EVALUATION SENSITIVITY ANALYSIS

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PO Box 5084, Lambton Quay, Wellington, New Zealand
Telephone (04) 499-6600; Facsimile (04) 499-6666

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AN IMPORTANT NOTE FOR THE READER

CONTENTS

EXECUTIVE SUMMARY

The guidelines for sensitivity analysis in project evaluation, as used in the Transit New Zealand Project Evaluation Manual (PEM), have been revised. This report provides an approach and methodology for sensitivity analysis that is of practical assistance in road project evaluation, and includes a revised version of Appendix A9, Sensitivity Analysis, for the PEM.

Issues of uncertainty in relation to road project evaluations are discussed, sensitivity analysis and other methods for dealing with such uncertainties are described as are the current sensitivity analysis procedures applied by Transit New Zealand. Possible directions for development of improved procedures and the results of a consultation workshop are given, as well as recommendations for revising the procedures and for on-going developments for project evaluation.

Recommendations are:

Project Categories

- Different procedures should be adopted for "large" and "small" projects. "Large" projects are defined as all those with capital cost equal to or exceeding:
    - $1.0 million, in the case of projects where the principal objective is to reduce accidents;
    - $2.0 million, in the case of all other projects.

Procedures for "Large" Projects

- All "large" projects should be subject to mandatory uncertainty analysis, using the sensitivity analysis approach.
- This analysis should be applied both in project optimisation (involving selection of design features, etc.) and in prioritisation of optimised projects for inclusion in the Land Transport Programme.
- The sensitivity analysis should be undertaken by the project evaluator.
- The sensitivity analysis should be consistent with the revised guidelines set out in the PEM.

Procedures for "Small" Projects

- Uncertainty analysis of any sort is not mandatory for "small" projects that are to be included in the Land Transport Programme. However, evaluators are encouraged to use sensitivity analysis procedures in project development and project optimisation wherever appropriate.
- In specific cases (e.g. accident reduction projects), Transit New Zealand may specify that sensitivity analysis procedures are required, or may refer such projects for sensitivity analysis where considered necessary.

Further Development Proposals

- An independent review process should be established for evaluations of all large projects, to cover not only the uncertainty analysis but also all other aspects of the project evaluation. This process needs to be further developed in conjunction with Transit New Zealand Review and Audit Division.

- Further guidelines may be necessary to assist decision-makers in the project selection process when they are faced with projects having different benefit:cost ratio (B/C ratio) distributions (resulting from the sensitivity analysis procedures). Such guidelines could be developed at a later stage and incorporated in PEM Appendix A9.

- Although risk analysis procedures have not been proposed for inclusion in the revised PEM Appendix A9, a trial of such procedures should be undertaken. If the trial is successful, risk analysis procedures could be introduced subsequently as a standard for larger projects.

Revision of PEM Appendix A9, Sensitivity Analysis, is part of this report. This revised version contains the following significant changes from the present Appendix A9:

- Sensitivity analysis is to be undertaken by the evaluator, as an integral part of the overall project evaluation.

- Sensitivity analysis is to be applied both in project optimisation and in presenting the evaluation results for the optimised projects to be included in the Land Transport Programme.

- Sensitivity analysis is to be mandatory for "large" projects only.

- A list of variables for sensitivity testing is given as a guide. The list may be modified by the project evaluator as appropriate.

- The list of variables incorporates all those in the current PEM but includes several additional variables relating to the "base" (existing) traffic level and composition.

- A wider range is suggested for estimated changes in accident numbers.

Proposals for a full-scale trial of risk analysis procedures are also recommended. The technique should be trialed in an operational environment to:

- Ascertain how readily practising engineers become adept at using risk analysis, and

- Identify the costs and benefits of undertaking risk analysis in an operational environment, and to establish a rational basis for deciding whether such an analysis is worthwhile on a more general basis.

ABSTRACT

The guidelines for sensitivity analysis in project evaluation, as used in the Transit New Zealand Project Evaluation Manual (PEM), have been improved. This report provides an approach and methodology for sensitivity analysis that is of practical assistance in road project evaluation, and includes a revised version of Appendix A9, Sensitivity Analysis, for the PEM. Sensitivity analysis determines how sensitive a project analysis (e.g. its benefit:cost ratio) is to the effect of varying one input parameter at a time.

Issues of uncertainty in relation to road project evaluations are discussed, sensitivity analysis and other methods for dealing with such uncertainties are described as are the current sensitivity analysis procedures applied by Transit New Zealand.

Possible directions for development of improved procedures and the results of a consultation workshop are given, as well as recommendations for revising the procedures and for on-going developments for project evaluation.

1. INTRODUCTION

Improving the guidelines for sensitivity analysis in project evaluation, which are contained in Transit New Zealand (1991) Project Evaluation Manual (PEM), is one of the research projects in Transit New Zealand's 1991/92 Research Programme. This report records the outcomes of that project and incorporates a revised version of Appendix A9 of the PEM. The research has been undertaken by Travers Morgan (NZ) Ltd in association with Dr Alan Nicholson, Department of Civil Engineering, University of Canterbury.

The aim was to provide an approach and methodology for sensitivity analysis that will be of practical assistance to Transit New Zealand, and other parties, in road project evaluation. The project was to focus on the **methodology** for sensitivity analysis rather than on the variation in individual input parameters.

Decision-makers and analysts were consulted about their requirements for any sensitivity analysis procedures before developing improved procedures. This consultation was crucial to ensure that the improved procedures are of the greatest practical use to those people they are designed to assist, and hence that they will be used to improve decision-making.

The project involved the following principal tasks:

1. Preparation of Discussion Paper
2. Workshop
3. Development of Proposed Methodology
4. Recommendations and Reporting

This report is structured as follows:

- Section 2 discusses issues of uncertainty in relation to road project evaluations, and describes sensitivity analysis and other methods for dealing with uncertainties.

- Section 3 describes and appraises the current sensitivity analysis procedures adopted by Transit New Zealand.

- Section 4 discusses possible directions for development of improved procedures and the results of the consultation workshop.

- Section 5 sets out recommendations for changed procedures and for on-going developments on the topic.

A revised version of PEM Volume 2, Appendix A9 (Transit New Zealand 1991) is included as an Annex to this report. Various topics are also covered in more detail in appendices.

2. DEALING WITH UNCERTAINTY IN PROJECT EVALUATION

2.1 Introduction

This section discusses issues of uncertainty in relation to road project evaluations and methods for dealing with the uncertainties. It draws heavily on the paper presented by Nicholson (1991) at the 1991 New Zealand Land Transport Symposium (refer to that paper for more detailed discussion on many of the points summarised here).

2.2 Why is Uncertainty an Issue?

"Uncertainty is an inherent and unavoidable feature ... which, whether formally recognised or not, enters every decision concerning highway investment" (Martin & Voorhees Associates 1982). Uncertainty is all-pervasive in any evaluation of roading projects: the only real issue is whether analysts and decision-makers try to ignore it, or whether they attempt to take it into account in reaching decisions.

Potentially, consideration of uncertainty in all the areas of application of evaluation results is needed. For example when:

- Comparing mutually exclusive options which address the same problem (e.g. alternative schemes for realignment of a section of road).
- Comparing the relative performance of projects which address different problems (e.g. values of benefit:cost ratios (B/C ratio) of two projects in different localities).
- Assessing the absolute performance of projects (e.g. B/C ratio values in relation to a pass mark).

2.3 Sources of Uncertainty

Uncertainty can arise from a number of sources, as set out more fully in Nicholson (1991). A major UK study on the treatment of uncertainty in highway appraisals (Martin & Voorhees Associates 1980) concluded that three categories of errors would arise in traffic modelling:

1. **Specification error** - arising from the imperfections in the traffic model formulation.
2. **Calibration error** - arising from inaccuracies in the estimation of the model parameters (even if the form of model is correct), owing to inappropriate calibration procedures and/or errors in the data used in calibration.

3. **Input forecasting error** - arising from inaccuracies in the forecasts of the input variables (such as population levels, fuel prices), even where the model is specified and calibrated precisely.

The study demonstrated that many of the sources of uncertainty, particularly in the calibration error and forecasting error categories, could be systematically quantified and the effects of these uncertainties on the evaluation results assessed. While specification errors could not be measured, their effects could be investigated by giving greater attention to model validation.

Appendix A1 describes in more detail the procedures that the UK Department of Transport has adopted for dealing with uncertainty in highway evaluations, and the development work that it has undertaken.

2.4 Methods for Dealing with Uncertainty

Methods that have been used by different practitioners and authorities in cost-benefit analysis to deal with uncertainty (further description in Nicholson 1991) are as follows:

1. **Assured certainty** approach: the most common approach, which basically entails ignoring uncertainty.

2. **Payback period** approach: biases project selection against projects with longer economic lives.

3. **Risk-adjusted discount rate** approach: also biases against selection of projects with longer economic lives.

4. **Conservative data adjustment** approach: entails adopting conservative estimates for uncertain inputs, resulting in a conservative B/C ratio value. It provides little information on the effects of uncertainty.

5. **Sensitivity analysis** approach: discussed in Section 2.5.2.

6. **Risk analysis** approach: discussed in Section 2.5.3.

The authors' view, which is supported by others (e.g. Copeland 1980), is that the first four approaches are not adequate for addressing the uncertainties associated with substantial roading projects. In fact, they would be a backward step from the present procedures adopted in the PEM and they are not discussed further. The discussion in Section 2.5 is therefore confined to methods 5 and 6, i.e. sensitivity analysis and risk analysis.

Any analysis of uncertainty should comprise three phases:

- **Risk identification** - involves identifying the sources of uncertainty and their relative importance with respect to uncertainty in the B/C ratio value.

- **Risk estimation** - involves estimating the probability distribution for the important uncertain variables and obtaining the resultant probability distribution for the B/C ratio.

- **Risk evaluation** - requires consideration of the implications of uncertainty for decision-making. It involves comparison of the cumulative distribution functions for several options, in order to select the preferred option. Other than in straightforward cases, this selection would depend on the attitudes of the decision-maker to risk acceptance/aversion. The approach to be adopted in regard to risk evaluation is beyond the scope of the present project and, although it is not considered further here, it may well warrant further consideration subsequently.

2.5 Sensitivity Analysis and Risk Analysis

2.5.1 Definitions

Both **sensitivity analysis** and **risk analysis** are methods of assessing the sensitivity of the B/C ratio (or other response variable) to potential variations in the input variables.

- **Sensitivity analysis** involves assessing the effects of selecting different values for each uncertain input variable on its own.

- **Risk analysis** involves the use of the probability distribution for each uncertain variable and varying more than one variable at a time.

2.5.2 Sensitivity Analysis

This approach is widely known, and is that incorporated in the present PEM (discussed in Section 3). It is one method for risk identification.

A number of issues and problems arise in its application, including the following (Nicholson 1991 gives more detailed discussion):

- The extent of variations in each uncertain variable has to be decided, albeit somewhat arbitrarily.

- To reduce such arbitrariness, upper and lower bounds for each variable may be specified, representing a 95% (say) confidence interval.

- Once such a confidence interval is defined, the task of deriving the confidence interval for the B/C ratio (or other dependent variable) is often quite complex statistically.

- Furthermore, there may often be interactions between variables, which complicates identification of the separate effects of each uncertain variable.

2.5.3 Risk Analysis

This approach is more rigorous and demanding than sensitivity analysis. Unlike simple sensitivity analysis, it involves the use of a probability distribution for each uncertain variable and also takes account of the interactions between the variables.

Points of note about this method include:

- It is more demanding than sensitivity analysis (or other methods) as it requires estimation of the probability distribution of each uncertain variable.

- If all such distributions are normal and simply additive, then the resultant distribution of the dependent variable (B/C ratio, etc.) may be calculated by statistical methods.

- In general, this assumption will not be valid. It is then necessary to resort to simulation (Monte Carlo) methods to derive the probability distribution of the dependent variable.

2.6 Overview of Practices and Research in United Kingdom and New Zealand

In the UK, the Department of Transport commissioned extensive research studies in the late 70s-early 80s, in an attempt to develop improved procedures for uncertainty analysis in highway project evaluation. However, most of the recommendations of these studies do not appear to have been adopted into standard procedures by the Department of Transport, and the current Department of Transport procedures relating to uncertainty analysis remain very basic.

Appendix A1 describes the UK situation and in particular summarises the research studies undertaken (by consultants Martin & Voorhees Associates 1980, 1982) which are particularly relevant to this project.

In New Zealand, only a few studies of roading projects in the last 10 years have involved sensitivity analysis and/or risk analysis. An overview of these studies is given in Appendix A2.

3. CURRENT PROCEDURES AND PRACTICE

3.1 Current Procedures

Transit New Zealand's current procedures for sensitivity analysis in project evaluation in New Zealand are contained in Appendix A9, Sensitivity Analysis, of the PEM (Transit New Zealand 1991).

Before publication of the PEM, Transit New Zealand had no formal procedures for applying sensitivity (or uncertainty) analysis. The previous National Roads Board TR9 Manual (Bone 1986) made minimal reference to such procedures.

Key factors of the PEM procedures are:

- Only four input variables are subject to sensitivity testing, i.e. capital costs, traffic volumes, traffic speed changes and predictions of accident changes.

- The "standard" percentage range of variation of each of these variables to be used for sensitivity testing purposes is specified. A summary of the standard range of values is given in Table 3.1.

Table 3.1 Present standard range of values for sensitivity analysis (summary)[1].

Item	Minimum Value	Maximum Value
Capital Cost		
1st Costing (Group 2)[2]	-20% of estimate	+30% of estimate
Traffic Volumes		
Traffic Growth	-2% pa[3] absolute of the forecast rate	+2% pa absolute of the forecast rate
Generated/Diverted Traffic	-50% of estimate	+50% of estimate
Traffic Speed	-25% of speed **change** estimate	+25% of speed **change** estimate
Accident Predictions	-25% of estimated savings	+25% of estimated savings

Notes: (1) Full details given in PEM Appendix A9 (Table A9.1 in particular).
(2) Relates to initial costing stage for new road construction, bridge replacement, extension of seals etc. (Refer PEM for figures in other situations.)
(3) pa = per annum

- These "standard" ranges are to be used for all projects unless the analyst can substantiate the case for using a different range of values.

- The sensitivity tests involve varying each variable on its own and reassessing the B/C ratio at the maximum and minimum values of that variable (with all other variables retaining their "base" values).

These procedures are not required when using the Simplified Evaluation Procedures of the PEM. When using the Full Procedures, the use of sensitivity analysis by the project evaluator is optional. (The Manual states that "The project analyst does not need to do a sensitivity analysis for each project....This will be done by Transit New Zealand when considering projects for funding under the National Land Transport Programme.")

3.2 Current Transit New Zealand Practice

While the systematic use of sensitivity analysis procedures for roading projects in New Zealand has been recommended by Copeland (1980) and others for some years now, such procedures had not been adopted as standard practice until the issue of PEM in 1991. As stated above, the sensitivity analysis procedures apply only when the Full PEM Procedures are used, and even then their use by the evaluator is optional.

Thus, experience with the PEM procedures is very limited to date. We understand that a number of district councils have used the PEM procedures (or similar) in developing their Land Transport Programmes. In some cases however the tendency has been to use the procedures only where the B/C ratio for a project is marginal and an authority wishes to justify deviations from the standard variable ranges in order to enhance the case for the project.

Within Transit New Zealand itself (and within regional councils), very little, if any, use of the sensitivity analysis procedures has been made in reviewing the results of project evaluations put forward by district councils or Transit New Zealand regional offices.

Thus it is difficult at this time to draw any firm conclusions from experience so far with use of the PEM procedures. However, if sensitivity analysis procedures are to be used, they should be treated as an integral part of the overall project evaluation. Therefore the analysis should be undertaken by the project evaluator, and not left to another party (e.g. Transit New Zealand) to undertake as an optional add-on after the main evaluation. Only if project evaluators have to undertake the analysis, will they be encouraged to consider the sensitivity of the evaluation results to various factors and thus to carefully review the estimates of the most sensitive factors.

4. REVIEW OF ISSUES AND POSSIBLE DEVELOPMENT DIRECTIONS

4.1 Potential Uses and Benefits of Improved Procedures

Improved methods for examining the effects of uncertainty are potentially useful in any situation where evaluation results are used to assist decision-making, such as when:

- comparing mutually exclusive options to address the same problem;
- comparing the performance of projects which address different problems;
- assessing the absolute performance of projects (against a pass mark).

Research projects overseas, in particular for the UK Department of Transport (refer Appendix A1), have demonstrated the potential benefits to decision-makers of providing improved uncertainty analysis procedures for roading schemes. The two UK research studies concluded that:

> "The extra information about the level of uncertainty puts the designer in a far better position for taking decisions than conventional analysis: for instance, he is able to judge whether the risk attached to providing a lower standard of road is justified" (Martin & Voorhees Associates 1980).
>
> "(The information may be applied and is valuable in) a number of important aspects of highway planning, including choice of alignment, junction design, pavement thickness and economic evaluation" (Martin & Voorhees Associates 1980).
>
> "We are confident that decision-makers could exercise their professional judgement to greater beneficial effect when faced with the information about uncertainty that is contained in complete outturn probability distributions" (Martin & Voorhees Associates 1982).

The thrust of these conclusions is supported. Of course, the extra information obtained by decision-makers from uncertainty analysis does not make the decision any easier, and indeed may make it more difficult, although it should be a better decision. As noted in Section 2.4, further guidance on which approach is appropriate to project selection when presented with the results of uncertainty analysis may be useful for evaluators. However such guidance is outside the scope of this study.

4.2 The Range of Possible Approaches and Their Implications

This research has identified four broad options (listed in Table 4.1) from the range of possible approaches that might be adopted by Transit New Zealand for uncertainty analysis of roading projects. In summary, these are:

1. No uncertainty analysis - a backward step, but put in for reference. Would result in only a single B/C ratio value for each project.

2. Range of traffic growth forecasts - the current UK Department of Transport (COBA) method, but also a step backward from the use of the present Transit New Zealand PEM procedures. Would result in two single B/C ratio values for each project.

3. Current Transit New Zealand PEM procedures - as contained in the present PEM (and assumed to be used in practice).

4. Risk analysis - along the lines suggested to UK Department of Transport (from research by Martin & Voorhees Associates 1980, 1982). Would result in probability distributions of B/C ratio values for each project, and also assist in decisions on specific aspects of projects (e.g. junction design, pavement thickness).

In terms of application effort, options 1 and 2 would be somewhat simpler to apply than the present procedures 3, while option 4 would be rather more complex. However, once the system and programs are established for option 4, the analytical resources required in individual project evaluations should not be greatly increased from the present procedures. It should be practicable for Transit New Zealand to pre-specify the variables to be adjusted (see Section 4.3), the form of their probability distributions, and the computation procedures.

4.3 Key Variables and Their Specification

The original brief for this research project noted the intention that any improved procedures should still focus on the same variables that are subject to sensitivity testing under the current PEM procedures (as in Table 3.1). However during the project it became apparent that it would be appropriate to review the variables selected, and also the appropriate ranges for each variable.

The 1977 Advisory Committee report to the UK Department of Transport (Appendix A1) found that B/C ratio values were most sensitive to variations in:
- Unit accident values
- Growth rates in unit values of time and accidents
- Car ownership saturation levels
- Discount rate

However it should be noted that the **relative** performance of two schemes may well be more sensitive to other factors (depending on the scheme characteristics). The Advisory Committee report did not examine all potential variables, and it excluded capital costs.

The subsequent research study for UK Department of Transport (Martin & Voorhees Associates 1980, 1982 - see Appendix A1) concluded that major influences on B/C ratio values included GDP (Gross Domestic Product) growth rates and fuel prices, as well as errors in the base year trip matrix.

Table 4.1 Range of approaches to uncertainty analysis.

Title	Summary of Approach	Comments
1. No Analysis	No consideration of uncertainty. Single B/C ratio value only calculated.	• Backward step. • Easily achieved by deleting Appendix A9 from PEM.
2. Range of Traffic Growth Forecasts	All projects assessed on 2 traffic growth rates ("high" and "low"). No other uncertainty analysis.	• As current UK Department of Transport (COBA) standard requirements. • Backward step.
3. Current Transit New Zealand Procedures	Simple sensitivity analysis on specified variables individually. Range pre-defined by Transit New Zealand.	• Requires no/minor change to PEM or to computer programs. • Need for current procedures to be used in practice. • Gives no information on interactions between variables or on confidence interval for B/C ratio results.
4. Risk Analysis	Involves definition of probability distribution of each input variable. Then uses (in general) Monte Carlo simulation methods to derive the probability distribution of B/C ratio and other dependent variables.	• May employ experimental design techniques to examine interactions between variables. • "Systematic Sensitivity Analysis", as proposed by MVA[1] (1980, 1982) is a somewhat simplified version of full risk analysis. • Transit New Zealand could specify factors to be included and their probability distributions. • Additional work for the analyst could be minimised by use of standard software and procedures.

[1] MVA Martin & Voorhees Associates

In New Zealand, perhaps the most comprehensive work on the factors affecting the accuracy of roading evaluations is that for the National Roads Board (NRB) by Clark (1982). He divided the relevant variables into four groups:

1. **Conceptual framework,** e.g. discount rate, analysis period,
2. **Unit economic values,** e.g. unit values of time savings and accident savings,
3. **Traffic data,** e.g. traffic volumes, traffic growth rates,
4. **Physical (resource) data,** e.g. reduction in numbers of accidents, changes in travel time.

Of the traffic and physical data, Clark found the following had the most influence on the evaluation outcome:

Traffic data
- Traffic growth - very important,
- Present (or base year) traffic levels - important,
- % HCV (Heavy Commercial Vehicles) - important,
- Vehicle occupancy level - important,
- % cars in work time - significant.

Physical data
- Speed changes - critical,
- Construction costs - important,
- Maintenance cost savings - significant,
- Accident savings - vary from critical to significant (depending on project).

4.4 Issues Arising from Consultation Workshop

Task 2 of the project involved holding a consultation workshop "to elicit opinions on what features and outputs of the sensitivity analysis process would be of greatest assistance in enabling better project evaluations and decisions to be taken". Appendix A3 presents a summary of the views expressed at that workshop. The desirable features of uncertainty analysis procedures and comments on the present procedures and possible developments in the light of these features are set out in Table 4.2.

The main conclusions from the workshop that relate to the desirable directions for development of uncertainty analysis procedures are as follows:

- Different procedures would be appropriate for different scales or types of projects, with projects being divided into two groups:

    - "Large" projects, over a certain capital cost threshold in general, but with maybe a lower threshold for safety-oriented projects.

    - "Small" projects, all other projects.

- For "large" projects:
    - Uncertainty analysis should be applied, both to ensure that the optimum option/design was selected and to use in comparisons between competing projects.

    - Initially at least, the uncertainty analysis should involve sensitivity analysis, as in the present procedures, but with a greater flexibility and ensuring that the variables/ranges considered are appropriate to the project.

Table 4.2 Uncertainty analysis: desirable features and appraisal of present procedures (workshop outputs).

Desirable Features of Uncertainty Analysis (UA)	Comments on Present Procedures/Practices and Scope for Improvement
• Two principle areas for use of UA: • developing best option to address a problem • prioritising projects which address different problems.	• Present procedures not seen as very helpful in either area. Need for less mechanical approach, to be applied by evaluators rather than by TNZ later.
• To assist in 2 major areas of weakness in present project evaluations, i.e.: • treatment of intangibles • evaluation with congested networks	• UA methods not a central solution to these problem areas, although could assist in examining effects of variations in evaluation of intangibles and in assessing effects of uncertainties in urban traffic modelling. Evaluation with congested networks is a complex topic which is being addressed separately by TNZ.
• UA procedures cannot be a substitute for skilled basic evaluations, but should be an integral part of overall evaluation process.	• SA treated as an optional add-on to the present evaluation procedures. Needs to be made an integral component, undertaken by the project evaluator.
• Procedures should focus on those variables to which evaluation results are most sensitive.	• The variables in the present procedures, or the ranges given, are not always the most appropriate ones. More flexibility is needed for individual cases.
• Procedures need to assist decision-makers in project selection.	• Dubious whether application of present PEM procedures to all projects would improve quality of decision-making in Regional and National land Transport Programmes, as it is impractical to review all project results in detail. Implications of any new methods for decision-making process will need to be carefully considered.
• Procedures should not be excessively difficult to apply.	• Any methods more complex than the present procedures will probably need standard computer packages for their application.
• Procedures need to be appropriate to the scale and nature of the project.	• Simple procedures are appropriate for smaller projects; more sophisticated procedures for larger projects. Need two (or more) project groups for this purpose.

   - Risk analysis methods should be considered further, but a pilot project would be needed on selected schemes before they were brought into general use.

   - Procedures should be developed for independent review/audit of project evaluations (this conclusion is largely independent from, but related to, the suggestions about uncertainty analysis).

- For "small" projects:
   - Any uncertainty analysis should be made through sensitivity analysis.

   - There would be no general requirement for such analysis. However Transit New Zealand regional offices could stipulate sensitivity analysis on a specific project, or refer such a project back for analysis.

- Any uncertainty analysis procedures required should be applied by the project evaluator, as an integral part of the project evaluation (i.e. rather than by Transit New Zealand subsequently).

These conclusions had a major influence on our development of recommendations, which are described in Section 5.

5. RECOMMENDATIONS AND OUTPUTS

5.1 Introduction

Recommendations of the projects are presented in three sections:

- A summary of all recommendations,
- Revised procedures for sensitivity analysis of large projects, for incorporation in the PEM.
- Proposals for further development of procedures, relating to risk analysis.

These recommendations have been based on the research work of the whole project, and are largely consistent with the general consensus of views expressed during the consultation workshop (which was a very helpful component of the overall project).

5.2 Summary of Recommendations

5.2.1 Project Categories

- Different procedures should be adopted for "large" (Section 5.2.2) and "small" (Section 5.2.3) projects.

  "Large" projects are defined as all those with capital cost equal to or exceeding:

  - $1.0 million, in the case of projects where the principal objective is to reduce accidents;

  - $2.0 million, in the case of all other projects.

5.2.2 Procedures for "Large" Projects

- All "large" projects should be subject to mandatory uncertainty analysis, using the sensitivity analysis approach.

- This analysis should be applied both in project optimisation (involving selection of design features, etc.) and in prioritisation of optimised projects for inclusion in the Land Transport Programme.

- The sensitivity analysis should be undertaken by the project evaluator.

- The sensitivity analysis should be consistent with the revised guidelines set out in the PEM (see Section 5.3 and Annex).

5.2.3 Procedures for "Small" Projects

- Uncertainty analysis of any sort is not mandatory for "small" projects that are to be included in the Land Transport Programme. However, evaluators are encouraged to use sensitivity analysis procedures in project development and project optimisation wherever appropriate.

- In specific cases (e.g. accident reduction projects), Transit New Zealand may specify that sensitivity analysis procedures are required, or may refer such projects for sensitivity analysis where considered necessary.

5.2.4 Further Development Proposals

- An independent review process should be established for evaluations of all large projects, to cover not only the uncertainty analysis but also all other aspects of the project evaluation. This process needs to be further developed in conjunction with Transit New Zealand Review and Audit Division.

- Further guidelines may be necessary to assist decision-makers in the project selection process when they are faced with projects having different B/C ratio distributions (resulting from the sensitivity analysis procedures). Such guidelines could be developed at a later stage and incorporated in PEM Appendix A9.

- Although risk analysis procedures have not been proposed for inclusion in the revised PEM Appendix A9, a trial of such procedures should be undertaken. If the trial is successful, risk analysis procedures could be introduced subsequently as a standard for larger projects. Further details are discussed in Section 5.4.

5.3 Revised Sensitivity Analysis Guidelines for "Large" Projects

Consistent with the above recommendations, a revised version of PEM Appendix A9, Sensitivity Analysis, has been prepared and is annexed to this report.

The revised version contains the following significant changes from the present Appendix A9:

- Sensitivity analysis is to be undertaken by the evaluator, as an integral part of the overall project evaluation.

- Sensitivity analysis is to be applied both in project optimisation (i.e. selecting the best option to address a given problem) and in presenting the evaluation results for the optimised projects that are to be included in the Land Transport Programme.

- Sensitivity analysis is to be mandatory for "large" projects only (as defined in Section 5.2.2).

- A list of variables for sensitivity testing and suggested ranges for these variables is given as a guide only. The list may be modified by the project evaluator as appropriate. The main focus should be on those variables which make the greatest contribution to total costs and benefits.

- The list of variables incorporates all those variables in the current PEM but includes several additional variables relating to the "base" (existing) traffic level and composition. These additions recognise the possibilities of significant errors in such variables and their potential substantial impact on the evaluation results. It also draws attention to the point that evaluations should give particular care to obtaining better estimates of these base variables. (Significant improvements in evaluation accuracy may be obtainable in this way, whereas forecasting of future traffic growth is inherently uncertain and cannot be similarly improved.)

- A wider range is suggested for estimated changes in accident numbers. This change recognises the particular difficulties in predictions of accidents and the importance of accident savings in overall project benefits in many cases.

5.4 Proposals for Trials of Risk Analysis

A full-scale risk analysis of a major transport project is a substantial task. For a project with significant network effects (i.e. where substantial redistribution of traffic within a network can reasonably be expected), the computing requirements will be massive because of the complexity of the models required for traffic prediction in a network and the need for numerous runs with varying values for the uncertain input variables. Full risk analysis for such a major project has not been done, in either a research or operational environment.

The network effects will generally be small for rural highway projects, and can generally be omitted. Although numerous runs with varying inputs are again required, each run does not involve complex models, and it is thus feasible to undertake risk analysis for such projects. Nevertheless, to date risk analyses for this kind of project have been undertaken in a research environment only. Examples are the risk analyses completed by Tai (1987) for two research projects, the Albany Hill and Waipu By-pass projects.

Therefore the technique should be trialed in an operational environment to:

1. Ascertain how readily practising engineers become adept at using risk analysis;
2. Identify the costs and benefits of undertaking risk analysis in an operational environment, so as to establish a rational basis for deciding whether such an analysis is worthwhile on a more general basis.

The use of commercially available software for risk analysis (e.g. @RISK) may assist practising engineers to become proficient in the use of the technique. A trial of risk analysis could involve evaluating such software packages: packages may well differ with regard to the number of uncertain variables and the forms of probability distributions that can be handled, and their ease of use.

Risk analysis entails gathering additional information about the uncertain variables (in particular, the probability distributions that best describe the variations of those variables) and processing that information. Identifying the costs of carrying out these two tasks is needed, as well as the benefits from the results of a risk analysis. The benefits can be ascertained only by trials to investigate the extent to which both the engineer's analysis of the project options (to identify the best option) is improved and the final decision (whether to proceed with the best option) is affected by the results of the risk analysis.

Hard information about these costs and benefits requires an empirical approach. Estimates based on theorising are unlikely to be sufficiently accurate to provide a sound basis for deciding to proceed with risk analysis on a general basis, given the effort involved in doing such analysis.

For "small" projects, the costs of doing risk analyses are high relative to the total cost of design and implementation, and the benefits are unlikely to be sufficient to justify risk analyses. Given that "small" projects are quite numerous, to omit an analysis of uncertainty for such projects is legitimate on the basis that errors in estimating B/C ratios will compensate (i.e. for each over-estimate there will be a similar under-estimate for another project). For the few "large" projects, one cannot rely on errors compensating, and the costs of risk analyses are low relative to the total costs. For such projects risk analysis may well be justified. The problem is to identify the investment cost threshold above which risk analysis should be done.

Until some reliable information is available regarding the costs and benefits of operational risk analyses in relation to real projects, it is not possible to identify the appropriate investment cost threshold. Therefore the recommendation is to undertake trials of risk analysis for selected projects. The projects should be selected on the basis of their investment cost (this should be high) and the nature of the project (in particular, the relative importance of accident savings, travel time reductions, and operating cost savings as contributors to the expected project benefits). In this way, experience in doing risk analyses for a range of project "types" would be accumulated. In due course, it would be possible to define an appropriate investment threshold, and to be confident that the expertise to undertake operational risk analyses would be available.

The "systematic sensitivity analysis" technique proposed by Martin & Voorhees Associates (1982) can be considered as either a sophisticated form of sensitivity analysis or a simplified form of risk analysis. Trials of risk analysis could include evaluation of both full risk analysis and systematic sensitivity analysis, to ascertain the costs and benefits of each, and consequently their relative merits. On larger projects systematic sensitivity analysis may well be found to be worthwhile, but the extra effort associated with full risk analysis may not be worthwhile.

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ANNEX: PROJECT EVALUATION MANUAL
APPENDIX A9: SENSITIVITY ANALYSIS (Revised Version)

A9.1 INTRODUCTION

Transport project evaluations involve making estimates of many factors which are subject to uncertainty, e.g. traffic growth rates, traffic speeds, capital costs, accident predictions.

The traditional method of evaluating projects, by use of a single-valued estimate of each uncertain variable, does not provide useful information on the extent of the uncertainty in the final result (i.e. B/C ratio) or of the probability of this result exceeding a certain value.

Some form of "uncertainty analysis" is thus desirable, to provide better information for evaluators and decision-makers on the effects of uncertainties on the overall project performance. The method chosen for the evaluation of transport projects for the National Land Transport Plan (NLTP) is sensitivity analysis.

Sensitivity analysis involves defining a range of values for an uncertain variable in the evaluation and assessing the effects on the project outcome (principally the benefit:cost ratio). As applied here, the effects of changes in each variable are considered individually, without examining the effects of any interactions between variables. Sensitivity analysis highlights those variables for which a change in the input value has the greatest effect on the project outcome.

A9.2 THE APPLICABILITY OF SENSITIVITY ANALYSIS IN PROJECT EVALUATION

The sensitivity analysis procedures described in this appendix are to be applied to all "large" projects being considered for inclusion in the NLTP. In this context "large" projects are all those that equal or exceed the following capital cost thresholds:

- $1.0 million, in the case of projects where the principal objective is to reduce accidents,
- $2.0 million, in the case of all other projects.

Sensitivity analysis should be regarded as an integral part of the overall evaluation of the project. In all cases (including smaller projects, where there is no mandatory requirement), the analyst should focus on those variables which have a substantial influence on the evaluation result, and should consider carefully the best estimate and likely range for these variables.

In the following sections of this appendix, some guidance is given (based on an extensive range of experience) on those variables to which evaluation results are generally most sensitive, and on indicative ranges of these variables suggested for sensitivity analysis.

However, it needs to be recognised that this information is given for guidance and there may be situations in which it will be appropriate for the evaluator to carry out sensitivity analysis with different ranges for the stated variables or with other variables.

Sensitivity analysis will generally have two main areas of application in development and evaluation of projects for inclusion in the NLTP:

- In developing and selecting the best option (in terms of design features, etc.) to address a specific problem.

- In determining priorities between projects which address different problems.

Thus the analyst should apply the sensitivity analysis procedures in developing/selecting the best option; and then provide the sensitivity analysis results for this best option in compiling information for the NLTP. Transit New Zealand will then take these results into account in determining the approved Programme.

A9.3 VARIABLES TO BE CONSIDERED FOR SENSITIVITY ANALYSIS

The variables which are incorporated into project evaluations may be divided into four groups:

(1) Conceptual framework, e.g. discount rate, analysis period
(2) Unit economic values, e.g. unit values of time savings and accident savings
(3) Traffic data, e.g. current traffic volumes, traffic growth rates, average occupancy rates
(4) Physical (resource) data, e.g. numbers of accidents saved, changes in travel time.

The aim of the sensitivity analysis is to identify the effects of uncertainty in the predictions of traffic and physical data, but not to include consideration of the effects of uncertainty associated with economic values. Hence the variables used in sensitivity analysis should be taken from only groups (3) and (4) above.

The variables to be subject to sensitivity analysis should be those for which plausible variations are likely to have the greatest effects on the evaluation results (B/C ratio); and particularly those which are likely to make the greatest differences to the relative performance of different projects.

Table A9.1 provides a check-list of possible variables for sensitivity testing. The analyst should use judgement as to whether all these variables should be included in sensitivity testing for a "large" project, or whether some can be excluded, e.g. owing to their small contribution to the final result. For any variable excluded, brief comment should be given on the reasons for its exclusion.

Table A9.1 Sensitivity testing variables and ranges (Guidelines).

Variable	Suggested Minimum Value	Suggested Maximum Value
Capital Cost[1]		
1st costing	-20% of estimate	+25 to 35% of estimate[2]
2nd costing	-15% of estimate	+15 to 25% of estimate[2]
Final costing	-10% of estimate	+10 to 15% of estimate[2]
Base Traffic Level & Composition		
Total Traffic Volume (AADT)	-10 to 20% of estimate	+10 to 20% of estimate
Proportion HCV	-5 percentage points	+5 percentage points
Proportion cars in work time	-5 percentage points	+5 percentage points
Average vehicle occupancy	-0.3 from estimate	+0.3 from estimate
Future Traffic Volume Trends		
Normal traffic growth rate	-2% pa (absolute) of the forecast rate	+2% pa (absolute) of the forecast rate
Traffic generated by specific (uncertain) developments	Zero	As forecast
Traffic generated or diverted by project	-50% of estimate	+50% of estimate
Traffic Speed Changes	-25% of estimated change in speed	+25% of estimated change in speed
Accident Changes	-50% of estimated change	+50% of estimated change

Notes: (1) The appropriate range for capital costs depends on the detail of investigations, design and costing. The 1st costing relates to initial rough estimates; the final costing to the estimates after the final design stage.

(2) The range of values relates to different project types: costings for more routine projects (e.g. shape correction, resealing) are generally more accurate than those for larger complex projects (e.g. new motorway construction).

AADT Average Annual Daily Traffic; HCV Heavy Commercial Vehicles pa per annum

The table also provides guidelines on the appropriate range of values for each variable. Again, these are guidelines and it may be appropriate to vary these ranges for particular projects. In such cases, the evaluator should provide a brief statement of the reason for such variation.

A9.4 PRESENTATION OF RESULTS

In presenting evaluation results for the inclusion of a project in the NLTP, a summary format for the sensitivity analysis results would be appropriate, along the lines of the example given in Table A9.2. This might be usefully supplemented by a graphical presentation of the same results.

Table A9.2 Sample presentation of sensitivity analysis results.

Variable	Minimum Value of Variable			Maximum Value of Variable			Comment
	Value	**Resultant B/C ratio**	**Change in B/C ratio**	**Value**	**Resultant B/C ratio**	**Change in B/C Ratio**	
Best Estimate		5.0			5.0		
Capital Cost	-20%	3.9	-1.1	+30%	6.0	+1.0	
Base Traffic Level & Composition:							
Total traffic volume (AADT)	-20%	3.5	-1.5	+20%	6.7	+1.7	
Proportion HCV	-5pts	4.8	-0.2	+5pts	5.2	+0.2	
Proportion cars in work time	-5pts	4.4	-0.6	+5pts	5.8	+0.8	
Average vehicle occupancy	-0.3	4.0	-1.0	+0.3	6.2	+1.2	
Future Traffic Volume Trends:							
Normal traffic growth rate	-2%[pa]	4.2	-0.8	+2%[pa]	6.4	+1.4	
Traffic generated/diverted	-50%	4.9	-0.1	+50%	5.1	+0.1	
Traffic Speed Changes	-25%	4.4	-0.6	+25%	5.5	+0.5	
Accident Changes	-50%	3.6	-1.4	+50%	6.7	+1.7	

[pa] per annum

APPENDIX A1. PROCEDURES AND DEVELOPMENTS IN THE UNITED KINGDOM

A1.1 COBA

The COBA Manual is the UK Department of Transport's equivalent to the Transit New Zealand PEM. It is designed primarily for the economic evaluation of inter-urban/rural road schemes and has been in use (with progressive refinements and updates) since the early 1970s.

Until 1978, COBA did not include sensitivity analysis procedures of any sort. Scheme NPV (Net Present Value) and B/C ratio results were based solely on a single set of assumptions.

A1.2 SACTRA Report

In its initial (1977) review for the UK Department of Transport of the procedures adopted for trunk road assessments, the UK Advisory Committee on Trunk Road Assessment (SACTRA) examined a sample (25) of schemes assessed using COBA and varied key variables or assumptions (examined one at a time) to assess the effects on the economic evaluation results (UK DOT 1977). The variables examined all related to the traffic forecasting and user benefit aspects of the evaluation. Scheme capital costs were not considered.

In summary, the conclusions of this work were that (absolute) B/C ratio values were most sensitive to plausible variations in:

- discount rate,
- free flow speeds,
- growth in real unit values of time and accidents.

B/C ratio values were also quite sensitive to:

- car ownership saturation levels,
- assignment assumptions for local traffic,
- intersection capacities,
- unit values of travel time,
- future speed increase trends,
- seasonal traffic flow characteristics,
- proportions of heavy goods vehicles.

The **relative** rankings of schemes were sensitive to some of these factors and less sensitive to others, depending on the particular schemes. The greatest changes in ranking resulted from varying the proportion of heavy goods vehicles, from changes in car ownership saturation levels and from changes in unit accident valuations.

One of SACTRA's recommendations from this work was that:

> "The Department should indicate the likely range of uncertainties involved in the forecasts (of traffic flows) and demonstrate the consequences of selecting different values within the likely range. It should never put itself in the position of appearing to defend a single figure as if it were uniquely correct" (UK Department of Transport 1977).

A1.3 Consultant (Martin & Voorhees Associates) Studies

In response to this recommendation of the SACTRA report, the UK Department of Transport issued a memorandum advocating the use of two levels of traffic growth forecasts, based principally on alternative views of future economic prospects. While this represented an advance over previous procedures, it still fell short of the recommendation to "indicate the likely range of uncertainties".

The UK Department of Transport then appointed consultants (Martin & Voorhees Associates (MVA)) "to investigate whether it was feasible to quantify the level of uncertainty attaching to the forecasts, and if so, how such knowledge might assist in highway appraisal" (Martin & Voorhees Associates 1980). Martin & Voorhees Associates' major task was to investigate the potential errors in the traffic forecasting models commonly used, by reference to the appraisal of a hypothetical scheme.

The main conclusions of the consultant report were that:

- It is feasible to estimate the uncertainty attached to traffic forecasts, in terms of possible ranges for traffic volumes on particular routes and the likelihood of the volumes being within given ranges.

- This additional information is of considerable value to the decision-maker. For instance, it may be used to assist decisions on aspects such as alternative alignments, junction designs and pavement thickness, as well as in the overall economic evaluation.

- The methods could be generalised without undue difficulty, to incorporate an analysis of uncertainty as a standard element of highway appraisal.

Following a review of these recommendations by the UK Department of Transport, Martin & Voorhees Associates was then appointed, for a second project, to address the following issues:

> - "Which of the numerous potential sources of error in traffic forecasting are the main contributors to the overall uncertainty surrounding the model outputs?
>
> - "Could an analysis of uncertainty be readily implemented in standard trunk road appraisal practice?" (Martin & Voorhees Associates 1982).

Regarding the first of these issues, 17 potential sources of error within the traffic modelling process were identified. These included forecasts of GDP growth and real fuel price changes, planning data projections and errors in the distribution and assignment components of the full traffic model. For a typical trunk road scheme, experimental design techniques were applied to determine the effects of the 17 individual factors on variations in link flows and NPVs, using a relatively small number of tests. Interactions between factors were also investigated. Using probability distributions for the individual factors, the resulting probability distributions for link flows and NPV values were determined.

It was found that:

1. Most of the uncertainty in link flows and NPVs arose from relatively few of the 17 factors.

2. The value of the experimental design technique was confirmed because:
   - more factors were significant than could be reasonably considered using current sensitivity analysis approaches;
   - several interactions between factors proved to be important.

3. The dominant influences on link flows and NPVs were the economic forecasts of GDP growth and fuel prices. Random errors in the base year trip matrix were also an important source of uncertainty. Factors which were less important tended to be the projections of population and planning data.

4. Given that economic factors rather than traffic model factors are the dominant sources of uncertainty, there may be scope for simplifying the traffic model used without an appreciable sacrifice of predictive accuracy. (The resultant savings in effort might then be applied to more thorough sensitivity analysis.)

Regarding the second issue above, it was concluded that:

- The experimental design approach is an appropriate method for more comprehensive investigations of scheme uncertainty than the existing practices, because it:
  - is closely related to sensitivity testing, but is far more efficient in identifying the separate effects of several sources of uncertainty,
  - can also identify significant interactions between sources of error,
  - can readily be automated and applied to factor probability distributions to produce outturn distributions,
  - gives rise to valuable and interpretable results.

- The following factors should be included in any experimental design:
  - GDP growth,
  - fuel prices,
  - route choice coefficient,
  - study area population.

- The contribution to uncertainty of factors relating to the base year matrix and to link speeds is independent of the above factors, and therefore is best assessed outside the experimental design.

- It would be feasible to define suitable standard experimental designs (as an extension of the uncertainty analysis in current practice), and these could be pre-specified by the UK Department of Transport. The experimental design analysis could be used in conjunction with probability distributions of the key factors, which could also be specified by the Department of Transport.

- While adoption of the system proposed would be an elaboration of current appraisal practices, such a system would be justified because of the improved information available for decision-makers. Automation of the process may enable the work to be undertaken with no increase in resources beyond those required in current sensitivity testing.

The **main** recommendation of the report was that the UK Department of Transport should "favourably consider the adoption of small experimental designs as the primary means of uncertainty analysis in trunk road appraisal". It was proposed that the technique be used in conjunction with probability distributions of the error factors, so that the uncertainty in link flows or NPVs may be represented by outturn probability distributions.

Other recommendations included:

- Some piloting of the above proposal should be undertaken, on a variety of scheme types.

- Further work on improving forecasts of GDP growth and future fuel prices should be a high priority, given their dominance in overall uncertainty.

- It is important to minimise model specification error (which cannot be allowed for with confidence in the uncertainty analysis).

- A further investigation should be undertaken within the context of COBA into possible sources of error in evaluation and their effects on the uncertainty of NPV.

The report concluded that:

> "We are confident that decision-makers could exercise their professional judgement to greater beneficial effect when faced with the information about uncertainty that is contained in complete outturn probability distributions."

A1.4 The Current Position

Despite the two MVA studies just described, the traffic appraisal and economic evaluation methods specified by the UK Department of Transport appear to have hardly changed in respect to the evaluation of uncertainty since the late 1970s.

The COBA evaluation manual still uses only "high" and "low" traffic growth forecasts; i.e. policy in this area does not appear to have advanced since 1978 and, specifically, the main recommendations of the two MVA reports have not been adopted.

The UK Department of Transport Traffic Appraisal Manual (TAM, a companion volume to COBA), takes a similar line to COBA, but with rather more discussion of the traffic forecasting issues. It comments that:

> "The treatment of uncertainty in traffic forecasting adopted by the Department relies upon the use of a range of forecasts which have been adopted as a matter of policy for trunk road planning purposes" (TAM, para 12.4.1.2).

> "Selective sensitivity testing (where a high and low value is chosen for each parameter, and the model run) is the approach adopted in both the National Road Traffic Forecasts and the economic evaluation using COBA. