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INFLUENCE OF ENVIRONMENTAL SOLUTIONS ON ROAD CONSTRUCTION COSTS IN POLAND

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ABSTRACT: New transport routes irreversibly interfere with the environment. The construction of transport routes negatively affects the acoustic climate, landscape, surface waters, underground waters, air, soil, animate nature, causes fragmentation of habitats. Each one of these negative impacts can be effectively mitigated (with use of appropriate financial outlays) by properly prepared road design, taking into account the natural values, developed from the very beginning in cooperation with specialists in range of nature, acoustics, and environmental protection. The aim of the article is to assess the impact of targeted environmental solutions on the costs of road construction in Poland.

KEY WORDS: environmental aspects of road construction, road construction costs

Introduction

Road construction brings many social and economic benefits, mostly in range of accessibility and access, reduction of time waste and travel time savings, as well as reduction of traffic and road maintenance costs. The benefits of road construction and operation are indisputable, but attention is often paid mainly to their negative impact on their adjacent surrounding, i.e. environment and people's health and living conditions. Such negative impact is closely related to the traffic flow, type structure, and other traffic parameters. However, each negative impact can be effectively minimized. In Poland, the large-scale use of environmental protection methods and equipment in road engineering began at the end of the 20th century. At that time the environmental protection became very important in the whole process of preparing road investments, both in terms of regulations and use of effective and efficient methods and equipment. The regulations in force require road managers to meet the environmental quality standards (in most cases at the border of the road lane), which significantly impacts the investment costs.

The aim of the article is to assess the impact of selected targeted environmental solutions on the costs of road construction in Poland. Among the analysed solutions there are solutions which valuation can be made using the commonly accepted cost evaluation principles.

Realization of investment in terms of environmental protection law

Environmental protection is an activity which enables the preservation or restoration of the natural balance, which primarily consist in rational shaping of the environment and management of environmental resources in accordance with the principle of sustainable development, counteracting pollution and restoring the natural elements to their proper condition (Act of 27.04.2001, Environment protection law). "Environment Protection Law" in section VII "Environment protection in spatial management and during the execution of the investment" indicates the investor's obligations during the construction works, who while realizing the project should take into account the protection of the environment in the area of realization of works, in particular the protection of soil, greenery, natural landscape, and water relations. While realizing the construction works it is allowed to use and transform the natural elements only to the extent that is necessary in connection with realization of a specific investment. If it is not possible to protect the natural elements, actions should be taken to repair the damages caused, in

particular through the natural compensation. Therefore, the necessity to realize the environmental protection and to compensate for environmental damages is a statutory requirement.

Polish natural wealth, protected in 23 Polish national parks (8 of which have been declared the world biosphere reserves), 1,496 nature reserves, 123 landscape parks, and 385 protected landscape areas, is unique. The most beautiful corners of our country hide high cliffs (Wolin Island), migrating islands (estuary of Świna River), extraordinary rock formations (National Park of Góry Stołowe), the largest and best preserved peat bog complex in Europe (National Park of Biebrza). In the national parks 317 plant associations have been identified, out of a total number of 410 known in our country, including 20 endemic associations (unique for a given place or region), and about 180 plant species under species protection. In the parks one can also meet the representatives of all mammal species occurring in Poland, about 250 species of birds, and several thousand species of insects, as well as numerous representatives of reptiles, amphibia, and fish.

The road network, which has been built in recent years and which is included in the construction plan for the following years, also looks equally impressive in figures. By 2017, 1,639 km of motorways and 1,807 km of expressways were commissioned (compared to 266.8 km of motorways in 1994). Poland's location in the central part of Europe means the location of international transport routes on its territory, connecting the North with the South and the East with the West. Many of those roads go through the valuable natural areas, cross the animal migration routes and ecological corridors. Although the construction of roads poses a threat to the natural environment, it is important to try to route them at the design stage in such a way as to minimize this negative impact (Van der Ree, Smith, Grilo, 2015).

"Pro-environmental" approach to road design

The first stage, in which a "pro-environmental" approach to the subject of road construction is marked, is the road conceptual project. According to the traditional approach to the road design usually one design was prepared for one route of a new road section, and due to the reduction of construction costs such route was to be characterized by the shortest possible length, taking into account only the obvious terrain obstacles (mountains, rivers, lakes, dense buildings) (Wójcicki, 2018, p. 32). It was only the search for an optimal ecological course enforced by law that led to the consideration of several variants of the project (Act of 03.10.2008 On providing information about the environment and its protection, public participation in environmental pro-

tection, and environmental impact assessments), among which, apart from a few environmentally beneficial variants, there should be a zero variant (no investment). One of the best known and most commonly used methods of decision process support, based upon the selection of many alternative solutions, is the multi-criteria analysis.

