Green Technology for Motorway Overpasses

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Abstract. Overpasses are essential to establish permeability of highways for the wildlife. Width and length are the key technical parameters influencing the overpass effectiveness. It is crucial to secure the proper technology and correct water management on its surface. Wildlife behaviour and their requirements for the above stated technical parameters of overpasses have also been investigated. In all cases, the overpass performance increases with enlarging the width and drop with an increasing length. The goal is therefore to achieve a balanced compromise allowing sufficient functionality while also sustaining reasonable costs. Data envelopment analysis (DEA) provides a method to select a "good" solution in the sense of sufficient overpass performance with moderate total expenses. Overpass performance calculations were made on the original methodology pioneered by the author. Overall expenses were provided based on actual construction costs in the Czech Republic, including expenses for preparations, design, construction, maintenance, and demolition. The results show that DEA has proven to be a very appropriate method for identifying suitable solutions that can be effective in designing measures to secure the highway's permeability for the wildlife.

1. Introduction

Overpasses are constructed to secure highway's permeability for feral species. Other options involve building overpasses or using already constructed bridges over waterways, roads, and uneven terrain. Sometimes, the design needs to accommodate the increased width or height or to adjust their surface or system of construction to ensure the proper functionality. The presented paper deals with the analysis of overpasses. Overpasses are productive in many conditions, however, current data envelopment analysis (DEA) input parameters do not facilitate solving for underpasses and overpasses at the same time. Development of a method is currently underway that will be able to solve for all kinds of migration structures using the DEA methodology.

It is critical for a suitable migration overpass design to involve the determination of overpasses' performance (migration potential) as accurately as possible, see [1] and [2]. Imprecise migration potential estimates might lead to unnecessary growth of the cost or the lack of the desired migration performance.

The subsequent foundations for efficient planning of overpasses should be used. Overpasses' length and width should be appropriate to the necessary needs of those species present. During the construction phase of the overpasses, it is essential to employ suitable technology to reduce environmental consequences and to ensure similar surface as nearby landscape. Fences, rather than overpasses, should be used to avoid wildlife-vehicle collisions. Design of the overpasses should be performed in the...
locations where wildlife is concentrated and with parameters enabling wildlife migration. Long term monitoring of the overpasses should be performed to gain experience and knowledge to design upcoming migration structures.

2. Materials and methods
In our case, it is obvious that an overpass’ technical and ecological migration potentials have to be considered as inputs for the analysis. The overall costs are crucial input, this includes the costs of preparations, design, construction, maintenance, and demolition of the overpass after its period of usability has concluded. In case that an existing highway bridge can be used for the migration, then potential additional costs increasing its performance are noted as a percentage of its initial cost.

DEA models are created as specialized model instruments for assessing the effectiveness, efficiency, and productivity of homogeneous production units. DEA includes the usage of linear programming methods to construct a non-parametric piecewise surface (or frontier) over the data, so as to be able to determine efficiencies compared to this surface. DEA models obtain from the concept that for each given issue there exists a so-called production possibility set which includes of all possible (feasible) combinations in input and outputs. The set of attainable options is calculated by the so-called efficiency limit. Production units with the combinations of inputs and outputs lying on the efficiency limit are considered as efficient ("good") units.

Our solution uses the BCC models. This model presumes variable returns to scale; data are contained by a convex set and therefore more than one unit can be defined as efficient. The model can either try to maximize the given outputs so-called output oriented. It can also try to minimize the inputs, so-called input-oriented. Related DEA procedure has been employed in [3] for technological, environmental and economic analysis of motorways overpasses.

In the following paragraphs, we present mathematical expressions of the dual input-oriented BCC model. We can assume units \( U_1, \ldots, U_n \). Let us also assume we have \( m \) inputs and \( r \) outputs. We the input matrix as \( X = \{x_{ij}, i = 1, \ldots, m, j = 1, \ldots, n\} \) and the output matrix as \( Y = \{y_{ij}, i = 1, \ldots, m, j = 1, \ldots, n\} \). The model for unit \( U_q \) is formulated as follows, minimizing the function

\[
Z = \theta_q - \varepsilon (1^T s^- + 1^T s^+) \tag{1}
\]

under the conditions

\[
X \lambda + s^- = \theta_q x_q, \\
Y \lambda - s^+ = y_q, \\
1^T \lambda = 1, \\
\lambda, s^-, s^+ \geq 0,
\]

where \( \theta_q \) is the efficiency of unit \( q \); \( x_q \) is the \( q \)th column of the \( X \) matrix; \( y_q \) is the \( q \)th column of the \( Y \) matrix; \( \lambda = (\lambda_1, \ldots, \lambda_m)^T \geq 0 \) is the weight vector; \( s^- \) and \( s^+ \) are vectors of additional variables in limitations for inputs and outputs, \( 1^T = (1, \ldots, 1) \); and \( \varepsilon \) is an infinitesimal constant that usually equals \( 10^{-8} \).

We define efficient overpasses those which scored the highest possible migration potential and with the lowest possible expenses. Hence, we choose minimized input matrix \( X \)-cost \( C \), additional costs \( AC \) maximized output matrix \( Y \)-technical migration potential \( P_t \) and ecological migration potential \( P_e \). For every overpass, migration potentials are inputs for three animal categories: large \( L \), mid-sized \( M \) and small \( S \). Results are evaluated separately for each category.
The resulting matrix gives a large supply of data, especially the identification of "good" solutions (units). Inputs that result in the highest inefficiency and which shall be revised where possible, are also marked.

