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Forecasts: uncertain, inaccurate and biased?

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Abstract

Cost Benefit Analysis (CBA) is the dominating methodology for appraisal of transport infrastructure projects across the globe. In order to adequately assess the costs and benefits of such projects two types of forecasts are crucial to the validity of the appraisal. First are the forecasts of construction costs, which account for the majority of total project costs. Second are the forecasts of travel time savings, which account for the majority of total project benefits. The latter of these is, inter alia, determined by forecasts of travel demand, which we shall use as a proxy for the forecasting accuracy of project benefits. This paper presents results from an on-going research project on uncertainties in transport project evaluation (UNITE) that find forecasts of demand to be not only uncertain, but at times also highly inaccurate and often displaying a concerning degree of bias. Demand for road projects appear to be systematically underestimated, while demand for rail projects appears to be systematically overestimated. We compare the findings in the present study with those of previous studies and discuss the implications for the validity of project appraisal in the form of CBA. It is recommended that more attention is given to monitoring completed projects so future forecasts can benefit from better data availability through systematic ex-post evaluations, and an example of how to utilize such data in practice is presented.

Appraisal of transport infrastructure

Cost benefit analysis (CBA) is the most common method employed for appraisal of public works projects, and transport infrastructure projects are no exception (Haezendonck 2007; Hayashi and Morisugi 2000; Mackie 2010; Odgaard, Kelly, and Laird 2005). CBA measures the total economic return of a project by comparing costs and benefits of a given project. Such appraisal is typically condensed into a set of performance measures in the form of net present value (NPV), internal rate of return (IRR), or benefit-cost ratio (BCR) (TRM 2003). Due to the complex interaction between transport related activities and other parts of society, there is a wide range of impacts that are desirable to evaluate when appraising transport infrastructure projects. However, for the vast majority of new projects there are two factors that dominate the results of an associated CBA. The first is the estimated construction costs, which is by far the largest item on the cost side of the budget. The second is the expected travel time savings, which is by far the largest item on the benefit side of the budget. It is common for these two factors to make up three fourths or more of the total costs and benefits respectively (Banister 2008; Mackie, Jara-Diaz, and Fowkes 2001), and for trivial road projects they will be closer to nine tenths of the total budget (Nicolaisen and Næss 2011). It is thus imperative that the associated forecasts of construction costs and travel demand have a considerable degree of accuracy if CBA results in their current form are to hold any validity as decision support for policy makers.

In the present paper we wish to evaluate the accuracy of forecasts used in transport infrastructure planning. In the case of road projects the demand forecasts are of course also important for the environmental impact assessments (EIA). We are interested in accuracy measured in terms of potential bias (a general tendency of deviation in a specific direction) as well as potential imprecision (a general tendency of a large spread). The distinction between inaccuracy in terms of bias and imprecision can be seen in Figure 1. Bias is mainly problematic because it introduces a systematic error that consistently under- or overestimates the performance of projects dependent on the direction of the bias. Imprecision is mainly problematic because it causes uncertainty about the exact performance measure and thus makes it difficult to rank alternatives against each other.

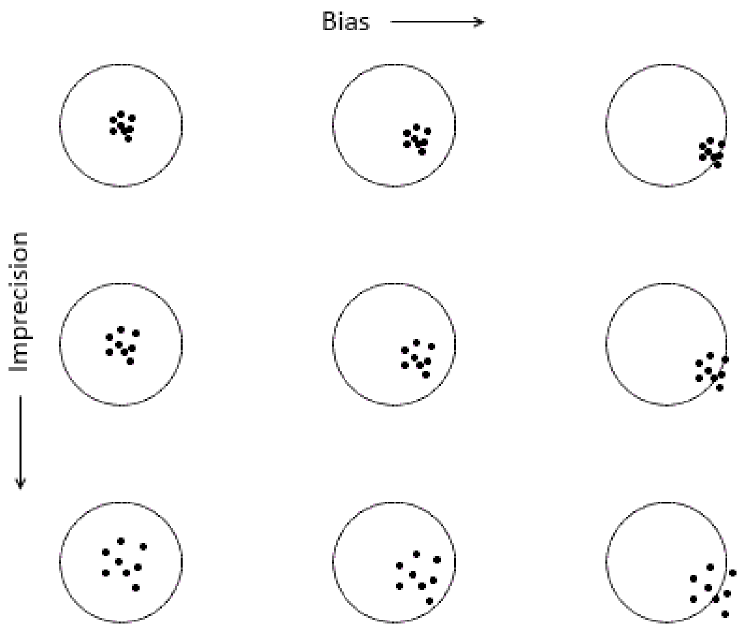

Figure 1: Inaccuracy can be the result of both bias and imprecision. Inspired by De Jongh (1998).

the forecasts available to policy makers at the time of project approval we use the available decision support in the form of CBA or EIA documents as a source of demand forecasts.

Previous studies of forecasting inaccuracy

Since the widespread introduction of computer-assisted transport modelling during the 1970s there has been a focus on the predictive accuracy of the demand forecasts, but there have been surprisingly few studies based on ex-post evaluations from larger samples of completed projects. Most of the ex-post evaluations come in the form of case studies that contain only a few or even a single project as reference. There are several reasons for this, but the result is that relatively few studies with large samples of ex-post evaluations exist for transport infrastructure projects, and especially so for demand forecasts. Furthermore, some of these fail to provide relevant information about the methodology employed or the source of data for either demand forecasts or traffic counts. An overview of the results from some of the largest studies of ex-post evaluations can be seen in Table 1. Ex-post evaluations of cost estimates have been more critically scrutinized, and we refer to Siemiatycki (2009) for an overview of results from previous studies in this field.

The levels of inaccuracy in the different studies have been summarized in Table 1, where projects are split into three categories: non-toll roads, toll roads, and rail projects. Inaccuracy is measured by the following formula[1]:

$$I = \frac{O - P}{P} \times 100$$

The mean values reported in Table 1 thus indicate the relative difference between expected and actual traffic volumes, i.e. a mean inaccuracy value of +10% indicates that 10% additional traffic materialized compared to the figures presented in the forecast. The results indicate a tendency in forecasts for non-toll road projects to be underestimated while forecasts for rail projects and toll road projects tend to be overestimated. This can be considered an expression of forecasting bias. In addition, we also observe a large degree of deviation from the mean in most studies. This can be considered an expression of forecasting imprecision. Both are of course problematic to the validity of subsequent decision support based upon such demand forecasts.

Study	Sample	Mean	Std. dev.
Mackinder & Evans (1981)	Road: 44	-7%	N/A
National Audit Office (1988)	Road: 161	+8%	43
Pickrell (1990)	Rail: 10	-65%	17
Fouracre et al. (1990)	Rail: 13	-44%	26
Flyvbjerg et al. (2005)	Road: 183 / Rail: 27	+10% / -40%	44 / 52
Bain (2009)	Road (toll): 104	-23%	26
Parthasarathi & Levinson (2010)	Road: 108	+6%	41
Welde & Odeck (2011)	Road: 25 / Road (toll): 25	+19% / -3%	22 / 21

Table 1: An overview of results from previous ex-post studies of forecasting accuracy. Based on Nicolaisen (2012).

The UNITE study approach

Due to the lack of project specific data in many of the previous studies we conducted an ex-post evaluation of transport infrastructure projects in Denmark, Norway, Sweden, and the United Kingdom. The purpose of this study has been twofold. First, to investigate whether the results from previous studies hold true for more recent projects completed in these case areas. Second, to identify characteristics of projects that are prone to bias or imprecision in their demand forecasts. It is probably a fairly uncontroversial claim that forecasting of future events is bound to be associated with some inherent uncertainty that makes completely deterministic forecasting impossible, and thus some degree of inaccuracy is to be expected. However, as Table 1 suggest, forecasts are not only uncertain, but at times also highly inaccurate and often displaying a concerning degree of bias. The data included in the present study, where available, contain data with regard to the forecasted travel demand (F), as well as the estimated observed values (E) after the projects have been completed.

[1] I: Inaccuracy, P: predicted value, O: observed value

While (I) seem relatively simple to calculate, there are both theoretical and practical problems in obtaining validated (E) and (F) values. First, planning and construction of large projects often run across a decade or more, which often entails changes to the original design. If a forecast is made for a solution that differs significantly from the final project, the forecasts are unlikely to be very accurate. Secondly, the boundaries of the network to be included need to be well-defined. When conducting large scale traffic forecasts not only the link to be constructed needs to be scrutinized, as most often a whole network of links will be affected. However, sufficient data is often only available for the new link. Thirdly, consecutive forecasts have often been made due to multiple assessments of the project, and it might be difficult to pinpoint exactly when a political decision to go ahead with it was made. Finally, a major obstacle is lacking information about the relevant reference points and data types. Throughout the construction of the database sample it has become obvious that even projects with reasonable data representation neglect to provide a year of reference for the traffic counts/forecasts. Typically, it is assumed that the reference year is the opening year. However, this assumption often provides bias to the data in terms of ramp-up traffic, varying degree of data formats (i.e. annual daily traffic vs. annual weekday traffic) and in many cases does traffic counts simply not exists for the opening year.

The point of raising the obstacles of the data gathering process is to highlight the key assumptions and simplifications necessary to conduct ex-post evaluations of forecasting accuracy, especially in situations where data availability is often sparse. These issues are rarely given much explicit attention when comparing the findings from the studies presented in Table 1, but they can obviously have great impact on whether forecasts are deemed accurate or not. It is not uncommon for different ex-post evaluations to reach radically different conclusions about the performance of the same project[2]. For example, certain projects in the database for the present study are also included in Flyvbjerg et al. (2005), but due to methodological differences the authors reach different conclusions regarding forecasting accuracy for these projects than we do[3]. The main reason behind this is that they do not appear to adjust for mismatching reference points in cases where the opening year for a project is different than the target year for the forecast, whereas we adjust the demand values based on the following formula[4]:

$$A = O(1 + r)^{Y-T+1}$$

This adjustment typically serves to adjust the inaccuracy measure closer to zero, as the majority of projects open later than the forecast target year and have thus experienced additional growth in this period. Whether this approach is more valid than e.g. Flyvbjerg et al. (2005) is for certainly debateable and depends on the specific purpose of the ex-post evaluation. It is, however, important that the interpretation of the resulting measure of inaccuracy is treated with such important methodological differences in mind.

Results of ex-post evaluations in Scandinavia and the UK

In this section we provide some of the findings from the present study for forecasting accuracy. These are grouped into two overall categories road and rail projects. Overall, road projects and demand data have been more readily available than rail projects. The results presented in this section are based on Nicolaisen (2012), and we refer to this source for more detailed discussion of both methodology, results and implications. The distribution of accuracy for road and rail projects can be seen in Figure 2 and Figure 3 respectively.

[2] We refer to Brinkman (2003) for more examples of such conflicting conclusions.

[3] See Nicolaisen (2012) for an elaborate discussion of the adjustment problem and its impact on results ex-post evaluation.

[4] A= adjusted value, O=observed value, r = growth trend, Y = opening year, T = forecast target year

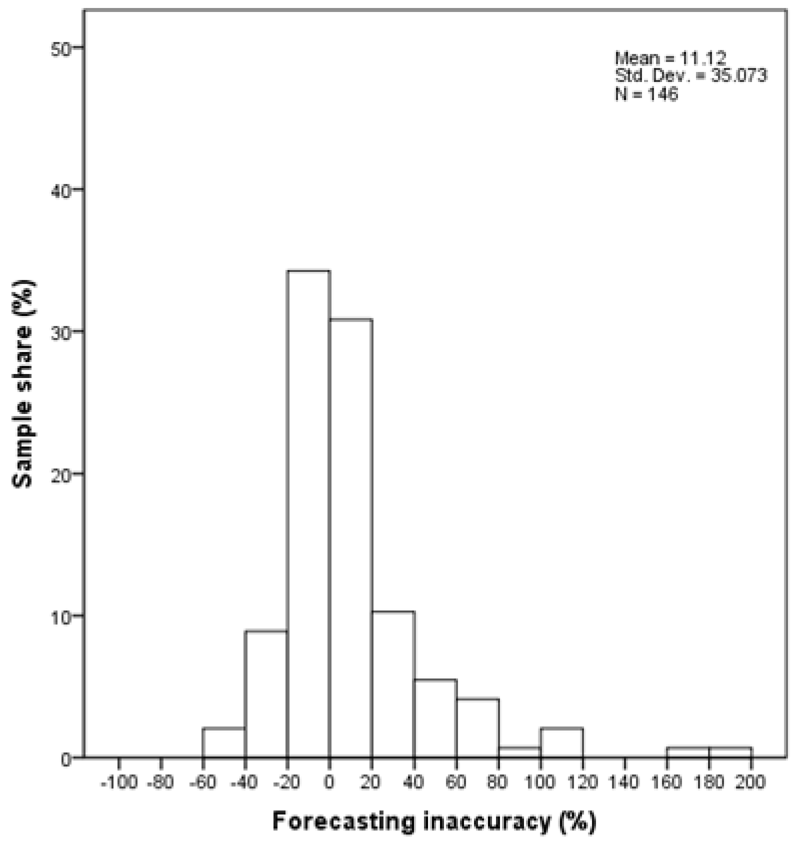

Figure 2: Inaccuracy of demand forecasts for road projects Nicolaisen (2012).

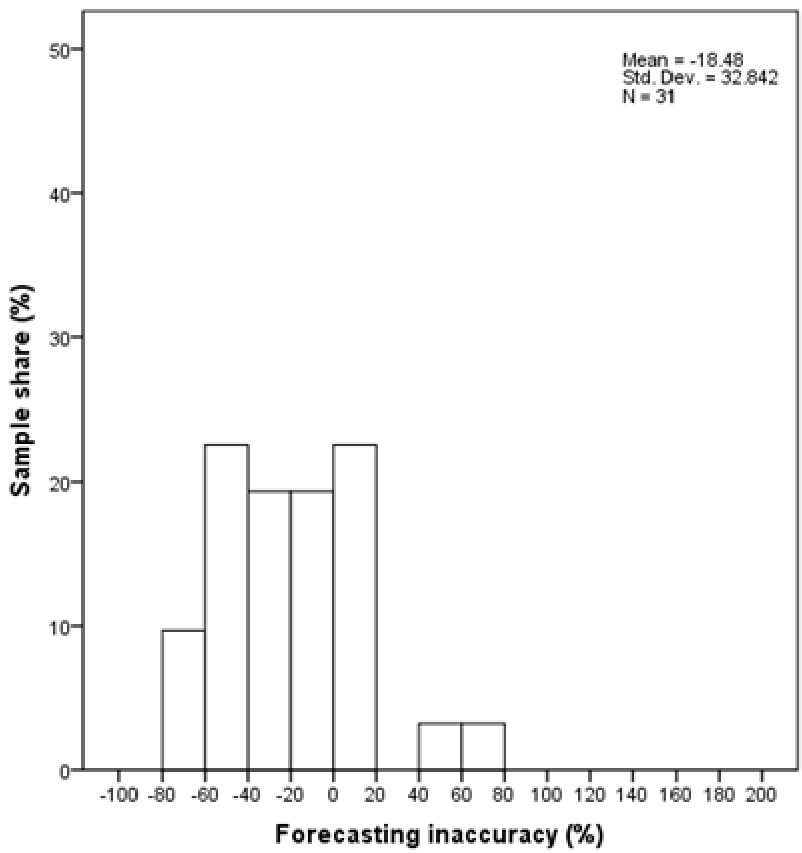

Figure 3: Inaccuracy of demand forecasts for rail projects Nicolaisen (2012).

Figure 2 displays the observed inaccuracy of demand forecasts for road projects. It should be fairly clear from this figure that the results of the present analysis are well in line with the results of previous studies of road projects (see Table 1). This goes for inaccuracy measured both in term of bias as well as imprecision. There seems to be a tendency of underestimating demand in the appraisal for road projects, and more than one third of the projects experience traffic volumes that deviate more than ±20% from forecasts. The heavy tail on the right indicates that the observed bias is partly a result of a small subset of the sample that experiences quite dramatic deviations between forecast and actual demand levels.

Figure 3 displays the observed inaccuracy of demand forecasts for rail projects. Once again it should be fairly clear that the results of the present analysis are well in line with the results of previous studies, indicating a general trend of demand overestimation and a large spread of forecasting accuracy in the sample. However, the mean inaccuracy value for rail projects differs quite a lot from those reported in previous studies, whereas the mean value for road projects was very close to that of previous studies. This indicates that forecasting bias has been less problematic in the rail projects from the present study compared with those of previous studies.