With regard to road investments, it should lead to selection of the optimal variant in view of functional, technical, traffic, economic, environmental, and social criteria (Szafranko, 2014, p. 18).

Functional criteria include:
- length of the route of analyzed variant,
- number of connections (junctions, intersections) with other existing roads,
- inter-node distances,
- throughput of the route,
- traffic freedom level.

Among the technical criteria there are:
- number, length, or area of engineering objects,
- collisions with the technical infrastructure,
- technical solutions,
- geological and engineering conditions.

The traffic criteria include:
- travel time,
- road traffic safety.

In the group of economic criteria there are:
- investment costs,
- land purchase costs,
- annual maintenance costs,
- criteria of economic efficiency.

The social criteria include:
- number of houses to be demolished,
- number of buildings remaining in the zone of negative impact of the road,
- area of land to be expropriated,
- breach of spatial structures preventing links between the areas,
- compliance of investment with the existing spatial development plans,
- possibility of occurrence social conflict.

The environmental criteria include:
- length of crossing of high natural value areas,
- crossing of watercourses,
- crossing of migration routes for wild animals,
- area of natural habitats that may be degraded,
- amount of emissions of hazardous substances.

One of the most important criteria among presented above are the environmental criteria. The linear nature of road projects affects the scale and spatial range of environmental disturbances and changes. On one hand, the roads, especially of the higher technical classes, connect regions that are very diverse in terms of geographical location, landscape, climate, vegetation, and on the other, due to their linear arrangement, they cross the natural ecological systems and various spatial structures of environment over a multi-kilometre long distance. Such intersection of multi-spatial structures severely disrupts the physical, chemical, and biological processes, interfering with existing relationships, interdependencies, and dependencies in ecosystems. The impact of roads on the environment is permanent but short-term (during the road construction) in the road lane area and long-term and often very intense during the road operation.

The difficult, multi-aspect and multi-variant process of determining the road route affects the design costs, which have increased three times on the average (Wójcicki, 2018, p. 34). Such multidimensional assessment also influences the choice of route option, which is not always the most financially advantageous.

Environmental solutions in road construction and their impact on costs

Every road construction affects the environment and natural relations in a given area. Such impact is visible in relation to (Spellerberg, 1998, p. 317-333; siskom.waw.pl/nauka-srodowisko.htm):

- atmospheric air,
- surface of the earth,
- soil,
- surface waters,
- underground waters,
- acoustic climate,
- fauna and flora,
- landscape,
- cultural goods.

However, each of these negative impacts can be effectively minimized using legal and technical capabilities and several proven principles (siskom.waw.pl/naka-srodowisko.htm):

- use as far as possible the course of existing line objects (railway lines, high-voltage lines, roads of lower technical classes) in the field, which have already had a negative impact on the environment,

- for protection of areas surrounding roads against noise use the noise barriers, designed for noise reduction by reflecting or absorbing sound waves,
- build culverts and passageways for fauna protection which significantly minimize impact of road infrastructure on wildlife,
- maintain water relations in wetlands, especially by avoiding communication routes through peat bogs, warps, and other highly irrigated unstable soils,
- protect the landscape by building roads in such way that they fit into the natural landscape or complement it and do not constitute a strange element.

1) Noise protection

Road noise is currently one of the biggest sources of problems connected with environment protection. Both in Poland and in Europe, together with air pollution, it is one of the decisive factors adversely affecting human life and health. Such situation results from the rapid development of both the automotive industry and expansion of road network (Leśnikowska-Matusiak, Wnuk, 2014, p. 61). Construction of a new road causes deterioration of the acoustic climate in the area adjacent to the investment, at the same time relieving the parallel, existing roads and leading to the improvement of the acoustic climate around other sections of the road network. The most efficient method of limiting the effects of acoustic climate deterioration in the vicinity of roads is to choose an appropriate location of the road in the areas least sensitive to the effects of exceeding the allowable noise levels. In case of taking actions on an already existing communication route, the security measures can be applied in three zones:

1) between source and receiver,
2) in the immission area,
3) in the emission area (at the source).

Among the solutions improving the acoustic climate in areas adjacent to the transport routes there are (Buczek, 2013, p. 3):

- acoustic screens,
- road tunnels,
- earth embankments,
- quiet surfaces (only on road sections where speed of moving vehicles exceeds 50 km/h),
- appropriate traffic management,
- road location in an excavation,
- dense greenery,
- appropriate location of non-sensitive buildings.

