

Risk Evaluation of the Guideway by Stochastic Approaches

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ABSTRACT: In early planning stages, it is very difficult to provide a detailed estimation of the investment costs of a Maglev or high-speed railway system. This is mainly caused by a lack of information to the quantities as well to the prices of the items. It is well-known, that prices will vary depending on many influences and lead to risks in the realization process. A practicable way to take risks into account in cost estimations are stochastic approaches for the multiple variation of prices and quantities. In the following, research results are shown using stochastic cost distributions and the Monte-Carlo-simulation to consider different risks.

1 INTRODUCTION

1.1 Decision making models

The construction and the operation of major infrastructures have many influences on the population, the national economy, the industries and the ecology. Therefore models have to be developed to value these influences. Most common is the cost-benefit analysis, which compares the advantages and the disadvantages of an infrastructure system or project on the basis of costs and benefits. So all influences can be transformed in cash values. This may be quite difficult in many cases, for example if ecological influences or the effects of mortal and non-mortal accidents have to be evaluated. Another basic model which should be mentioned is the value-benefit analysis. The decision between different variants or systems is done on a measure of advantages on the basis of different criterions. These can be marked differently. The advantage of the value-benefit analysis is, that original values of units do not have to be transformed in cash values. But finally the individual evaluation of the different criterions have the determining influence to the result.

It is to mention that the decision making models for most infrastructure systems are faced with another problem: the long period of using these systems. So usually dynamic and not static approaches are incorporated in the above mentioned methods, for example the capital value method. But many questions still remain like the used interest rate, the influence of inflation and the period under consideration.

In all cases it is important to mention, that the final decision has to be made by the decision maker or group. All models give only specific views on the

system and it is typical, that different models or different evaluations come to different results. In the end we have to realize, that it is not given to human to predict the future.

1.2 Investment costs

Independent to the models used to prepare the decision for high-speed transportation systems the investment costs, the operating costs and the earnings have an important or determining influence. Other influences as ecological for example are usually less determining. The reason is, that in comparison of Maglev and railway systems both have similar negative impacts. Otherwise it may be possible to improve negative situations by a well-designed or more costly construction. This raises not only the investment costs, but influences the operating costs as well.

It is typical for infrastructure projects, especially for high-speed transportation systems, that the investment costs are very high. In addition it is quite difficult to determine these costs in early design stages. This is caused by many undetermined factors, which lead to existing risks. For example the final and exact location of the route can not be determined in early design stages. So the length of tunnels, bridges and other constructions are not definitely fixed. The conditions of earth, rock and soil are only roughly known. But these aspects have a decisive influence on the construction costs. But much more factors influence the final investment costs. To mention are quality standards, the price levels of the construction market or influences of extreme weather conditions.

In comparison between investment costs, operating costs and earnings all of them are linked with typical risks. Operating costs are especially influenced by energy costs, maintaining costs and the accepted period before replacement investments will be realized. The earnings are determined by the predictions of the number of people which would use a new high-speed transportation system and the level of fare. All these undetermined factors may influence the result of a comparison and have to be substantially included in an accepted method.

2 TRADITIONAL ESTIMATION OF INVESTMENT COSTS

2.1 The traditional approach

The investment costs C_{tot} [Euro] are estimated by

$$C_{tot} = \sum_{i=1}^n (m_i \cdot c_i)$$

where m_i = quantity of a specific partial work i which have to be executed and c_i the unit costs of the specific partial work.

Calculating C_{tot} we are faced with several problems:

- The partial works i are unknown in detail. In addition there are so many works, so that in early planning stages we have to concentrate on main works. We consider secondary, additional and supporting works mostly by raising the unit costs of the main works by a certain percentage.
- The quantities m_i to be executed are unknown. They are determined by the quantity surveyors during or after execution of the works. So we have to use estimated quantities in early design stages.
- The unit costs c_i are determined as soon as the construction contract is signed. If we have several construction contracts we have to use weighted means of these unit costs. Unfortunately we do not have these unit costs in early planning stages. So we have to use expert knowledge to assume acceptable unit costs.

