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ESTIMATION OF PRO-ECOLOGICAL APPROACH TO ROAD CONSTRUCTION IN ECONOMIC EFFICIENCY ASSESSMENT

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ABSTRACT: The development of the road network has a positive impact on a wide range of factors determining the efficient functioning of the state and the development of its regions. At the same time, it is an interference in environmental and agricultural space and a threat to landscape and cultural values. Protection of a very diversified natural environment means preservation, sustainable use, and restoration of resources, creations, and components of nature. Hence, the environmentally friendly design and construction of road investments should include passive and active environmental protection and compensation. All effective solutions from a wide range of "good practices" minimise or eliminate the negative environmental impacts. At the same time, all those activities leading to the creation of an environmentally friendly "green" road network are "economically" estimated in economic analyses. The main goal of this paper is to indicate the "simplified" valuation of the pro-ecological approach to road construction in the assessment of economic effectiveness on the example of the Polish section of the S8 expressway (especially within protected areas). The lack of valuation in the monetary value of potential benefits resulting from avoidance, prevention or mitigation, unfortunately, has an impact on the economic result of cost-benefit analysis.

KEYWORDS: assessment of the economic effectiveness of road and bridge projects, cost-benefit analysis, environmental protection, natural environment

 https://doi.org/10.34659/2020/4/32 JEL: P34, P56

Introduction

The development of the road network is an economic and social benefit, but also the possibility of permanent and irreversible environmental changes. That road network interferes with protected areas in many places, and the construction of each of the roads has a negative impact on the atmospheric air, ground surface, soil, surface and underground water system, acoustic climate, fauna and flora, landscape, and cultural assets in the surroundings of the investment (Spellerberg, 1998; Forman and Alexander, 1998; Trombulak and Frissell, 2000; Seiler, 2003; Van der Ree, Smith, Grilo, 2015).

Making investment decisions in such range depends on the results of the cost-benefit analysis, which, going beyond the financial analysis, allows to assess the economic benefits. However, in its assumptions, it encounters many difficulties (Hauer, 2011; Seiler, 2016; Daniels, 2019; Pilger, 2020) and problems with monetary valuation of difficult to evaluate the effects of investment execution, among which one can mention: avoiding losses as a result of investment execution or minimising the risk.

The paper presents the assessment of economic efficiency with "economically" priced pro-environmental approaches to road construction (within protected areas). A linear road investment consisting in the reconstruction of a section of the existing national road to the standards of an expressway, constituting a fragment (38.5 km long) of the I Trans-European Transport Corridor Warsaw – Kaunas – Riga – Tallinn – Helsinki (so-called Via Baltica), was used for the analysis. The presented section of the road runs along practically the entire length within the boundaries of the Biała Forest Nature 2000 area. The economic efficiency of the project was assessed, taking into account the necessary environmental safeguards. The case of a lack of intentional environmental solutions has also been analysed, which has allowed for the comparison of economic efficiency indicators (Johansson and Kriström, 2018).

Each linear road investment should generate social and economic benefits and interfere as little as possible with the surrounding environment and natural relationships. Air pollution, initially a local problem, has now developed into a global threat leading to irreversible changes. The pollution level depends on the traffic volume, its liquidity, and the share of heavy vehicles. The issue of over-regulatory pollution is primarily a problem of large urban agglomerations, which are characterised by equally large traffic volumes. In the case of extra-urban routes, the problem may only concern the area directly adjacent to the roads, mainly in environmentally valuable areas, in which case appropriate protection should be designed to protect the environment against fumes. Ways of reducing emissions and spreading exhaust gases include technical progress in engine design, increasing the fluidity of driving, limiting heavy vehicle traffic, proper shaping of the road surface, design of insulating green lanes, use of guards (artificial and green), and roads in tunnels.

The impact of roads on land surface and the soil is a direct occupation of land for roads causing their exclusion from agricultural production (Bohatkiewicz, 2008) and:

- pollution with heavy metal compounds (zinc, cadmium, copper, nickel, lead),
- acidification with sulphur and nitrogen compounds,
- salinating with winter road maintenance agents,
- change in hydrographic conditions,
- destruction of soil structure.

Among the methods of soil protection (as well as surface water and groundwater), there is an appropriate drainage system to prevent the ingress of harmful substances into the water and soil, and the use of planting of complex insulating greenery, consisting of appropriate species of shrubs, deciduous trees, and coniferous trees.

Road construction always means worsening of the acoustic climate in the vicinity of the investment and its improvement in the surroundings of relieved roads. 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. On the other hand, in the case of existing communication routes, the protection means may be located in the following zones: between the source and the receiver, in the zone of immission, in the area of emission (at the source). Among the solutions improving the acoustic climate in the areas adjacent to the traffic routes are (Buczek, 2013): acoustic screens, road tunnels, earth embankments, quiet pavements, proper traffic management, leading the road in a trench, compact dense greenery, proper location of insensitive buildings.

The most serious consequences resulting from the development of road infrastructure are the degradation and reduction of the availability of habitats and the prevention of free movement of animals – creating environmental barriers (Seiler and Bhardwaj, 2020). Those barriers may take the form of a physical barrier resulting from artificial changes in the terrain, the presence of fences or objects, or may become a psychophysical barrier resulting from vehicle traffic and related impacts (acoustic, light, and chemical emissions). Most ecological systems show a characteristic time lag (sometimes called extinction debt) between habitat degradation and the time when its ecological effects are fully detected (Tilman et al., 1994; Loehle and Li, 1996; Banks, 1997; Cowlishaw, 1999). The impact of roads is also characterised by such "delayed response" as different effects of roads on clumping and populations of wildlife – for example, habitat loss, reduced habitat quality, mortality, and reduced cohesion – usually manifest themselves at different rates. The most rapid effects are observed in the case of habitat loss, the lack of which causes population losses. Decreases in population due to habitat quality decline appear slightly later. On the other hand, changes in population mortality resulting from collisions of animals and vehicles are evaluated along with an increase in traffic accumulation of fatal accidents, and are observed in the context of impact on the whole population, after one or two generations since the road has been built (Forman et al., 2003). The effect of the road appears as a barrier to cohesion may only be observed after several generations, when local populations will be dying out.

All those negative impacts of roads should be mitigated by designing, installing, and building all possible solutions to bring us closer to an environmentally friendly "green" road network (Iuell et al., 2003; Trocmé et al., 2003; Clevenger and Huijser, 2009; Clevenger and Ford, 2010; Huijser and McGowen, 2010; Van der Grift et al., 2013). Measures and methods minimising road hazards are an essential component of a sustainable transport strategy (Morrall and McGuire, 2000; McGuire and Morrall, 2000). Among the basic ones is to be mentioned:

- speed limitation in areas of particular risk of collision with animals (active speed-limiting systems),
- reflective elements,
- protective fences for amphibians and small mammals, as well as large and medium-sized mammals,
- anti-glare shields,
- acoustic screens,
- protective and insulating planting of vegetation,
- animal walkways.

The development of road infrastructure is also a threat to landscape and cultural values, as each investment is a foreign element in a given area. In the areas of high natural value, special attention should be paid already at the design stage to integrating the road with the surrounding landscape (shaping it properly, minimising the cutting of ecosystems). The road grade line should be adapted to the topography of the surrounding area, and all engineering structures should be designed with almost architectural asceticism. The communication routes should be planted with greenery, including planting corresponding to native tree and shrub species.

Object and methodology

Linear road investment

To indicate a pro-ecological approach to the construction of Polish roads, an analysis of solutions (applied during the reconstruction of a section of the existing national road to expressway standards, constituting a fragment (38.5 km long) of the 1st Trans-European Transport Corridor Warsaw – Kaunas – Riga – Tallinn – Helsinki (so-called Via Baltica), has been prepared. The presented section of the road runs along practically the entire length within the boundaries of the Biała Forest Nature 2000 area (Special Protection Area PLB 140007). That area extends over several dozen kilometres on both the northern and southern side of the analysed investment. On the south side of the road, there are also three other Natura 2000 areas: Dolny Bug River Valley (Special Protection Area PLB 140001) together with Nadbużańska Ostoja (Special Habitat Protection Area PLH 140011) and Liwiec River Valley (Special Protection Area PLB 140002). Approximately 63.00% of the road runs through forests, 33.86% through agricultural areas, and 3.12% through built-up areas. The need to build an expressway was a response to the ever-increasing volume of traffic and the increase in the number of accidents (resulting from the volume and lack of safety improvement solutions). The project under consideration is among those which significantly affect the environment, and in particular, adversely affect its natural value. It is located in an area where there are no other forms of nature protection: national parks, landscape parks, nature reserves, nature monuments, documentation stands, ecological sites, and nature complexes. The road is a modern communication route providing communication facilities, but at the same time, it is also equipped with the necessary environmental protection. The route in this section has 15 viaducts, 7 bridges, and 3 footbridges. In this case, the structures allowing for collision-free movement of animals across the road and at the same time preventing an increase in animal mortality and mitigating habitat fragmentation are the lower passages for large animals (5 pcs.). Those passages are designed for wolves, elks, and deer, but may also be used by medium-sized animals such as roe deer, wild boar, and small animals. In addition to those 5 passages, there are 5 more passages integrated with bridges over watercourses, and 41 facilities for small animals. Drainage is provided by drainage ditches and culverts (11 reconstructed ones are at the same time the animal passages). The areas adjacent to the crossings have been separated from the environment by a development similar to the natural one. On the edge of some of the objects, structures were made to insulate visually and partly acoustically. Passages for small animals: reptiles, amphibians, and small amphibians, as well as rodents, are situated, if possible, at the locations of former passages. The modernised surface drainage system is supplemented by 26 retention, infiltration, and evaporation tanks (located in places that required by far the least interference with forest areas and at a distance from animal crossings), as well as cleaning devices – settling tanks and sandboxes (open ones of appropriate retention capacity, placed, among others, at outlets from road ditches). To reduce the acoustic nuisance, absorbing and reflecting acoustic screens have been made. As a result of a change in the regulations (which occurred during the investment), less than half of the proposed 14,089 m (72,616 m^2) of the area of noise protection was made. Moreover, the structures were planted with vines, which additionally made it possible to mask and incorporate them into the surrounding landscape. To prevent the accidental intrusion of migrating animals into the roads, practically the entire length the road has been protected with a fence (mesh with appropriate mesh size, hurdles for amphibians). To minimise the impact at the operation stage and in connection with the need to cut down trees for the entrusted task, lanes of insulating greenery have been made (10-15 m wide as far as possible in the field), as well as a number of compensatory plantings in the form of decorative and functional greenery, also making the forest denser.

Cost-benefit analysis and economic performance indicators

In Poland, the guidelines contained in two separate studies are used to assess the economic efficiency of road and bridge projects: the "Blue Book" (Blue Book, 2015), recommended for use in the case of investment projects in the transport sector, for which beneficiaries apply for financial aid from European Union funds and in the "Instructions for Assessing the Economic Effectiveness of Road and Bridge Undertakings", which make the detailed economic analyses dependent on the type of road, dividing them into communal, county and provincial (Instructions for economic efficiency assessment..., 2008). In the case of all projects, a cost-benefit analysis (CBA) method is adopted for the assessment of economic efficiency, taking into account the benefits of the users of the analysed investment and road costs (construction, repairs, maintenance, and all costs of works aimed at ensuring the safety of the road infrastructure in technical terms and its availability for daily operation, as well as preventing its degradation).

The basic stages of the cost-benefit analysis are (Drobniak, 2008; Foltyn-Zarychta, 2008): identification of all project costs and benefits, monetary valuation of all costs and benefits, discounting future net benefits, which makes it possible to include future costs and benefits in current prices and compare them with the investment outlay. The strength of the cost-benefit analysis is the inclusion not only of financial expenditures and receipts but also of social, economic, and environmental results. However, the effects in the economy, the local community, or the environment are difficult to evaluate; hence the advantage becomes at the same time the basic disadvantage of the cost-benefit analysis method.

The first step of the cost-benefit analysis, according to its idea, is to identify all costs and benefits related to the implementation and operation of the investment. Table 1 shows the classification of the main costs and benefits for road infrastructure investments.

Table 1. Main categories of economic costs and benefits for road infrastructure investments

Roads and bridges costs	Costs/benefits/savings for users and environment
Investment costs	Vehicle operating costs
Maintenance costs	Time costs of infrastructure users
	Costs of road accidents and victims
	Costs related to the emission of pollutants
	Climate change and noise costs ("Blue Book")

Source: author's work.

The economic assessment of projects involves the determination of the following indicators (Blue Book, 2015; Instructions for economic efficiency assessment..., 2008):

a) the economic net present value (ENPV), i.e., the difference in total discounted benefits and costs associated with the investment; that difference should be positive for economically efficient projects,
b) economic rate of return (ERR), which should exceed the assumed discount rate,
c) relation of discounted advantages to discounted costs (NB/NC), which should be higher than one.

The calculation of economic efficiency shall be carried out upon the basis of separate input data and parameters of the elements of the economic account, which include:

- traffic measurements, calculation of average daily traffic, and forecast of average daily traffic,
- travel speed,
- road costs,
- vehicle operating costs,
- costs of time in passenger transport and costs of time in freight transport,

- costs of road accidents,
- costs of toxic exhaust emissions,
- costs of users and the environment.

The sensitivity analysis is the supplementary stage in the assessment of road and bridge investments.

Results and their evaluation

The cost-benefit analysis is based upon the incremental method consisting of comparing the project scenario for the investment variant (WI) with the base scenario for the non-investment variant (W0 – without project).

To determine the indicators of the economic assessment for the investment task consisting in rebuilding the national road to the expressway standards (the required technical data are presented in table 2), the following assumptions have been made:

- reference period – 25 years (for road projects; from the start of construction),
- a year consists of 365 days.
- Recommended forms have been developed:
- traffic forecasts,
- road costs,
- operating costs of vehicles,
- costs of time in passenger transport,
- costs of time in freight transport,
- costs of road accidents,
- costs of toxic exhaust emissions,
- summary of the user and environmental costs,
- economic analysis of costs and benefits,
- economic values and indicators (table 3 – including the necessary environmental safeguards, table 4 – excluding the necessary environmental safeguards).

The forms include costs for both variants: W0 and WI. The road net costs and savings for users and the environment have been calculated for all years of the analysed period. In the analysed case, all necessary environmental safeguards were taken into account.

A similar procedure has been carried out assuming the absence of any environmental safeguards, where values and economic indicators are presented in table 4.

Table 2. Technical data of the national road rebuilt to the major road standards

No.	SPECIFICATION	UNIT	W0	WI
1	NATIONAL	-	ROAD	
2	SEGMENT LENGTH	km	38.5	
3	TERRAIN TYPE	-	FLAT	
4	ROAD TYPE	-	COUNTRY ROAD	
5	ROAD CLASS	-	S	
6	NUMBER OF ROADWAYS	pcs.	1	2
7	NUMBER OF ROADWAY LANES	pcs.	2	2
8	ROADWAY WIDTH	m	6.50	7.00
9	SHOULDER WIDTH	m	1.50	0.75
10	AVERAGE ALLOWABLE SPEED	km/h	90	120
11	PAVEMENT TECHNICAL CONDITION ACC. TO SOSN		B	A
12	BUS BAYS		yes	yes
13	TRAFFIC CHARACTER		ECONOMIC	
14	INVESTMENT NET COST	PLN	-	1,033,800,000.00
15	TRAFFIC CATEGORY	KR	6	6
16	BRIDGE OBJECTS, VIADUCTS AND FOOTBRIDGES	CONDITION	4	5

Source: author's work.

Table 3. Value and economic indices for the investment task consisting in rebuilding the national road to the expressway standards [thousands of PLN]

DESCRIPTION		VALUE OR INDEX FOR DISCOUNT RATE r			
		0.01	0.05	0.10	0.13216
NC	DISCOUNTED INVESTMENT NET COSTS	-1,045,909,172	-964,719,351	-893,437,757	-856,857,912
NB	DISCOUNTED NET ENVIRONMENTAL COST SAVINGS	3,844,466,393	2,176,258,231	1,192,791,556	856,857,912
ENPV	ECONOMIC NET PRESENT VALUE [-]	2,798,557,219	1,211,538,879	299,353,799	0
NB/NC	ADVANTAGES – COSTS INDEX [-]	3.68	2.26	1.34	1.00
EIRR	ECONOMIC INTERNAL RATE OF RETURN [%]	13.216			

Source: author's work.

Table 4. Value and economic indicators for the investment task consisting in the reconstruction of the national road to the expressway standards without taking the necessary environmental safeguards into account [PLN]

DESCRIPTION		VALUE OR INDEX FOR DISCOUNT RATE r			
		0.01	0.05	0.10	0.13407
NC	DISCOUNTED INVESTMENT NET COSTS	-977,805,001	-926,837,009	-873,447,672	-841,237,417
NB	DISCOUNTED NET ENVIRONMENTAL COST SAVINGS	3,844,466,393	2,176,258,231	1,192,791,556	841,237,417
ENPV	ECONOMIC NET PRESENT VALUE [-]	2,866,661,393	1,249,421,222	319,343,885	0
NB/NC	ADVANTAGES – COSTS INDEX [-]	3.93	2.35	1.37	1.00
EIRR	ECONOMIC INTERNAL RATE OF RETURN [%]	13.407			

Source: author's work.

The realised procedure has revealed, for various values of the discount rate, that in each of the analysed variants:

- the project consisting in the reconstruction of a national road to the expressway standards (both in case of applying for the necessary environmental protection and in the absence thereof) is economically justified – the discounted savings exceed the discounted net costs including all investment, repair, and maintenance expenditures (ENPV is positive), and the sum of the discounted savings divided by the sum of the discounted net costs is higher than 1 (Blue Book, 2015; Instructions for economic efficiency assessment..., 2008),
- the interest rate, at which the economic net present value of benefits expected from a given investment will be equal to the value of outlays, is 13.216% in the case of an investment task including the necessary environmental safeguards and 13.407% in the variant without the necessary environmental safeguards (the difference is 0.191%),
- the discounted savings of environmental costs in both analysed cases are identical, which means that the necessary environmental safeguards are only included in the investment costs, which is a much-simplified approach,
- the absence of monetisation of the potential benefits of avoidance, prevention, or mitigation of results has an impact on the economic outcome of a cost-benefit analysis, a thorough analysis should include a discussion/description of costs and benefits that cannot be quantified,
- the selected discount rates applied to all items are identical, which affects similar "discounting of the future" and indeed some benefits may increase over time,

- a targeted analysis would be a BCA ex-post, carried out at a certain time after the implementation of the project to assess the extent to which the project is giving results and to help identify "areas" for improvement in the BCA ex-ante (Kelly et al., 2015; Odeck and Kjerkreit, 2019).

Conclusions

The implementation of all road projects entails a number of environmental effects and impacts, which include, among others, direct impacts associated with the stage of construction and use, indirect impacts, usually limited to the immediate vicinity of the investment and secondary impacts. However, all those impacts can be minimised or completely eliminated by using a wide range of "good practices" and appropriate design, technical, technological, and organisational solutions, consisting in the construction of passages and culverts for animals, use of acoustic screens, screening greenery, buffer zones, taking into account the protection periods for animals and birds, environmental supervision over the works, number of activities limiting the occurrence of pollution, use of appropriate environmental protection devices and methods of conducting construction works and modern technologies.

The assessment of economic efficiency is a practical and multilateral evaluation of an investment project and whether it "deserves" to be implemented from a social point of view. To that end, the social, environmental, and health advantages/savings are evaluated, and the economic efficiency indices are determined being the basis for the investment decision. The costs and social and economic advantages of the road infrastructure projects are estimated dividing them into categories including vehicle operational costs, time costs of the road infrastructure users, costs of the road accidents and victims, costs connected with the emission of pollutants, or costs of excessive noise influence. When making an assessment, it is a serious problem to reliably quantify or monetise a certain part of the costs and benefits, especially those that are not measurable (life) or difficult to estimate (environmental costs). The lack of valuation in the monetary value of potential benefits resulting from avoidance, prevention, or mitigation of results has an impact on the economic result of cost-benefit analysis, unfortunately. There is, therefore, a need to modify and advance the CBA, especially regarding "road projects".

References

Banks, J.E., 1997. Do imperfect trade-offs affect the extinction debt phenomenon? Ecology, 78, 1597-1601.

Blue Book, 2015. Road infrastructure prepared by Jaspers Initiative experts.

Bohatkiewicz, J., 2008. Podręcznik dobrych praktyk wykonywania opracowań środowiskowych dla dróg krajowych. Ekkom. ISBN 978-83-926079-2.

Buczek, P., 2013. Zabezpieczenia akustyczne stosowane na polskich drogach w aspekcie racjonalizacji kosztów. Drogownictwo, 2.

Clevenger, A.P., Ford, A., 2010. Wildlife crossing structures, fencing, and other highways design considerations. In: Beckmann, J.P. et al. (Eds.), Safe passages-highways, wildlife and habitat connectivity. Island Press, 17-55.

Clevenger, A.P., Huijser, M.P., 2009. Handbook for design and evaluation of wildlife crossing structures in North America. Department of Transportation, Federal Highway Administration.

Cowlishaw, G., 1999. Predicting the pattern of decline of African primate diversity: An extinction debt from historical deforestation. Conservation Biology, 13, 1183-93.

Daniels, S. et al., 2019. A systematic cost-benefit analysis of 29 road safety measures. Accident Analysis and Prevention, 133, DOI: 10.1016/j.aap.2019.105292.

Drobniak, A., 2008. Podstawy oceny efektywności projektów publicznych. Wydawnictwo Akademii Ekonomicznej w Katowicach, Katowice.

Foltyn-Zarychta, M., 2008. Analiza kosztów-korzyści w ocenie efektywności inwestycji proekologicznych. Wydawnictwo Akademii Ekonomicznej w Katowicach, Katowice.

Forman, R.T.T. et al., 2003. Road Ecology. Science and Solutions.

Forman, R.T.T., Alexander, L.E., 1998. Roads and Their Major Ecological Effects. Annual Review of Ecology and Systematics, 29, 207-231.

Hauer, E., 2011. Computing what the public wants: Some issues in road safety cost–benefit analysis. Accident Analysis and Prevention, 4, 151-164, DOI: 10.1016/j.aap.2010.08.004.

Huijser, M.P., McGowen, P.T., 2010. Reducing wildlife-vehicle collisions. In: Beckmann, J.P. et al. (Eds.), Safe passages – highways, wildlife and habitat connectivity. Island Press, 51-74.

Instructions for assessment of economic efficiency of road and bridge projects for the local roads, 2008. Research Institute of Roads and Bridges, Warsaw.

Instructions for assessment of economic efficiency of road and bridge projects for the district roads, 2008. Research Institute of Roads and Bridges, Warsaw.

Instructions for assessment of economic efficiency of road and bridge projects for the regional roads, 2008. Research Institute of Roads and Bridges, Warsaw.

Iuell, B. et al., 2003. Wildlife and traffic: a European handbook for identifying conflicts and designing solutions, KNNV Publishers.

Johansson, P.O., Kriström, B., 2018. Cost–Benefit Analysis. Cambridge Elements of Public Economics.

Kelly, Ch. et al., 2015. Ex post appraisal: What lessons can be learnt from EU cohesion funded transport projects? Transport Policy, 37, 83-91, DOI: 10.1016/j.tranpol.2014.09.011.

Loehle, C., Li, B.L., 1996. Habitat destruction and the extinction debt revised. Ecological Applications, 6, 784-89, https://doi.org/10.2307/2269483.

McGuire, T.M., Morrall, J.F., 2000. Strategic highway improvements to minimise environmental impacts within the Canadian Rocky Mountain national parks. Canadian Journal of Civil Engineering, 27, 523-32, https://doi.org/10.1139/l99-096.

Morrall, J.F., McGuire, T.M., 2000. Sustainable highway development in a national park. Transportation Research Record, 1702, 3-10, https://doi.org/10.3141/1702-01.

Odeck, J., Kjerkreit, A., 2019. The accuracy of benefit-cost analyses (BCAs) in transportation: An ex-post evaluation of road projects. Transportation Research, Part A Policy and Practice, 120, 277-294, https://doi.org/10.1016/j.tra.2018.12.023.

Pilger, J.D. et al., 2020. Environmental impacts and cost overrun derived from adjustments of a road construction project setting. Journal of Cleaner Production, 256, DOI:10.1016/j.jclepro.2020.120731.

Seiler, A. et al., 2016. Cost-benefit analyses for wildlife and traffic safety. Technical report No. 4. Conference of European Directors of Roads.

Seiler, A., 2003. Effects of infrastructure on nature. Office for Official Publications of the European Communities, 31-50.

Seiler, A., Bhardwaj, M., 2020. Problematic Wildlife II: New Conservation and Management Challenges in the Human-Wildlife Interactions.

Spellerberg, I.F., 1998. Ecological Effects of Roads and Traffic: A Literature Review. Global Ecology and Biogeography Letters, 7(5), 317-333.

Tilman, D. et al., 1994. Habitat destruction and the extinction debt. Nature, 371, 65-66, https://doi.org/10.1038/371065a0.

Trocmé, M. et al., 2003. COST 341 – Habitat fragmentation due to transportation infrastructure: the European review. Publications Office of the European Union.

Trombulak, S.C., Frissell, C.A., 2000. Review of Ecological Effects of Roads on Terrestrial and Aquatic Communities. Conservation Biology, 14, 18-30, DOI: 10.1046/j.1523-1739.2000.99084.x.

Van der Grift, E.A. et al., 2013. Evaluating the effectiveness of road mitigation measures. Biodivers Conserv, 22, 425-448, https://doi.org/10.1007/s10531-012-0421-0.

Van der Ree, R. et al., 2015. Handbook of Road Ecology. John Wiley & Sons, Chichester, UK.