

# TRANSPORT NOTES

TRANSPORT ECONOMICS, POLICY AND POVERTY THEMATIC GROUP



THE WORLD BANK, WASHINGTON, DC

Transport Note No. TRN-7

January 2005

## Notes on the Economic Evaluation of Transport Projects

*In response to many requests for help in the application of both conventional cost benefit analysis in transport and addressing of the newer topics of interest, we have prepared a series of Economic Evaluation Notes that provide guidance on some of issues that have proven more difficult to deal with.*

*The **Economic Evaluation Notes** are arranged in three groups. The first group (TRN-6 to TRN-10) provides **criteria** for selection a particular evaluation technique or approach; the second (TRN-11 to TRN-17) addresses the selection of values of various **inputs** to the evaluation, and the third (TRN-18 to TRN-26) deals with specific **problematic issues** in economic evaluation. The Notes are preceded by a **Framework** (TRN-5), that provides the context within which we use economic evaluation in the transport sector.*

*The main text of most of the Notes was prepared for the Transport and Urban Development Department (TUDTR) of the World Bank by Peter Mackie, John Nellthorp and James Laird, at the Institute for Transport Studies (ITS), University of Leeds, UK (The draft text of Note 21 was prepared for ITS by I.T. Transport Ltd). TUDTR staff have made a few changes to the draft Notes as prepared by ITS. Funding was provided from the Transport and Rural Infrastructure Services Partnership (TRISP) between the Department of International Development (DFID) of the Government of the United Kingdom and the World Bank.*

*The Notes will be revised periodically and we welcome comments on what changes become necessary. Suggestions for additional Notes or for changes or additions to existing Notes should be sent to [rcarruthers@worldbank.org](mailto:rcarruthers@worldbank.org)*

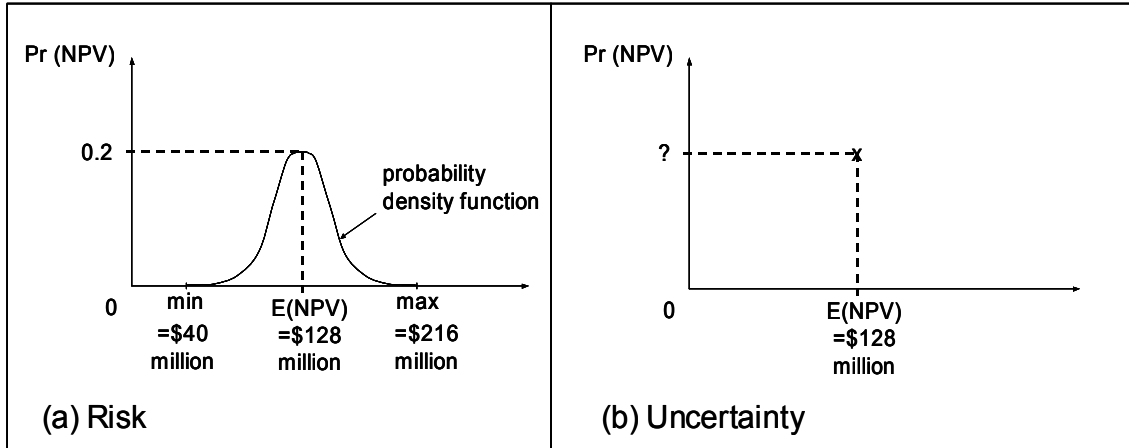
## RISK & UNCERTAINTY ANALYSIS

One statement that can confidently be made about any transport project is that the costs and benefits are uncertain. An important question is 'how uncertain'? By analysing the risk and uncertainty which surrounds the project the probability of a poor outcome can be assessed. In addition, it is often possible to identify ways in which the project can be made more robust, and to ensure that the risks that remain are well managed. Risk and uncertainty analysis is therefore a standard component in the project reporting requirements for World Bank projects. Risk and uncertainty analysis also features other in World Bank tools, such as the RED model (see Note *Low Volume Rural Roads*).

This note reviews the general principles of risk and uncertainty analysis in transport (Section [1](#)); and outlines the three principal methods which may be used – sensitivity analysis (Section [2](#)), switching values (Section [3](#)) and Monte Carlo simulation (Section [4](#)). Implications for risk management are given in Section [5](#) and Further Reading is referenced at the [end](#).

