transport work mode of transport no. r on the area no. ob , in types of carriage no. k .

This indicator determines the share of pro-ecological transport work (rail) for a certain area of the railway network (i.e.. single railway line, metropolitan) realized on this area of transport work in general. On the basis of this indicator we will assess the involvement of rail transport in the implementation of tasks on a selected area of the railway network.

In the second group of indicators, namely in the group of indicators to assess transport infrastructure in the aspect of pro-ecological we can identify six measures. The first indicator is the length of roads on protected areas by mode of transport $\eta I(r)$:

$$\forall r \in \mathbf{R} \quad \eta 1(r) = \frac{\sum_{(i,i') \in L^c} d(r,i,i')}{\sum_{(i,i') \in L} d(r,i,i')} \cdot 100\%, \quad (3)$$

where:

L^c – set of links, located in protected areas,

L – set of links in analysed transport system,

$d(r,i,i')$ – path length between vertices i and i' overcome with the use of mode of transport no. r .

This indicator determines the share of path length, which must travel all modes of a given branch on a protected area to accomplish the planned transport tasks in total distances travelled for each mode of transport in Poland in order to achieve a given plan. This will allow for the assessment of transport work done in protected areas in relation to the total volume of transport work.

Another measure of the system is indicator for assessing conditions for the development of intermodal transport $\eta 2^{IMOD}$:

$$\forall t \in \mathbf{T} \quad \eta 2^{IMOD} = \frac{LTI(t)}{LTI(t=t_0)} \cdot 100\%, \quad (4)$$

where:

t – time period number,

$LTI(t=t_0)$ – number of intermodal transport terminals in the period of time no. t_0 (adopted as the base year).

This indicator is characterized by the dynamics of changes in the number of intermodal transport terminals in relation to the base year. In the pro-ecological transport system for transporting cargo in long distances is used rail transport instead of road transport. However, rail transport due to the lower than in the case of road transport availability, must be assisted by cars. Therefore, it should be sought to increase the number of intermodal terminals in the transport network. This measure will allow the evaluation to improve the situation on the market of intermodal transport.

As already mentioned in the previous meter rail transport should be used to transport goods over long distances. So it is appropriate to determine the share of intermodal transport in the total transport work of cargo transport. One may use the participation rate of intermodal transport in the freight transport work $\beta^{IMOD}(r)$:

$$\forall r \in \mathbf{R} \quad \beta^{IMOD}(r) = \frac{\sum_{k \in K} q^{IMOD}(r,k)}{\sum_{k \in K} \sum_{r \in R} q(r,k)} \cdot 100\%, \quad (5)$$

where:

$q^{IMOD}(r,k)$ – the volume of intermodal transport work of transport no. r in types of carriage no. k .

Transportation by means of transport should be effective, i.e. mode of transport should be filled as much as possible. Then for the implementation of transport tasks need a smaller number of means of transport. Another measure of assessment of pro-ecological transport system is therefore a filling ratio of given vehicle type $\mu 1(st)$, which determines the average filling of the means of transport:

$$\forall st \in \mathbf{ST} \quad \mu 1(st) = \frac{\sum_{m(st)=1}^{l(st)} q(st,m(st))}{q^{st} l(st)} \cdot 100\%, \quad (6)$$

where:

$q(st,m(st))$ – filling $m(st)$ - no of means of transport no. st ,

q^{st} – capacity of type of means of transport no. st ,

$l(st)$ – number of vehicles of type of means of transport no. st .

Assessment should be subject to the rolling stock of the company. The gradual introduction of restrictions on entry of certain vehicles to city centres, vehicles that are in the enterprise (or owning by particular person) must meet certain emissions standards. It is important, therefore, to determine the ratio of the number of vehicles with enhanced environmental standards to all vehicles. One may use indicator of the number of vehicles on the Euro class not less than a given $\lambda(neu)$:

$$\forall neu \in NEU \quad \lambda(neu) = \frac{\sum_{st \in ST} l(st, neu)}{\sum_{neu \in NEU} \sum_{st \in ST} l(st, neu)} \cdot 100\%, \quad (7)$$

where:

neu – Euro class number,

$l(st, neu)$ – number of vehicles of type of means of transport no. st with Euro class no. neu .

On selected areas in Poland have been identified exceeding the permissible concentrations of the compounds emissions [1]. The developed solution should also be evaluated in terms of exceeding the acceptable level of emissions. This using indicator of is used to cross the limit value of compounds for the vehicle $\kappa(s, ob)$:

$$\forall ob \in OB \quad \forall s \in S$$

$$\kappa(s, ob) = \frac{\sum_{rsp \in RSP} \sum_{neu \in NEU} \sum_{st \in ST} \sum_{(i, i') \in L^{ob}} x(st, neu, rsp, i, i') em(s, st, neu, rsp)}{NEU(s, ob)} \cdot 100\%, \quad (8)$$

where:

$NEU(s, ob)$ – standard limit values of harmful compounds in a given area,

$em(s, st, neu, rsp)$ – emissions of no. s emitted by vehicle type no. st with Euro class no. neu and type of engine no. rsp ,

$x(st, neu, rsp, i, i')$ – number of vehicles of type no. st with Euro class no. neu and type of engine no. rsp passing along the conjunction (i, i') .

This measure is the ratio of the emission of given type harmful compound for vehicles with a given standard Euro and with given type of engine and fuel permissible standards, which is applicable in the given area.

5. Conclusions

Conducted considerations indicate that the designing of pro-ecological transport system is a multi-faceted process. Complexity of the problem result from technological and financial limitations, ecological forcing and different perspectives of transport process participants maximizing their own profit. One of the key elements is that the national transport system should be environmentally friendly.

Consequently it is necessary to search for multicriteria and multiobjective methods supporting decision making in transport organization, in transport network modernization or in expansion. In shaping the pro-ecological system the special role plays environmental restrictions, because they mainly determine the quality of solutions in terms of minimizing the negative impact of transport on the environment. Technical factors are equally important, because they allow, among others, to reduce the external costs of congestions and allow on the creation of transport tasks on the appropriate level.

The values of participation rates of pro-ecological transport work should achieve the highest possible value. It will have then meaning that analysed transport system is environmentally friendly. While the value of the indicator of transport work performed in protected areas should be

as small as possible. The values of participation rates of intermodal transport in realisation of transport tasks should achieve the highest possible value, because rail transport used over long distances very well affect that the transport is pro-ecological.

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