Technical migration potential was determined based on the methodology presented in [4]. In our case, it is defined mostly by overpass length and width. It is further affected by the traffic disturbances, with positive effects from noise barriers and by equipment designed to limit glaring from the vehicles. When endeavouring to increase a bridge’s technical migration potential, the first possibility is to widen the overpass (increasing its span) and also to adjust the surface under the bridge.

3. Results and discussions

To display the aspects of DEA, the analyses of the 12 selected overpasses is presented. Table 1 shows the input variables for DEA. Overall costs are the variables (inputs) that have to be minimized, while the technical and ecological migration potentials are the variables (outputs) to be maximized. Overpass dimensions (width and length) are the essential quantities for calculating technical migration potential. The DEA model gives an extensive quantity of results. Table 2 shows the most selected usable results for individual wildlife category L. The first column provides the overpass' reference number. The last

| No | width | length | \( P_e \) | \( P_t \) | Costs (CZK million) |
|----|-------|--------|--------|--------|-------------------|
| 1  | 12,00 | 95,90  | 0,77   | 0,08   | 38                |
| 2  | 15,03 | 36,50  | 0,59   | 0,11   | 25                |
| 3  | 15,80 | 65,50  | 0,53   | 0,27   | 42                |
| 4  | 17,25 | 55,50  | 0,20   | 0,29   | 51                |
| 5  | 22,00 | 65,50  | 0,07   | 0,13   | 66                |
| 6  | 24,80 | 35,50  | 0,09   | 0,21   | 78                |
| 7  | 52,00 | 35,50  | 0,20   | 0,37   | 84                |
| 8  | 70,80 | 47,40  | 0,60   | 0,64   | 88                |
| 9  | 125,80| 45,90  | 0,60   | 0,71   | 125               |
| 10 | 133,80| 65,90  | 0,62   | 0,88   | 256               |
| 11 | 133,80| 55,90  | 0,58   | 0,87   | 315               |
| 12 | 228,40| 45,90  | 0,27   | 0,95   | 355               |

| No | \( dP_e \) | \( dP_t \) | dCosts | Efficiency |
|----|--------|--------|--------|-----------|
| 1  | 0,000  | 0,499  | 0,00   | 0,053     |
| 2  | 0,000  | 0,399  | 0,00   | 0,213     |
| 3  | 0,000  | 0,110  | -2,20  | 0,400     |
| 4  | 0,000  | 0,100  | -3,15  | 0,563     |
| 5  | 0,514  | 0,299  | 0,00   | 0,000     |
| 6  | 0,400  | 0,099  | -8,25  | 0,000     |
| 7  | 0,350  | 0,099  | -12,55 | 0,092     |
| 8  | 0,000  | 0,0880 | -6,15  | 0,110     |
| 9  | 0,000  | 0,000  | 0,00   | 0,330     |
| 10 | 0,000  | 0,000  | -111,95| 1,000     |
| 11 | 0,000  | 0,000  | -88,12 | 0,870     |
| 12 | 0,152  | 0,000  | 0,00   | 1,000     |
column gives the total overpass efficiency. Efficient ("good") overpasses are denoted as 1. With the decreasing value, the overpass becomes less efficient. The values in the second to the fourth column show how much input variables have to be modified for an overpass to become efficient. The columns show how much ecological (column dPe) and technical (column dPt) migration potentials have to increase as well as how much total (dCosts column) costs would need to be reduced.

4. Conclusions

The current results display that neither the least expensive solutions nor the overpasses with enormous technical potential are automatically "good" in the sense of DEA.

Established on the prior experience, our own data, and the first DEA results, we can recommend these following principles for designing overpasses.

1. Correct design of a migration overpass should ensure a minimum width corresponding to the requirements of those species inhabiting the location.
2. Overpasses should be designed to the optimal size guaranteeing a sufficient migration potential for those species occurring at the location while also keeping in mind the total expenses. Too generous overpass dimensions produce motorways unnecessarily expensive and do not bring any essential gain in functionality.
3. It is crucial to use the technology that minimizes environmental impacts when constructing overpasses.
4. In the effort of preventing the wildlife-vehicle collision, building a continuous fence on both sides of the road is necessary. Fencing type must be adapted to those species occurring at the location and it must create an impenetrable barrier for them. It is necessary to carry out regular inspections of the fencing.
5. Migration structures should be designed in locations where the wildlife is concentrated and with the parameters appropriate for those particular animals.

Acknowledgment

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References

[1] A. P. Clevenger, M. P. Huijser, Wildlife Crossing Structure Handbook, Design and Evaluation in North America, Washington D.C., USA: Federal Highway Administration, 2011, pp. 211.

[2] A. P. Clevenger, “15 Years of Banff Research: What We Have Learned and Why It is Important to transportation Managers beyond the Park Boundary” in Proceedings of the 2011 International Conference on Ecology and Transportation, edited by Paul J. Wagner, Debra Nelson, and Eugene Murray. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, 2012, pp. 433-447.

[3] K. Myšková, J. Žák, Modelling of Wildlife Migrations and its Economic Impacts, Proceedings of the International Conference on Numerical Analysis and Applied Mathematics 2013 (ICNAAM-2013) ISBN: 978-0-7354-1184-5

[4] J. Žák, A. Florian, Green Bridges and their Migration Potential, World Academy of Science, Engineering and Technology, International Journal of Civil, Architectural Science and Engineering Vol:7 No:10, 2013, pp. 890-896, ISSN 1307-6892