The results from the present study support those of previous studies in terms of relatively large standard deviations observed in the ex-post evaluations of demand forecasts, although bias appears to be much smaller for rail projects in the present study when compared to those in Figure 1. The large degree of imprecision makes it difficult to clearly distinguish between results for different projects types, and at best we can consider the observed inaccuracies as crude tendencies. Splitting the samples into specific types of road or rail projects would be highly desirable, but given the relatively small sample sizes this would not yield very reliable results for rail projects. The sample for road projects is more suitable for this purpose, and if we split this into different types of road projects we get an indication of some different tendencies among the various subgroups. The results of the different subgroups can be seen in Table 2, which suggest that demand forecasts for upgrades to existing links are relatively unproblematic (low bias and imprecision), whereas more substantial changes to the transport network have quite severe effects on the ability to provide accurate predictions of travel demand (high bias and imprecision).

Project type	**Sample**	**Mean**	**Std. dev.**
Fixed link	19	28%	66
Bypass	39	17%	32
Motorway (new link)	38	9%	29
Motorway (upgrade)	50	2%	20

Table 2: Inaccuracy of demand forecasts for road projects split on different project types (Nicolaisen 2012).

Analysis of results and discussion of implications

While road projects display less forecasting inaccuracy both in terms of imprecision and bias when compared to rail projects, the inaccuracy is quite considerable for both types of projects when employed for subsequent appraisal methods such as CBA. This can distort the performance measures quite drastically, which in turn can lead to a different prioritization of investments than if this information had been available to policy makers prior to project approval[5]. We therefore advocate better treatment of

[5] This is based on the perspective that the quality of decision support should be evaluated based on whether it leads policy makers to make the same decisions as if they had complete information about the consequences of different

uncertainties in the preparation of decision support, to inform policy makers of the possible outcomes of infrastructure projects in relation to the variability of the construction costs and travel demand. Means to accomplish this will be briefly discussed in the remainder of the present paper and will also be the topic of other presentations from the UNITE project at Trafikdage 2012 (e.g. Salling 2012).

A necessary condition for improved uncertainty management is a structured archiving of relevant project data to be used for ex-post evaluations. The present study has tried to construct a database based on relatively simple data items, but the quality of this data is far from satisfactory for the purpose of uncertainty management. One of the main obstacles in achieving the necessary data quality is the poor access to relevant documentation for both road and rail projects. In this relation there are two primary obstacles that need to be overcome. First, a structured framework for ex-post evaluations must be specified. This should take into account the primary preferences of policy makers for the type of project being assessed, such as travel time savings for congestion relief initiatives, accident reductions for safety improving measures, emission levels for environmental abatement projects, etc. Currently there is very little follow up on whether the objective of a project has been achieved compared to the rigorous analysis of expected impacts prior to project approval. In practice this means that we have no information on whether the expected benefits (e.g. in the form of time savings) actually materialize. Furthermore, due to the difficulty in retrieving the necessary information it is often impossible to undertake such assessments by external peer-reviewers. A consistent ex-post evaluation programme for completed projects is thus a necessity if we are to improve uncertainty management in decision support. Second, the responsible authorities must be required to supply the necessary data items in the ex-post evaluation format during the different phases of the project. As already mentioned, it is often difficult, if not impossible, for external peer-reviews to obtain this information after project completion, and it would much more resource efficient to have a structured archiving system for this data. This would also result in improved validity and reliability of the results, since many of the existing ex-post evaluations suffer from relatively weak source material.

Both of these requirements of course involve an additional amount of resources devoted to such a monitoring programme, but it would improve the available data for decision support tremendously. In addition, it would provide an assessment of whether the objectives of individual projects are actually fulfilled. It would also provide rich empirical material for research projects, which often suffer from a severe lack of data availability in this area. Since both the observed forecasting inaccuracy and lack of available data is an issue in most countries, such a programme would surely produce state-of-the-art research results of great international interest. Researchers at DTU have already worked on developing practical methods of employing such data for improved decision support for some time, and in the next section we will use a reference class approach that is currently being refined in the UNITE research project to show how the results of such a systematic ex-post programme could be used in practice.

Using ex-post data in decision support

In order to account for uncertainties underlying the construction costs and travel time savings Salling (2008) proposed to supplement cost-benefit analysis with a quantitative risk assessment (QRA) and Monte Carlo simulation by applying relevant probability distributions to these impacts. As already mentioned, the traditional CBA communicates its results by one or more of the following condensed single performance measures: BCR, NPV or IRR. These measures are typically only communicated as point estimates and provide little or no information about the robustness of these results. By applying the abovementioned risk analysis techniques it is possible to get a more nuanced perspective on the uncertainties related to the socio-economic feasibility of projects. In practice this is achieved by transforming the point estimate into an interval by comparing it with the forecasting accuracy observed in ex-post evaluations from previously completed projects. The performance indicator is represented in terms of a certainty graph depicting the

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alternatives at the time of deciding between them (including the option of doing nothing). We share this perspective and refer to a Van Wee (2011) for a more thorough discussion of such issues.

likely outcomes of an investment by the use of probability estimates for the different values. In this way policy makers are informed about how the feasibility of an investment can change in relation to the variability of forecasted construction costs and travel time savings. The interval results are produced by identifying and simulating the probability distributions for latter impacts, however, the validity of the QRA obviously depends on the relevance of these probability distributions. Salling (2008) has showed that the Erlang and Beta-Pert probability distributions are adequate to be applied for the construction costs and travel time savings.

The input for probability distributions can be derived using a reference class forecasting technique based on historical information about the similar projects in the past. The main difference between this approach and traditional forecasting is the use of previous forecast as an input for producing future forecasts, as proposed by Goodman (1955). The theoretical and methodological foundations of prospect theory, which reference class forecasting is based upon, were first described by Kahneman and Tversky (1979) and later applied for cost data by Flyvbjerg (2008). The data presented in Figure 2 and Figure 3 can be used to provide the necessary historical information that is used to define the probability distributions. As our study has mainly focused on the inaccuracies in the demand forecast of the past transport infrastructure projects, we therefore will use small case example to illustrate how such information can be used when examining an investment and the robustness of its socio-economic feasibility. However, given the necessary data it could also be expanded to incorporate additional variables, e.g. as construction costs. Given that we do not have data for total project benefits we use the inaccuracy distribution for travel demand as a proxy. This is problematic since the relationship between travel demand and travel time savings is non-linear. In order to do a valid reference class forecast on this parameter we would need significantly more detailed data items for completed projects than is presently available, and it is partly such data insufficiencies that a systematic ex-post evaluation programme could help alleviate. For now we will make do with this proxy distribution to illustrate the method in practice.

Example: Frederikssundmotorvejen

To demonstrate the potential of quantitative risk analysis and reference class forecasting by the use of ex-post data, the case of Frederikssundsmotorvejen in Denmark has been chosen. The case demonstration makes of use of information described by Jensen (2008), in which the examination of four alternatives for a connection between Frederikssund and Motorring 4 in Denmark is presented. This includes the three upgrade alternatives replacing the old Frederikssundsvej and one alternative for the construction of motorway on a new alignment. The results of the examination pointed towards the latter alternative as the most socio-economically feasible at a BCR value of 1.83. By applying the quantitative risk analysis we now examine the robustness of this result with the regard to the variation of the forecasted demand. We use the Beta-Pert probability distribution for observed inaccuracy in demand forecasts proposed by Salling (2008), where the input for our distribution is based on ex-post evaluation of the 146 road projects in Figure 2. The following input is derived as the minimum, most likely and maximum data points for the traffic demand and correspondingly travel time savings: -45%, 11%, 194%. Based on these data points the Beta-Pert probability distribution is placed on the travel time savings and simulated together with the uplift of construction costs by 30 % as required in the appraisal of road projects.

Figure 4 presents the simulation results in terms of certainty graph, where the BCR is given on the x-axis and the probability of achieving BCR ≥ 1 is on the y-axis. The so-called certainty value (CV) depicting he probability for the investment to be feasible is derived on the basis of the threshold value (BCR = 1.0). The CV for our examined alternative is equal to 92%. Given that the project is comparable to our reference class there is thus a high probability that the project will provide a net-benefit in spite of possible demand shortfalls.