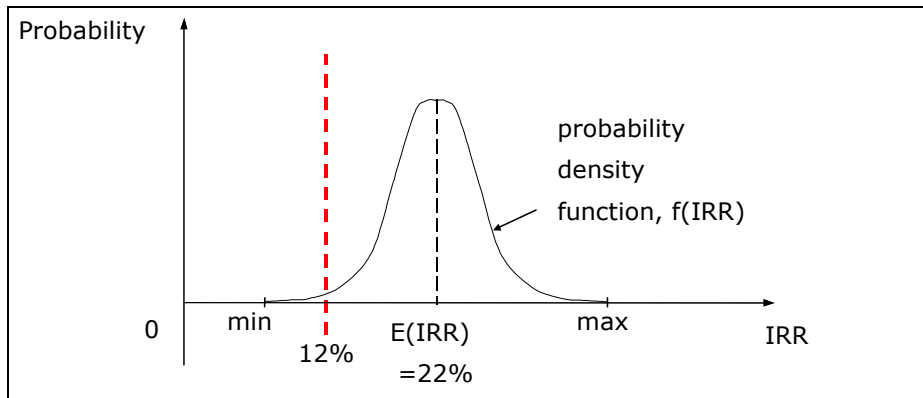
### GENERAL PRINCIPLES OF RISK AND UNCERTAINTY ANALYSIS IN TRANSPORT

At the start, we can differentiate between risk and uncertainty. **Risk** is the situation where there is a set of possible outcomes from the project, and the probability of each outcome is known (as in Figure 1(a)). **Uncertainty** is the situation where there is a set of possible outcomes, but the probability of each one is not known (as in Figure 1(b)). In Figure 1(b), only the **expected** (or **mean**) outcome is marked - estimating this is often the focal point of project appraisal in practice, however without some understanding of the likelihood of the predicted outcome, it is worth asking: "how much confidence can be placed in the appraisal results"?



**Figure 1. Risk vs. Uncertainty**

Consider the following example. When we say that the Internal Rate of Return (IRR) of a project is 22% (see *Note 1: When and how to use NPV, IRR and Adjusted IRR*), what we usually mean is that the expected outcome (strictly the 'mean' IRR) is 22%. Around this is a **distribution** of possible outcomes. [Figure 2](#) illustrates this, and highlights the 12% Internal Rate of Return which is the usual minimum criterion for **acceptability** of World Bank projects (see *Note 1: When and how to use NPV, IRR and Adjusted IRR*). In this case there is a chance that the IRR may turn out to be less than 12%, but that chance is very small. This type of information is very useful to decision-makers.



**Figure 2. A Probability Distribution on the Internal Rate of Return (IRR)**

Once a project is deemed acceptable, the World Bank's usual decision criterion for projects is then to maximise the expected NPV (see *Handbook on Economic Analysis of Investment Operations* (World Bank, 1998) [i]). It is worth noting that this is not the only possible decision criterion:

- ❑ a cautious, or 'risk averse' approach, is to maximise the minimum outcome (called the 'maxi-min' strategy, for obvious reasons). This would favour projects which are a 'sure bet', having only a small downside risk.
- ❑ more complex strategies, seeking to balance the risk across a portfolio of investment or to minimise the 'regrets' – the consequences of a lower-than expected outcome – are discussed in a range of source books, including Pearce and Nash (1981) [ii].

In order to make progress with risk analysis in practice, we need to know how the probability distribution in [Figure 2](#) is arrived at? The IRR is determined by the flows of costs and benefits over time, so any riskiness in particular cost or benefit items can be traced through into the IRR. In turn, the risk in each cost or benefit item usually depends on key underlying factors. [Box 1](#) sets out what these factors may be.

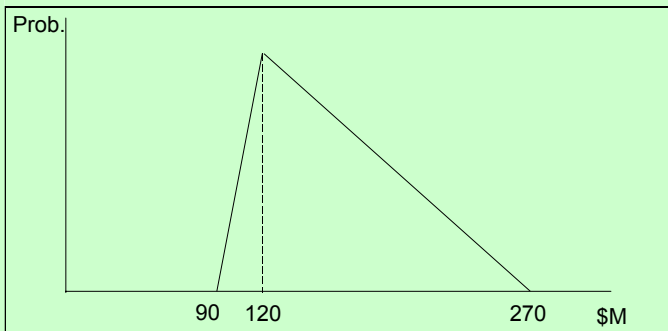
**Box 1. Sources of Risk in Transport Appraisal**

**Construction cost risk**

It is very common for the costs of major construction projects to be underestimated in appraisal. Underlying reasons for this include:

- engineering risks associated particularly with uncertain ground conditions (geology) and high technology structures, equipment and methods;
- variable input prices, especially energy, labour and imported materials;
- the complexity of the project management function.

