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FLEXIBLE DESIGNING OF A ROAD INFRASTRUCTURE EXAMPLE

ELASTYCZNE PROJEKTOWANIE NA PRZYKŁADZIE INFRASTRUKTURY DROGOWEJ

A b s t r a c t

The paper presents the idea of flexible design in the construction sector. Guidelines of the evaluation of a road infrastructure were discussed based on JASPERS Blue Book. An idea of how to proceed is presented through infrastructure projects concerned with economic efficiency analysis using a flexible approach. Moreover, the issue of flexibility is presented using the POZNAN BY-PASS A2 as the example of infrastructure, to which efficiency analysis was applied to variant solutions.

Keywords: flexibility, infrastructure, design, net present value

S t r e s z c z e n i e

W artykule przedstawiono idee elastycznego projektowania w budownictwie. Omówiono wytyczne oceny infrastruktury drogowej na podstawie Niebieskiej Księgi JASPERS. Pokazano ideę postępowania podczas analizy efektywności ekonomicznej przedsięwzięć infrastrukturalnych z uwzględnieniem podejścia elastycznego. Zagadnienie elastyczności zostało omówione na przykładzie budowy obwodnicy miasta Poznania POZNAN BY-PASS A2, w którym zastosowano analizę efektywności dla rozwiązań wariantowych.

Słowa kluczowe: elastyczność, infrastruktura, projektowanie, wartość bieżąca netto

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1. Introduction

Rapid technological growth and turbulence in the environment are factors that generate significant difficulties in construction project design, particularly infrastructure systems. The rapid growth of road infrastructure has been closely related to economic growth. Preparing a project design involving readiness for change during its life cycle means designing in a flexibility factor which provides the opportunity for adapting to possible change [1]. Considering the long life cycle of road infrastructure, changes in operating conditions (e.g. traffic load) and applicable requirements (such as increasing the acceptable ratings – traffic load categories), modernization and conversion of establishments is also given. Nevertheless, it is difficult to determine the exact point of time of their occurrence, or their actual values of the parameters. This supports the introduction of a new approach, based on flexibility, which can be interpreted as a possibility (however not a requirement) to introduce certain options with the assumption of changing the configuration of a system parameters or system components in time [11].

The purpose of this article is to present a flexible approach to designing in the construction sector. In terms of the scale of operations, the case under consideration refers to the construction of a part of the Poznań by-pass (POZNAŃ BY-PASS A2) as an example of infrastructure. In the life cycle of such a construction (which are often system components, such as a system of motorways, airports, etc.), one should consider changes in the requirements and parameters of supported processes in time [17]. Typically, a growing tendency is the assumption for this type of argument (e.g. gradually increasing number of buffer parking lot users, number of airport passengers, increase of number of motorway users, etc.).

2. Typical infrastructure design vs. flexible approach

Commonly encountered problems in managing construction processes have encouraged numerous researchers to attempt to resolve them. Sources of the approaches discussed can be specified chronologically, constituting development milestones over a perspective of several dozen years:

- The idea of flexibility in production management was described by Schumpeter in 1934 [12]; he saw the reasons for introducing flexibility in the necessity to build an efficient response to changes in the environment,
- The concept of buffering was presented by Kaplinski (1978) in a discussion regarding the issue of construction process harmonization [7],
- The key role of flexibility in planning and designing regarding the ability to adapt the response to changing operating conditions, in contrast to the traditional approach in engineering design, consisting of searching for a single best solution (De Neufville 2000, 2004) [2, 3],
- Analyses of construction processes with the use of flexibility, conducted by Thomas'Team (Horman, Thomas 2005; Thomas, Horman 2006; Thomas and Ridley and Sanvido in. 1999) [4, 15, 14],
- Application of flexibility in managing construction projects focused on operations on a tactical level (Olsson 2006) [9],

- Identification of both internal and external uncertainty factors supporting the need to apply flexibility (Mayer, Kazakidis 2007) [8],
- The concept of FLEMANCO, a flexible construction process execution management method, was proposed by Paslawski in 2009 [10],
- Application of multi-criteria choice in designing infrastructure was developed by Zavadskas and Vaidogas (2009) [16],
- Jaskowski and Sobotka (2012) pointed to the options of applying a flexible approach through alternative changes of process execution sequence in a network model [5],
- Shahu *et al*. (2012) indicated the need to consider flexibility in planning construction processes, beside typical criteria (cost, deadline, quality) [13].