So it is obvious, that this traditional method which is commonly used, can only hardly accepted for huge infrastructure projects.

2.2 Evaluation of risks by the traditional approach

There are two basic methods to evaluate risks, which are the result of the above explained traditional approach:

- Extremum analyses
Instead of using mean values, the most positive or the most negative values are used for the quantities m_i and for the unit costs c_i . The result of this calculation leads to extreme investment costs, which have an extreme low probability.

- Sensitivity analyses

By this method the estimated values for the quantities m_i and for the unit costs c_i are varied in steps for example by $\pm 10\%$, in the next step by $\pm 20\%$ and finally by $\pm 30\%$. We are faced with the problem, that the amount of calculations is very high. So usually the numbers of calculation is reduced to values only, where big changes in the result are assumed.

Sensitivity analyses are very valuable to determine assumptions theoretically fraught with high risks. But they do not tell us the probability of these risks. Extremum analyses can show extreme risks, which are not very probable. In total, both methods may be helpful in some cases, but they do not give us a wide view on the expected investment costs.

3 ESTIMATION WITH STOCHASTIC VALUES

3.1 Method

Stochastic distributions are particularly suitable to describe probabilities of the occurrence of certain events, in our cases of quantities and the unit costs. Generally we find unlimited and limited distributions. All unlimited distributions, to which the well known Normal or Gauss distribution is a member of, are in our case not usable, because with very low probabilities we may have unit costs or quantities which never can occur. Therefore, we use only limited distributions, which have a minimum and maximum value. In figure 1 two distributions are shown: triangular distribution and Beta distribution.

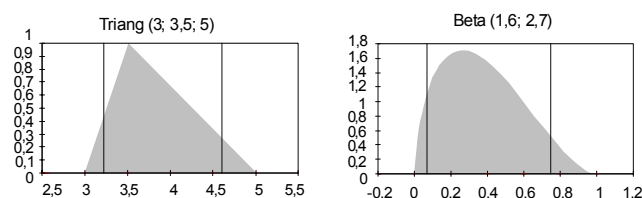


Figure 1: Typical distributions to describe quantities and unit costs

In many cases we may choose right skew distributions, for example for unit costs where the most probable value is usually much closer to the lower value than to the upper.

There exists no closed mathematical method to add or to multiply any and as many stochastic distributions as you like. But we can use simulations which are quite easy to realise with MS Excel and specific Add Ons like Palisade's @RISK [1].

The principle will be shown on a small example: A left skew triangular distribution (mode 6,00 €/m², lower limit 3,00 €/m², upper limit 8,00 €/m²) and a right skew triangular distribution (mode 20,00 €/m²,

lower limit 40,00 €/m², upper limit 240,00 €/m²) shall be added. As result we receive a right skew distribution, which is shown in figure 2.

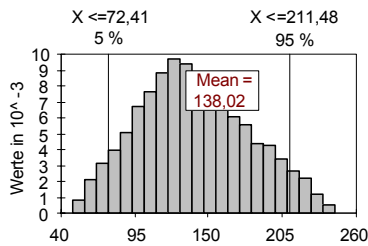


Figure 2: Result of the Addition of exemplified stochastic distributions

This distribution is not any more a triangular distribution but still quite similar. The mean is 138,02 €/m², which is not equal to the addition of the original modes (6,00 €/m² + 120,00 €/m² = 126,00 €/m²). This is very important to remember in regard of the addition of the costs for main works in infrastructure projects. As well the result is quite important, that with a certainty of 90 % the costs lie in between 72,41 €/m² and 211,48 €/m².

3.2 Stochastic procedure for unit costs

Before starting to calculate the costs of high-speed transportation systems we need a cost structure. In a typical structure we can distinguish for the guideway between the following costs:

- Purchase of land
- Foundations and superstructure
- Switches
- Special structures
- Buildings
- Conservation of the countryside
- Secondary expenses.

In a hierarchal structure it is possible to break the costs down to main items. These main items include all works which have to be done on sideline. Typical is for example:

- Earthwork for dams include drainage ditches. Unit-costs are calculated in €/m³.
- Tunnel-construction includes excavation and concrete work. Unit-costs are calculated in €/length of tunnel.
- Elevated Guideway includes foundations, columns, beams and propulsion system. Unit-costs are calculated in €/length of guideway.

For these unit-costs we need stochastic distributions not only to take into consideration the influences of the market but also technical and design influences. Normally it will not be possible to ascertain the distribution by statistic evaluations

based on a basic population of unit-costs as per accounts rendered.

In most cases we will use an expert group, which will lie down the distribution (e.g. triangular) as well as parameters of the distributions (mode, upper and lower limits).

In figure 3 two distributions for the Transrapid-guideway are shown, which have been stated by an expert group. An Erlang distribution had been chosen for the elevated guideway and a Pert-Distribution for noise protection in cities [2].

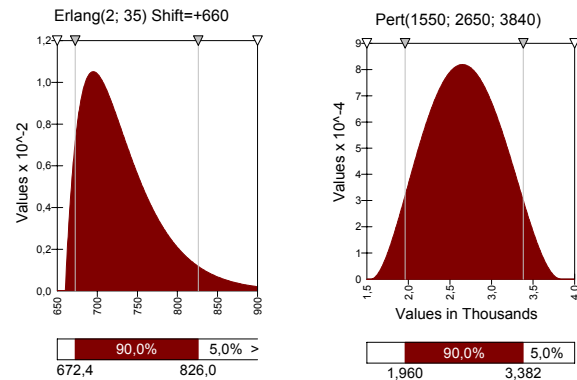


Figure 3: Erlang distribution for the elevated guideway and Pert-distribution for noise protection

3.3 Stochastic identification of quantities

The final quantities will be known only after the construction has been built. Therefore we have to submit stochastic values for the quantities. In a first step we may vary quantities, which we deduct from the design by a single uniform distribution. It is suggested, to vary at least by $\pm 10\%$, because it is typically, that between tender documents and the bill divergences of 5 % to 10 % are typically. If we regard, that in early design stages many technical details have not been decided, we have a big lack of information and we face many amendments. To include all these risks a variation of $\pm 30\%$ to $\pm 50\%$ of a single uniform distribution may be better.

To model the different risks more detailed, it is suggested, to use not only one but several distributions. Actually the impact of these approaches are still open, more research in this area has to be done.

4 RESEARCH RESULTS OF SIMULATIONS

4.1 The project

In this paper results of simulations are presented which were done for the comparison of a high-speed connection between Berlin and Budapest, passing Dresden, Prague, Vienna and Bratislava [3]. The ICE was the basis for traditional railway, with a maximum design-speed of 300 km/h. The alternative

system was the Transrapid with a design-speed of 500 km/h for the line. Each system was designed according to its specific advantages. For example for the railway system existing tracks were used to reach the existing stations near the city. Because it would be very expensive to pass through the existing stations for the Maglev system, new periphery stations were mostly assumed for this system. The gradient of the Maglev system can be up to 10 %, for the railway system only 3.5 % can be taken according to European standards [4]. The total distance for the Maglev system is approx. 885 km, the railway line is 53 km longer, so in total 938 km.

Client was the Sächsisches Staatsministerium des Innern (Saxon State Ministry of the Interior) consultants were IPE, Vienna, in joint venture with Kompetenzzentrum Hochleistungsbahnen und Magnetbahnsysteme (Center of Excellence of High Performance Railways) at the Technische Universität Dresden.