All above methods differ in range of efficiency, implementation costs, and level of interference with the environment. Selection of method of preventing the excessive noise depends on such factors as: traffic flow and speed of vehicles, course of the road grade line, type structure of vehicles specifying the percentage of trucks, road surrounding, and distance from the source of noise to the object to be protected. The most popular protection methods against traffic noise include acoustic screens, which construction costs vary greatly. The place of application of the screen itself influences the value of works, especially in built-up areas, where costs resulting from difficulties in traffic arrangement during the installation of covers or costs related to their safe location in the vicinity of technical infrastructure should be taken into account in the implementation costs.

The first stage of screen construction is realization of foundation piles. Type of the chosen foundation depends mainly on the ground and water conditions and on the load capacity of designed screen. The most popular way to install the acoustic screens is to fix them to the drilled piles. Spacing, diameter, and length of used piles should be appropriate for the ground and water conditions and applied filling (screen load capacity). On muddy, peat soils cost of foundation may be even doubled. The final cost of foundation of the screen structure on piles consists mainly of the material costs (concrete, steel), equipment (special drilling rig), and contractor's labour costs (Sakowski, Zawieska, 2011, p. 105-134). That stage accounts for approximately 40% of the total cost of the construction task. Assembly of the load-bearing structure is the next stage of screen construction, which corresponds to about 10-15% of the construction costs. Usually it is done by anchoring the pole to the pile head. In most cases the galvanized steel sections are the main element of the supporting structure. It is important that the installation is carried out according to the design documentation and recommendations of the manufacturer of used panels. In order to avoid any contact between the elements of the screen load-bearing structure and the soil, in most cases ground beams are placed as the panel base between the poles. Although they do not have any significant acoustic properties, as the screen base they fulfil the stabilizing function for the whole structure. The last stage of screen construction is the installation of the filling, which is the most important part of the screen structure as it determines its acoustic properties. Screen fillings are available in form of panels, plates, or cassettes. There are several basic types of fillings available on the market, which differ in range of properties of used material and above all in costs, while the cost of filling, depending on its type, may account for 50% of the task. The price difference between fillings is very large, even 3÷3.5 times. In some cases costs of screen filling should be added to the costs of anti-graffiti coatings,

which make it easier to clean the screens or protect them from collisions with birds (screen printing on transparent screens), and the difference in their price, depending on the manufacturer, may even exceed 100%. Moreover, attention should also be paid to the extra charge for thermally toughened glass panels which refers to a test that reduces the risk of spontaneous cracks by 99%. At the customer's request screen fillings can be made by the manufacturer in different colours, which additionally increases the cost of 1 m^2 of the screen by approximately 10÷15% of the price. It should not be forgotten that beside the costs of building the screen the additional costs are incurred in connection with the operation and maintenance of the screen (ongoing repairs, cleaning the screens from traffic or vandalism contamination). Screens are usually cleaned once a year at a cost of about 2÷10 PLN/m^2 (net), while graffiti removal from screens is comparable to the cost of anti-graffiti coating.

Another efficient way to improve the acoustic climate (reducing the noise level even by up to 25 dB) is the construction of earth embankments. They are characterized by significant durability and positive impact on the natural environment, as well as reception by local residents and road users. Such solution is also characterized by high occupancy of the area comparing to other solutions concerning noise protection, which is connected with additional cost associated with the purchase of land for the investment. On the other hand, cost of constructing the earth embankment depends significantly on amount and quality of material required for its construction. It should also be noted that in terrestrial screens it is important to protect the steep slopes of the excavation against erosion, which has a decisive impact on costs. In Poland earth embankments are not very popular yet.

Another way to achieve the noise reduction reaching even 4÷5 dB is the appropriate selection of road pavement type, especially where no other measures can be applied (Bendtsen, Larsen, 2002; Bühlmann, Cosandey, Ziegler, 2012). Each new surface reduces the noise level by eliminating the irregularities, cavities, and deformations, and the additional action of introducing a mineral – asphalt aggregate of finer grain size into the mixture (noise reducing mixtures include mixtures of grain size of up to 8 mm) results in additional noise reduction. Such operation is associated with a slight increase in demand for asphalt, and consequently with increase of price of the mineral – asphalt mix.

2) Protection of fauna

With the development of road infrastructure the construction of animal crossings is becoming the main task for the protection of fauna. Construction of new transport routes causes irreversible changes in the natural environ-

ment (Van der Ree et al., 2011). The design of such objects should be aimed for minimization, as far as possible, of the impact of roads on wildlife populations. Taking into consideration very high costs associated with the construction of the crossings it is necessary to make every effort to ensure that the newly built objects have the highest possible efficiency, and this efficiency depends on many factors. First of all, already at the design stage it is necessary to recognize the animal population and its habits, and thus correctly locate the object in the field so that it is integrated into the migration routes of animals and habitat areas. Secondly, the density of objects should be appropriate for the importance of the areas to be crossed, and the crossing type selection should be closely related to the species of animals using it. In addition, the designed structures must have appropriate geometrical parameters, which in particular concerns the width of the passage and the distance between the traffic route and the area of the passage. Moreover, in order to allow all animal species to cross the obstacle, the adjacent passageways must be varied. Used construction solutions and materials should be environmentally friendly. The passages for animals are constructed using various technologies and materials: steel, concrete, plastics.