In the traditional approach, the number of design and implementation variants is gradually reduced during planning. Engineering is usually based on a single key value (such as traffic load), without considering any possible changes of this value in time, thus producing very limited information about the actual values (it would be much more advantageous to define, for example, a range of values which might occur). Consequently, a designer acting in accordance with applicable specifications, codes and standards, as well as frequent financial restraints imposed by the investor, would usually produce a design with minimal options for further variants. However, the further we are from the point of taking decisions about the adopted design parameters, the harder it becomes to anticipate the actual requirements of the system. This is presented in ideographic form on Fig. 1. The introduction of flexibility serves the purpose of avoiding a situation when the construction ceases to meet the applicable requirements after a relatively short time, or does not match current requirements (and therefore generates losses) as a result of overly optimistic assumptions. In the approach presented, flexibility means assuming the option of changes in the construction (or system) during its life cycle to enable its adaptation to varying environmental conditions.

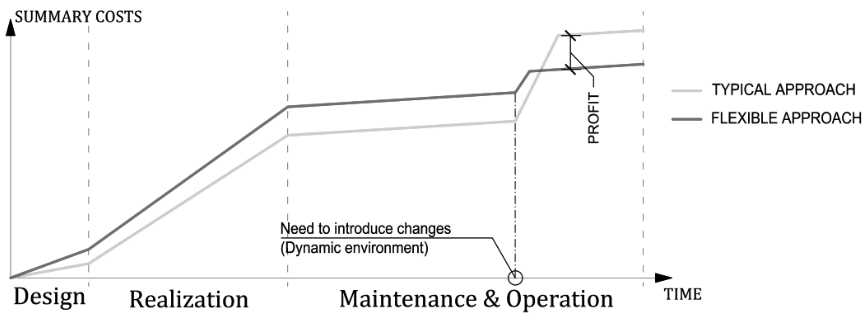

Fig. 1. Cost account in the investment process

3. Blue Book – guidelines for assessment of road infrastructure

At the end of 2008, an instruction book was written, presenting cost-benefit analysis (CBA) methods, referred to as the Blue Book [6].Complying with its main guidelines in all projects financed with public funds is highly recommended. The purpose of the techniques presented in the Blue Book is to provide assistance in choosing the optimum solution which will provide both economic and social advantages while guaranteeing the most efficient manner of utilising public funds.

According to the CBA, the first phase of project assessment is the identification of alternative variants in terms of the project goal, execution possibilities, and feasibility studies. This article disregards that chapter because the analysis relates to construction of the POZNAŃ BY-PASS A2, which is part of the motorway ring around the city of Poznań at the Poznań Komorniki – Poznań Krzesiny section of A2 motorway (ca. 13 kilometres). The research pertains to the following three variants for executing this project:

– initially building three lanes in one direction;
– building two lanes in one direction, with the option of adding another lane later, with prior adaptation of the infrastructure (bridges and viaducts) to extension;
– building two lanes in one direction, with the option of adding another lane afterward s, without prior adaptation of infrastructure.

3.1. Phase II – Socio-economic analysis

The purpose of this analysis is to demonstrate that the proposed investment variant is beneficial from a social perspective. Economic analysis was carried out on the basis of the so-called accruals method and economic profits are determined on the basis of the difference between total economic costs in non-investment variant (NV) and equivalent costs in one of the investment variants (IV).

3.1.1. Economic Net Present Value *ENPV*

The main formula defining the economic efficiency calculation is as follows:

$$ENPV = \sum_{t=1}^{n} \frac{NB_t + NC_t}{\left(1 + \frac{r}{100}\right)^t} \quad (1)$$

where:

ENPV – Economic Net Present Value,
NB_t – efficiencies for users and the environment in the consecutive year *t*,
NC_t – net road costs in the consecutive year *t*,
n – years over the period of analysis,
r – discount rate (%).

Net road costs are calculated as the difference between road costs in no-investment and investment variant $\left(C_t^{[WO]} - C_t^{[WI]}\right)$ the same procedure should be followed when calculating efficiencies for road users and the environment. In order to determine the economic net present value, you should sum up discounted net benefits for each year, being the sum calculated on the basis of the following formula:

$$NV_t = NB_t + NC_t \quad (2)$$

and

$$C_t = c_b + (c_m) + c_o + c_r + c_u \tag{3}$$

where:

$c_b(c_m)$ – construction (reconstruction) costs,
c_o – periodical overhaul costs,
c_r – partial overhaul costs,
c_u – daily maintenance costs.

$$B_t = b_e + b_c + b_z + b_w + b_s \tag{4}$$

where:

b_e – vehicle service costs,
b_c – time costs in passenger transport,
b_z – time costs in cargo transport,
b_w – costs of traffic accidents,
b_s – costs of emissions of toxic exhaust gas components.

3.1.2. Benefit-Cost Ratio *BCR*

Efficiency evaluation is expressed through the *BCR* calculation ratio, describing the proportion of benefits to costs. It is calculated as the sum of discounted annual benefits to the sum of discounted annual net road costs for the audited period, according to the following formula:

$$BCR = e = \left| \frac{\sum_{t=1}^{n} v_{rt} \cdot NB_t}{\sum_{t=1}^{n} v_{rt} \cdot NC_t} \right| \tag{5}$$

where:

$BCR = e$ – economic efficiency ratio,
v_{rt} – discounting factor in the consecutive year *t* of the period under review,
NB_t – efficiency for users in the consecutive year *t* of the period under review,
NC_t – road costs in the consecutive year t of the period under review,
n – period of analysis.