4.2 Distribution of costs

In figure 4 the distribution for the construction costs (without technical equipment and installation) for a 45 km long section of double-track for a typical section in between Berlin and Dresden is shown. Assumptions for both systems are:

- purchase of agrarian land
- no special noise protection

Typical for the Maglev system is:

- elevated guideway
- and for the traditional railway system
- small dams.

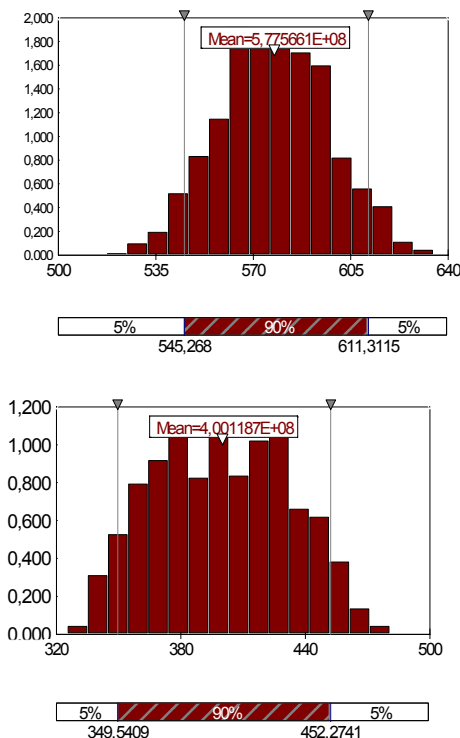


Figure 4: Distribution of costs for a 45 km long section top: Maglev system; bottom: railway system

The mean costs for the Maglev system are 12,83 million € per double-km ($577,56 \cdot 10^6 / 45$), whereas for the traditional rail system the costs are only 8,89 million € per double-km. But it is typical, that the 90%-quartil-range for the Transrapid is 13,58 - 12,12 = 1,46 million € per double-km, whereas it is 10,05 - 7,77 = 2,28 million € per double-km for the traditional rail system. This is mainly caused by much more earthwork for the traditional rail system, which is much more risky than concrete work of the beams of the Transrapid system.

It is typical for traditional railway systems that caused by the low gradient of the track, it is necessary to build more tunnels, whereas for Transrapid tunnels can often be avoided due to the possibility to climb amazing 10 %. In figure 5 typical costs for a railway-tunnel are shown. The mean is 43 million € per double-km, the 90%-quartil-range 23,96 million € per double-km.

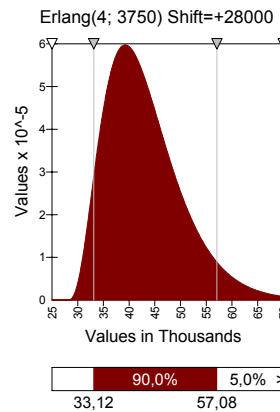


Figure 5: Distribution of costs for typical sections in ground-level area

5 SUMMARY AND OUTLOOK

The decision to realise high-speed transportation systems is depending on several factors. It should be done out of focus of

- users
- operator
- society and
- policy.

This includes of course different views, like economical, ecological, industrial policy and other more.

The economical view is usually very important, because there is a competition between maglev high-speed systems and traditional railway systems. Research work have shown, that investment costs are very important. The investment costs for a similar track for Transrapid and traditional railway show, that the Transrapid system is more expensive. Spe-

cial regard has to be taken for the risks. The use of stochastic cost distributions to calculate the investment costs show, that using only modes as deterministic values will give different results than the stochastic approaches. Already this understanding should lead to calculations using only stochastic values.

The stochastic attempt will also give a better understanding of risks. Due to design advantages for the Transrapid, the range of the 90%-quartil is smaller than for traditional railway systems.

The investment costs for the Transrapid are generally higher than for traditional railway systems. But the operational costs are lower, so that over the whole life-cycle the Maglev system may be more advantageously. Final results can only be determined for a specific project. This was the result of a research project [3].

More research work should be done to get more experienced dealing with stochastic approaches. This may be an advantageously way to take the various risks into account.

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