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Dynamic Planning of Road Infrastructure Financing

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Abstract. Strategic planning of large governmental investments is a nontrivial task, requiring deep problem knowledge, tight team cooperation and systematic utilization of latest tools and methods. The paper shows that even subjectively represented multidimensional problems can be processed in a generally understandable way using computer simulation. Although an exact prediction of a distant future is difficult, presented technique transforms the original problem into a knowledge-based model, where the interactive experiments and parametric changes can be safely realized. Straightforward ways of handling nonlinearity and nonstationarity are presented and discussed as illustrative examples.

Keywords: road infrastructure, road financing, system dynamics, strategic planning

1. Introduction

Most Governments consider the road infrastructure to be one of the cornerstones of an economic development. If the government invests insufficient amount of financial resources into the development of new road infrastructure and into the rehabilitation and maintenance of existing road network for the long time period we can talk about „short-investment“. Short-investment is the serious problem which currently has to be solved not only by the Eastern European economies, but also by other countries as a consequence of the global financial crisis. Although investment to the development of transportation infrastructure allocate considerable part of governmental budget, their strategic planning and management processes are still far from optimal.

Based on the analysis of the system of road infrastructure financing in the Czech Republic this article proposes a planning methodology supported by system approach. As a part of the methodology the article forecasts the evolution of short-investment using the system-dynamic model. Discussion part of the article focuses more closely on various types of changes the model user can perform in order to find required model solution. Under discussion are changes of parameters, non-stationary changes and non-linear relations.

2. Related Work

The changes in society and in its needs are very dynamic, the uncertainty in planning procedures increases with time and the planning processes together with used tools must adapt to that [1]. There is a wide range of tools, approaches and methods used for transport infrastructure planning. Among the best known example may be mentioned the Scenario analysis [2] or Monte Carlo as a tool to rationalize the planning process by quantifying risk and its simulation [3], [4], [5]. Some authors suggest mutual combination of benefits of different methods for the planning process, both the more and the less traditional. [6], [7]. Along with changes in society also changes the role of governments in the planning of road infrastructure. Countries apply at the time different approaches [8]. Because the planning of road infrastructure at the state level depends in the Czech Republic on the system of road financing, the article considers the use of system dynamics created during the mid-1950s by Professor J. W. Forrester of the Massachusetts Institute of Technology. The System dynamics is an aspect of systems theory as a method for

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understanding the dynamic behavior of complex systems and its application in transport infrastructure, economy and government finance has already been confirmed many times e.g. in [9], [10], [11].

3. Proposed Methodology

The Czech Republic, with its location in the centre of Europe, is an important transit country and a good-quality road infrastructure is one of the most significant prerequisites for its economic development. Current planning of the road infrastructure financing in the Czech Republic has number of shortcomings [12]. Insufficient amount of resources inserted into the road infrastructure for the long time period is resulting in an incessantly increasing short-investment problem.

To improve the planning process we propose to create a long term investment plan for both construction of new sections and reconstruction of existing network sorted by priorities (need for its realization). Then assign investments to free financial sources optimized in long-run according to the desired level of short-investment (complete elimination, reduction to a certain level, steady state, etc.). Optimization of financial sources is a decision - making problem which includes linear relations, which change over time (dynamic), multi-dimensional and causality (a large number of factors and relationships between them), subjective factors and uncertainty. Currently applied planning tools are deficient for described type of problem. As a suitable tool for analyzing the dynamic problem we propose to develop a system-dynamic model.

Strategic planners of large projects strive to employ such models, which are understandable for the widest possible spectrum of their stakeholders. This attitude naturally leads to the design of intuitive user interfaces, where the rough, e.g. mathematical representation of a real task is surrounded with a package of intermediate layers, containing sub-problems, expressed in graphical or textual programming languages. The reason is, that the layered architecture allows keeping both wide usability and rigorous formalism of processed task, along with an appropriate level of internal heterogeneity. According to our experience, every stakeholder can find own internal niche within such model, corresponding with the particular knowledge and expertise. Accordingly, we also believe that the system dynamics modeling, generating difference equations on the basis of graphical ”stock and flow“ representation satisfies exactly this strategy.