We conclude that an investment is efficient when $BCR \geq 1$

3.1.3. Economic Internal Rate of Return *EIRR*

An investment project can be accepted when: $EIRR > RRR$ meaning that the minimum threshold return rate is less than the discount rate [6], at which *ENPV* is nil. Namely:

$$ENPV_r = \sum_{t=1}^{n} \frac{NB_t + NC_t}{\left(1 + \frac{r}{100}\right)^t} = 0 \tag{6}$$

4. Case study

The presented infrastructure design case is a 13-kilometre section of the southern ring of Poznań, section of the A2 motorway. Due to its function and connection of two critical locations in Poznań, increasing volume of users should be considered for this road section. To illustrate the benefits of applying flexibility, two variants of the project have been prepared:

W1 – Building the road with three lanes at once, irrespective of demand fluctuations (Big One option).

W2 – Building the road with two lanes in the first stage and optional extension during the following years with another lane, according to traffic intensity (Step By Step option).

The principal assumptions of both options are as follows:

– both variants are compared to the so-called non-investment variant (W0), i.e. existing city road connecting the same critical points of Poznań as the designed variants;
– road service and maintenance costs have been calculated on the basis of cost indicators specified in the Blue Book issued by Joint Assistance to Support Projects in European Regions (Jaspers);
– the indicators were read on the basis of calculated rates of travel for each of the variants separately. They depend on the average daily intensity of passenger cars, vans, trucks and buses;
– all cost indicators were determined for specific years of forecast separately, applying relevant growth rates.

Initially, computations were carried out for a 25-year term NPV analysis as a universally used method. They also carried out an analysis for the period of c 60 years.

NPV outputs for both options: Big One (no flexibility) i Step By Step (with flexibility options) The results obtained are presented on Fig. 2. Comparison of NPV changes for both options indicates a clear advantage of the flexibility option.

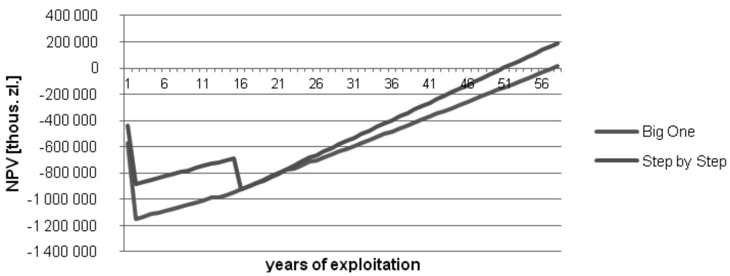

Fig. 2. NPV analysis for POZNAN BY-PASS A2

NPV for the Big One option initially covers a range of high negative values and would only reach positive levels after 57 years. The level of measures invested in the first year amounts to a value 35% higher for the variant Big One. The payback period (NPV = 0) for the Step By Step variant is about the 14% less than in the case of the Big One.

These calculations do not take certain technical and environmental factors, cooperation with UE and regional development factors which are very important for designing a traffic system, arising from city ring construction, e.g. movement of heavy vehicle transport outside the city, obtaining an EU grant, extension of the shipping network within the motorway area into account

The results obtained corroborate the idea of introducing flexibility, consisting of the mitigation of possible losses and enhancing the options for taking the opportunities. In the case under consideration, this option involved a limitation of the number of road lanes at the outset of the project and making the addition of another lane a contingent upon increasing volume of road users.

5. Conclusions

With the fundamentals of flexible approach in infrastructure design presented above, and with an example implementation, the following conclusions can be drawn:

1. 1Proactive attitude is of crucial importance for introducing flexibility in design, as opposed to the reactive attitude prevailing in the traditional approach;
2. Based on the average value calculated through determination, is a disadvantage of traditional design engineering which, considering the long life cycle of the facility, may lead to the inferior adaptability to the variable environment (higher costs, compared to proceeding in accordance with the flexible approach);
3. The presented NPV change analysis for the different options turned out to be an effective method of estimating the results of applying flexibility in the case under consideration;
4. The value of flexibility is given by uncertainty – one can add a new line on request (watching traffic problems vis a vis maintenance cost);
5. In terms of the flexibility application, the following are the main important elements:
   - scale of uncertainty impact (number of factors and range of possible changes),
   - life cycle phase considered (generally, introduction of flexibility in design engineering seems to be particularly beneficial considering the high potential for uncertainty).

The results presented prove the relevance of the applied method. In the case study under consideration, the costs of restarting the construction procedure with the next stage must be taken into account (they seem to be extremely low, as compared to the costs considered in the presented model). A hybrid approach, involving other methods was also considered for implementation in future research.

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