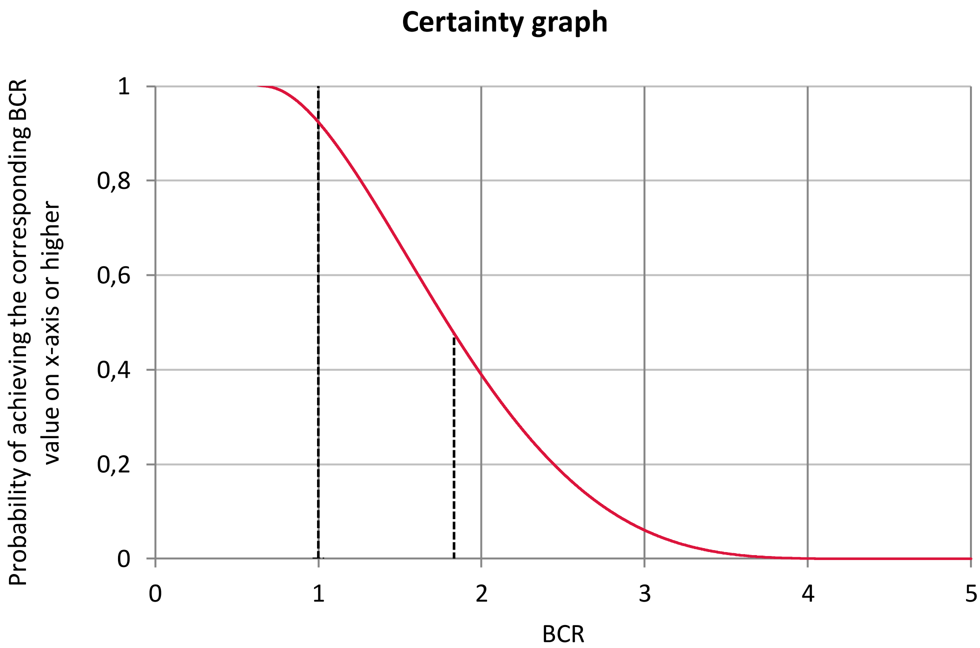

Figure 4: The Monte Carlo simulation result for the Frederikssundsmotorvej case.

As can be seen from the results of risk analysis in Figure 4, the feasibility of an investment becomes quite dependent on the inaccuracy distribution of forecasts for completed projects. Using the reference class forecasting technique applied with quantitative risk analysis can help to make more informed decisions by highlighting some of the known uncertainty associated with forecasting given performance indicator.

Concluding remarks

The purpose of the present article is to highlight some of the uncertainty and inaccuracy in appraisal of transport infrastructure projects. This has been done by presenting an ex-post evaluation of the forecasting accuracy of completed projects based on a database constructed for the UNITE research project. The results clearly show that demand forecasts are associated with quite significant levels of uncertainty, and a similar case can be made for cost estimates. The combined uncertainty of demand and cost forecasts is quite crucial to the validity of project appraisal, since these are the dominating impact factors upon which most impact appraisals are based. However, the forecasts are often treated with far more certainty that seems warranted, and we have therefore also discussed how decision support in the face of inevitable forecasting-related uncertainty can be improved.

Obtaining the necessary data for the present study has been quite difficult, and we therefore advocate the utmost importance of establishing of a systematic ex-post evaluation programme in Danish transport planning. The purpose of such a programme would be three-fold. First, to assess whether project objectives are being met for completed projects (impact monitoring). Second, to provide the necessary data for improving future decision support for policy makers (evidence-based policy making). Third, to position Danish research in transport planning as state-of-the-art internationally (knowledge export). Access to quality data is perhaps the primary obstacle for improving the quality of decision support and state-of-the-art research in transport planning, and the introduction of new, sophisticated modelling techniques are only likely to introduce considerable uncertainty through measurement error if this issue is not specifically addressed. In regard to the validity and reliability of model-based decision support, the quality of input data is as important as the quality of the model structure. Sadly, input data often lack in quality due to insufficient monitoring, and rather than attempting to amend this problem it seems most stakeholders choose to accept it and work with what they have. This is an acceptable solution from the perspective of a single stakeholder when faced with a lack of data for a specific case, but from a system perspective it is not acceptable if the data shortage is then not addressed for future cases.

Via a case example we have tried to illustrate one of the many ways in which such data could be utilized for improving decision support. The example was based on quantitative risk assessment, but in practice a systematic ex-post evaluation programme could be used for a large array of both qualitative and quantitative decision support tools. An example could be an extensive project portfolio that planners can access when assessing new policy initiatives, in order to compare it with similar initiatives in the past. Such a portfolio could easily include both the quantitative data necessary for QRA as well as more qualitative descriptions of the purpose of the project, the political visions in the period it was introduced, obstacles that were discovered during planning or construction, or additional benefits that was not accounted for in the project appraisal. Many of these issues lie outside the capabilities of traditional modelling based forecasts, and since forecasts are often highly inaccurate this case-study knowledge would be quite valuable. However, a necessary condition for all of these is better ex-post evaluation procedures.

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