Cost of building the animal crossings is closely related to the prices of materials used for their construction, and the wide variety of materials available on the market allows investors to choose the design according to their needs and financial capabilities. Among all types and types of crossings, the largest and most expensive is the landscape crossing (upper large), intended for all animals (Kurek, 2011, p. 23). According to data of General Director for National Roads and Motorways, the 50-metre upper landscape crossing costs PLN 10 million on the average. However, less expensive upper passages for medium animals (PLN 4 million) and lower passages for large animals (PLN 5 million), as well as lower passages for medium animals (PLN 2 million) are used more often (probably most often). According to General Director for National Roads and Motorways the least expensive are culverts under the road for small animals and amphibians, which were cost-estimated for PLN 0.25 million (Wójcicki, 2018, p. 36).

3) Protection of water relations in wetlands

Wetlands are usually areas rich in specific, valuable vegetation on one hand and areas where the construction of transport routes entails increased costs resulting from the need to use very expensive engineering solutions on the other. Moreover, a road running in heavily irrigated areas may be during its use dangerous due to frequent fogs and the possibility of formation of glazed frost, which makes its maintenance much more expensive than roads running in standard ground and water conditions.

In some cases development of the road network forces communication routes through areas with unstable soils, which in their original state are not a suitable base for the foundation of engineering structures. However, there are many methods and specialized procedures and technologies for strengthening and improving weak substrates. Among them one can distinguish those which do not require introduction of additional materials into the ground and the reinforcement is based on a change in the structure of the ground, and those which require such materials. While using the reinforcement technologies with use of additional materials, susceptible, rigid, or partially susceptible vertical inclusions in weak-bearing layers in form of columns, piles, or other inclusions, exchange of virgin soil, or mixing the soil with binders are used.

Costs of strengthening the subsoil depend mainly on technology, required depth of reinforcement, and required technical parameters. The most economical methods are those requiring the introduction of energy only in the virgin soil medium in order to improve its compaction (however, their use is limited only to loose non-cohesive soils), or methods involving stabilization of virgin soil.

Relatively expensive, but sometimes necessary solutions include methods and technologies requiring use of specialized equipment and unusual, expensive materials.

A very expensive and least invasive solution for protection of water relations in wetlands is to lead the road on a flyover. Correct execution is almost a guarantee of maintaining water conditions in an almost intact state.

4) Protection of landscape

Construction of road infrastructure should not disturb the natural landscape, but should blend in and complement it aesthetically (De Montis et al., 2018, p. 313-324). This is emphasized already at the design stage. For instance, while designing animal crossings one should strive to integrate them into the surrounding landscape and use the natural terrain, which in many cases will not only improve the accessibility of structure but also the financial outlays (Styś, 2014, p. 55), in which the costs resulting from raising the level of the main roadways are usually forgotten.

Conclusions

Cost of the entire road investment depends to a large extent on the environmental costs, which in turn result from the statutory necessity to realize the environmental protection and compensate the environmental damage.

Among the "cost-intensive" measures enabling the preservation or restoration of the natural balance one should mention: multi-aspect and multi-variant process of determining the route of the road which affects the design costs, causing their average tripling, proper forming of the acoustic climate, implementation of ecological crossings and culverts, as well as measures to secure water relations in wetlands, and measures to protect the landscape.

Appropriate forming of the acoustic climate is currently one of the priority tasks in range of environmental protection. Recent years have been characterised by rapid technological development and quick urbanization of new areas, connected with development of roads and transport routes, which in turn leads to increase of environmental noise levels. The negative impact of noise on the environment and health has led to legislation solutions and development of methods allowing to minimize the effects of noise exposure. There are many ways to prevent the traffic noise, differing both in terms of effectiveness and costs of implementation. Such costs should absolutely be included in the costs of each road investment, as they have significant impact on increase of total road construction costs.

Construction of ecological crossings and culverts is a basic solution that minimizes the effect of ecological barrier and habitat fragmentation, and is in some cases characterized by exceptionally high investment outlays. For instance, according to data of General Director for National Roads and Motorways, the upper landscape crossing costs PLN 10 million on the average.

Wetlands being a community of marshy and marshy and meadow plants are very valuable from the natural point of view, but also very "cost-intensive" areas from the point of view of realization of linear transport investments due to the use of very expensive engineering solutions.

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