4. Model Description

Based on the analysis of the system of road infrastructure financing in the Czech Republic a system dynamic model has been developed. The model describes the cycle of resources for financing of the road infrastructure in relation to economic growth, and the use of those resources for new investment, operation and maintenance as a tool to reduce short-investment.

The developed system dynamic model contains two basic cycles. First one is the cycle of funding sources represented by an excise tax, road tax, toll, vignettes, direct subsidies from the state budget and funds from the EU. These are intended to finance road infrastructure which is directly connected with economic growth. Economic growth is in conjunction with traffic volume and fuel consumption. The road usage generates sources which are intended to finance road infrastructure in following period. The second cycle expresses the cycle of expenditures on road infrastructure and its impact on short-investment. From public sources at first the operating costs are covered. Remaining funds are invested in construction of new roads or in reconstruction of existing road network. Both types of investment have a positive impact on the short-investment. Short-investment creates pressure on politicians to deal with adverse situations and to determine contribution from the state budget intended for road infrastructure financing.

Both cycles consists of a set of differential equations and various parameters. Table I. shows selected examples of differential equations the model is based on. The final set of system equations is solved numerically using Runge-Kutta method.

Table I.: Differential equations of simplified system

Equation	Explanation
$SI_{NR}(t) = SI_{NR}(t-dt) - NR * dt$	SI_{NR} = short-investment of new roads NR = investment expenses in new roads

$SI_{CR}(t) = SI_{CR}(t-dt) + CR * dt$ $CR = (1+\alpha) * MI_{CR} - I_{CR}$	SI_{CR} = short-investment of current road network CR = increase/decrease of SICR in current period I_{CR} = investment expenses in current road section MI_{CR} = investments required for the road network α = coefficient of increased abrasion resulting from increased traffic
$OC(t) = OC(t-dt) + OC_{NR} * dt$ $OC_{NR} = NR * UC$	OC = yearly operating costs of road network OC_{NR} = increase/decrease of OC in current period UC = operating costs per monetary unit of new roads (e.g. OPEX/1mld. CZK of CAPEX)
$ET(t) = ET(t-dt) + ET * (1+\beta) * dt$	ET = amount of share on excise tax on mineral oils β = coefficient of change in the share on excise tax resulting from the change in traffic in current period

5. Experimental Results

A simulation of a few sample scenarios was conducted using created system-dynamic model in order to check various types of changes the model user can undertake when searching the model solution of the short-investment problem in the Czech Republic. Simulation time was set on a period of 50 years. In the base case scenario the evolution of short-investment develops as in Fig. 1a).

The graph of the base-case scenario shows that the short-investment problem as a result of insufficient financial sources for reconstruction of existing roads is getting worse. The EU grants have a positive impact on the construction of new road sections. This situation is illustrated by the sharply decreasing trend of line "Short-investment – new roads". The model assumes that the Czech Republic will be entitled to receive the EU grants for the next 10 years and afterwards this source will be lost. In the period, where no more funds from the EU will be available, the trend significantly changes. EU funds are currently in the Czech Republic intended only to finance new investments and after subtraction of co-financing from the state budget there remains insufficient amount of funds for reconstruction of the current network, which is the main generator short-investment.

5.1. Parameter Changes

The developed system dynamic model contains various inputs and its values reflect the result of political decision. The model user can easily change those input values and by running the simulation can observe the effect of performed changes on the development of output values.

The change of parameters "share on excise tax on mineral oil" and "division of investment sources between investment in construction of new roads and investment in current road network" is an example of possible political decision in the Czech Republic. If the share on excise tax will be raised to 50% and 30% of investment sources will be intended for construction of new roads the situation would develop as in Fig. 1b). This figure indicates that this government decision would lead to the resolution of only one part of the short-investment problem. All new roads planed will be constructed in about 40 years while the short-investment of existing road network follows parabolic trend. It's value initially decreases but at the end of the simulation starts growing.

5.2. Non-stationary Changes

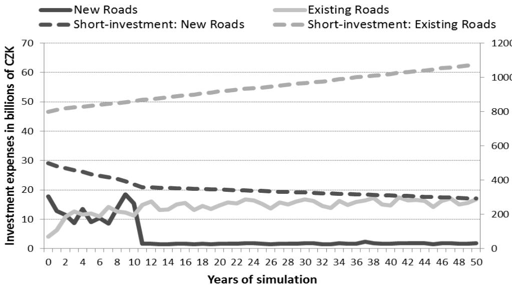
In real life decisions are made based on the development of actual situation. Traditional planning tools do not provide the possibility of immediate reaction on actual situation. Developed system dynamic model allows the user anytime to pause the simulation process, to change factor setting and to continue the simulation. Using these steps the user is able to discover the sequence of political decision that should be made in order to reach the required solution as indicated in Fig. 1c). This figure expresses the situation when the Government focuses in first 10 years mainly on new investments in order to use all EU sources. In this period there is insufficient amount of sources remaining to finance the investments into the current road network. In year 10 the political decision is made to focus on the investing in current roads and keep the short-investment of new roads stable. Change in year 30 represents the situation where the Government starts focusing on new roads while the short-investment of current road network keeps stable.

5.3. Functional Dependence

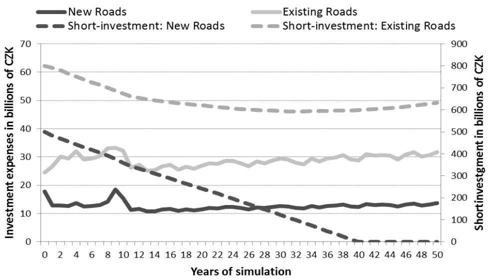
Discovering the sequence of optimal factor changes leading to required solution by pausing the simulation and changing factor values can be the long lasting task. Factor settings in developed system dynamic model can be changed into a functional dependence on other model factors. Actual values of other factors then determine the value of functionally dependent factor towards the required solution. For example the Government makes the decision to increase the share on excise tax on mineral oils to 50% and wish to solve both parts of short-investment. In this case the division of investment sources could be set up as follows:

Expression	Explanation
$D_{NR/ER} = \dfrac{SI_{NR}}{SI_{NR} + \max(MI_{CR}, SI_{CR})}$	$D_{NR/ER}$ = division of investment sources between new roads and existing road network

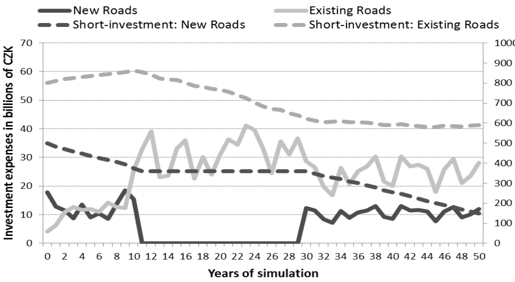
Described changes would lead to the development of the situation as shown in Fig. 1d). The graph shows that thanks to the functional dependence, the division of investments between new roads and existing sectors changes from year to year and it leads to steadily decreasing both parts of short-investment. Both parts of short-investment are eliminated in the same time around 85th year of simulation.



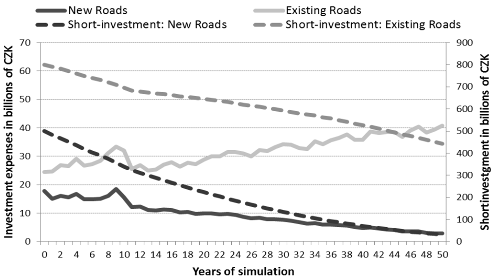
a) Base-case scenario



b) Parameter changes



c) Non-stationary changes



d) Functional dependence

Fig. 1: Development of short-investment in selected scenarios

6. Concluding Remarks

The planning of road infrastructure financing is complex and complicated task. To improve, ease and speed up the planning process the article proposed a methodology supported by system approach. Based on this methodology the system dynamic model of road infrastructure financing in the Czech Republic has been built on. Developed system dynamic model points out at increasing short-investment problem as a result of insufficient investments into current road network. If the problem will not be solved we can expect its significant worsening in following years. To find a solution the model allows the user to perform various changes and by rerunning the simulation to observe the development of both parts of short-investment problem. In addition to changes of factor settings at the beginning of the simulation the model allows to change parameters inside the simulation process. By this possibility the user can immediately react on the development and on actual situation of observed parameters. The model also allows changing input values into a functional dependence. Every year of simulation the model then assigns sufficient values in order to reach required solution. Performed experiments confirm that proposed methodology can simplify, improve and accelerate the planning of road infrastructure financing.

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