Whether these risks are directly a concern for the purchaser depends on the allocation of risk under the contract. However, even when the risk is fully transferred to the contractor, a premium will usually be charged to bear this risk, so the purchaser continues to face a cost. Figure 2 shows a typical probability distribution for construction cost – most of the risk is downside risk, so the distribution is not symmetrical. So in this case, the expected (mean) value exceeds the most likely value (\$120M).



**Figure: A Probability Distribution on Construction Cost**

**Operating and maintenance cost risks**

These are fuelled by some of the same sources as construction risk, especially rising real labour costs, energy prices and exchange rate risk on imports.

**Demand risks – ‘traffic risk’ and ‘revenue risk’**

Once a project is complete, the benefits derived from it depend crucially on the forecast user demand being realised. Demand is vulnerable, however, to:

- economic shocks, including fuel price shocks and economic boom or recession;
- changing demographics;
- shifting preferences and growth of competing facilities – eg. roads in competition with rail;
- political intervention;
- random error in the forecasts.

The benefits, in the form of consumers’ surplus, typically decrease as demand decreases. Revenue decreases too, which is an issue for the financial sustainability of projects.

**Other risks**

Mackie and Preston (1998) [iii] identified 21 sources of error and bias in transport appraisal. Many of these fall under the general heading of ‘appraisal optimism’, suggesting that downside risks outweigh upside risks in most real situations. HM Treasury (2002), Section 4.11 gives cautionary guidance on this.

**SENSITIVITY ANALYSIS – ‘WHAT IF’ SCENARIOS**

The simplest form of sensitivity analysis involves the creation of ‘what if’ scenarios to reflect the principal risks surrounding the project. Suppose, for example, that a bridge project is believed to be subject to demand risk, because much of the forecast traffic is generated traffic (see *Note 6: Treatment of Induced Traffic* and *Note 7: Demand Forecasting Errors*) which depends on changing patterns of trade and residential location. The analysts responsible for forecasting demand advise that they can only be confident in their forecasts to within +/- 30% of the expected value.

To assess the significance of this risk, the appraiser re-runs the IRR calculation for demand at +30% and -30%, and presents these as ‘what if’ scenarios, in [Table 1](#).

**Table 1. Sensitivity of IRR to Demand Risk for a Bridge**

Scenario	Demand in Year 2005, vehicle flow per day	IRR
‘Low’ demand	14,000	13.5%
Expected demand	20,000	16.0%
‘High’ demand	26,000	19.0%

Since the lowest IRR is above the 12% acceptable rate of return, this gives some confidence that the project is robust to the demand risk identified.

**SWITCHING VALUES**

The World Bank’s preferred approach to sensitivity analysis is to calculate **switching values**. These are the values of the ‘risky’ variables at which the IRR of the project equals the discount rate, and the NPV=0. [Table 2](#) gives an example for the bridge project.

**Table 2. Switching Values for a Bridge**

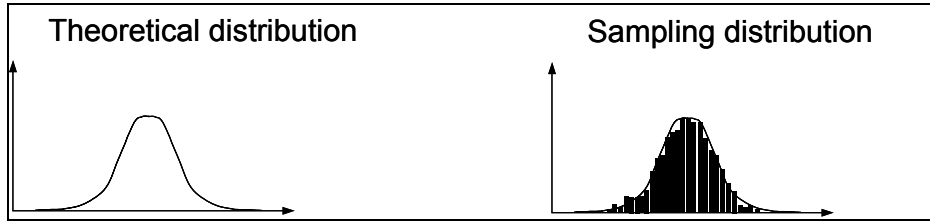
Variable	Switching value
Demand (vehicle flow in 2005)	-36%
Construction cost	+44%
Maintenance cost (in 2005)	+70%

Switching values prompt the reader to consider how (un)likely the required switch is, which gives a handle on the robustness of the project to each variable. However, in common with basic ‘what if’ sensitivity analysis, switching values have one great weakness: it becomes complex to understand the risks when several variables are acting simultaneously, rather than one at a time. To explore this, Monte Carlo simulation provides a higher level of analysis.

**MONTE CARLO SIMULATION**

A leading form of ‘quantitative risk analysis’ Vose (1996) [iv], Monte Carlo simulation produces a single probability distribution for IRR (or NPV), based on the risk profiles for all the relevant ‘risky’ variables. The method works in the following way:

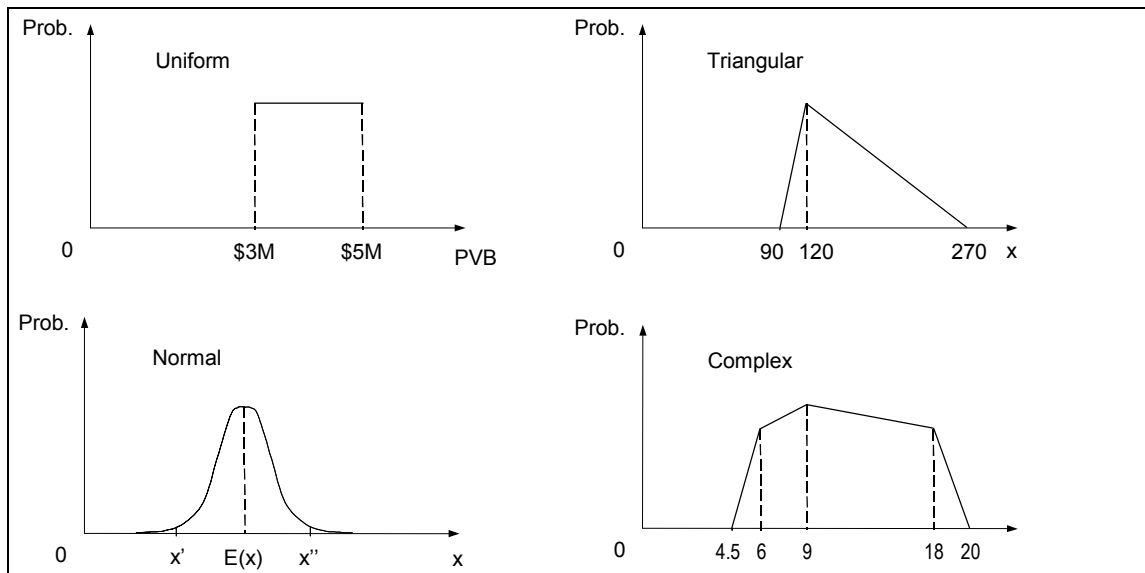
- a) the analyst is required to define a probability distribution for each variable - demand, construction cost, operating cost and so on. This is not as difficult as it sounds (see below).
- b) the Monte Carlo procedure then samples randomly from each of the different distributions and calculates the IRR (or NPV), many times over. By taking a very large number of samples from each distribution, the sampling distribution is made to approximate closely the theoretical distribution ([Figure 3](#)).



**Figure 3. The Law of Large Numbers in Application**

c) the outcome is a distribution in terms of IRR (or NPV), such as that shown in Figure 1. The more samples are taken, the more stable the distribution becomes.

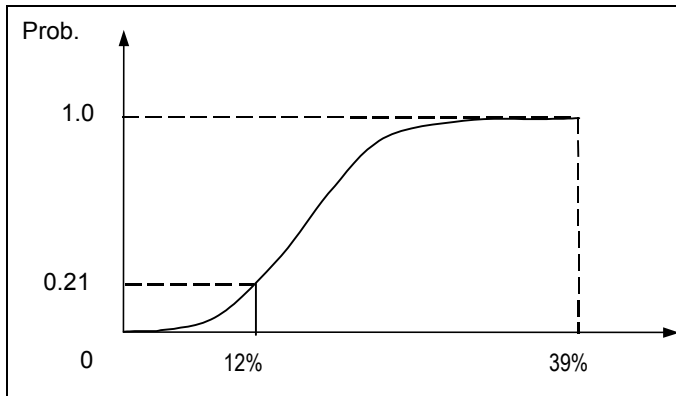
We said in (a) that Monte Carlo simulation requires information about the probability distributions for each 'risky' variable. This is more straightforward than it sounds. For example, based on our understanding of the variable in question we might choose a 'shape' for the probability distribution from the set shown in [Figure 4](#).



**Figure 4. Alternative 'Shapes' for Probability Distributions**

For example, we might adopt a triangular distribution for construction cost. Then by specifying the maximum cost, the minimum cost and the 'modal' cost (120 in the Figure), the distribution is fully defined. Alternatively, suppose we judge that demand is normally distributed around the expected flow  $E(x)$ . We can then fix the distribution by setting the 95% confidence limits on the distribution  $x'$  and  $x''$ .

The simulation itself is carried out by specialised computer software, however, this software is readily available as an add-in to conventional spreadsheet applications and reasonably easy to use. The results will enable the appraiser to report not only the mean value of the project IRR, but also the distribution of the IRR (as in Figure 1) and the cumulative distribution which is useful for representing the probability of meeting the desired rate of return ([Figure 5](#)). In this example, there is a 79% probability that the IRR will exceed 12%.



**Figure 5. Cumulative Distribution on IRR**

Further advice on Monte Carlo simulation is available in the *Handbook on Economic Analysis of Investment Operations* (World Bank, 1998) [i] and in the many textbooks on the market, such as Vose [iv].

An example of the application of this form of risk analysis to a toll road project in Colombia is shown in Box 2

**Box 2. Risk Assessment in the El Vino-Tobiagrande-Salgar Toll Road Project**

This project included the construction of a new 68.4 km highway from Tobiagrande to Salgar, including 19.5 kms of tunnels and 2.9 kms of bridges. This would significantly improve communications between the two largest population centers of the Colombia – Bogota and Medellin. This raised significant problems in assessing not only the likely construction costs but also the rates of traffic growth and newly generated traffic associated with such a major improvement to the infrastructure of the country. To handle this, the economic evaluation included a Monte Carlo simulation of the effect of the estimated risk profiles for these three elements.

In addition, risk analysis was performed to test the effect on the economic feasibility of the project with probabilistic changes in the assumptions related to traffic growth, construction and maintenance costs, and generated traffic. Traffic volume was varied according to major deviations in economic growth during the analysis period, assuming a beta distribution of economic (and consequently, traffic) growth rates between -0.2 and 1.5, with a median of 0.75. Generated traffic also is varied assuming a beta distribution with changes in the percentage of generated traffic from 0 to 1.2 of the estimated values and a median of about 0.9. Construction and maintenance costs were varied following a triangular distribution with a maximum of 1.7 and a minimum of 0.95 of the estimated costs. A Monte-Carlo simulation of these risks yields a distribution of economic rates of return with a probability of 25 percent of being lower than 12 percent in the case of not considering the passenger-time benefits and of about 11 percent in the case of including those benefits.

Colombia Toll Road Concession Project, Project Appraisal Report, Report 17986, June 1986  
 ([http://imagebank.worldbank.org/servlet/WDSContentServer/IW3P/IB/1999/06/03/000009265\\_3980709144721/Rendered/PDF/multi\\_page.pdf](http://imagebank.worldbank.org/servlet/WDSContentServer/IW3P/IB/1999/06/03/000009265_3980709144721/Rendered/PDF/multi_page.pdf))

## RISK MANAGEMENT

A first step towards effective risk management is **risk registration**, which includes:

- recognition that a particular set of risks are relevant in planning and implementating the project;
- identification of these risks, and at a very basic level what they are linked to (eg. construction cost of high-technology bridges on a road project; toll road revenues linked to demand growth, in which future income growth and car ownership are key factors; etc.)

Registering risks allows all parties within a project to remain aware of risks, and to **monitor** development of known risks as a project progresses. The risk register might contain quantitative information about risk – if any is available – and even a description of the type of probability distribution it is believed to follow.

More pro-actively, the project planner can think about **prevention, control** and **transfer** of risks. Prevention may be possible by, for example, choosing tried-and-tested solutions in place of riskier innovative ones. Another measure which can play a major role in preventing risk is a comprehensive maintenance programme, which is both designed and implemented to ensure that both level of service delivered by transport assets and the costs of operation remain in line with the project plan (see *Note 8: Treatment of Maintenance*). Risk control may be exercised by setting up monitoring systems which can alert project managers to emerging problems. Risk transfer can be used at the contract drafting stage to balance risk and reward for each partner in the contract – including the public sector and private partners [v].

## FURTHER READING

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[<sup>i</sup>] The World Bank (1998), *Handbook on Economic Analysis of Investment Operations*, Chapter 12. The World Bank, Washington, DC. [Available online at: <http://www.worldbank.org/education/economiced/project/projwork/Handbook.pdf>]

[<sup>ii</sup>] Pearce DW and Nash CA (1981), *The Social Appraisal of Projects: a text in cost-benefit analysis*. Macmillan, London.

[<sup>iii</sup>] Mackie PJ and Preston JM (1998), 'Twenty-one sources of error and bias in transport project appraisal', *Transport Policy* 5(1), pp1-7.

[<sup>iv</sup>] Vose (1996), *Quantitative Risk Analysis*. Wiley, New York.

[<sup>v</sup>] HM Treasury (2001), *Management of risk – a strategic overview* ('the Orange book'). The Stationery Office, London.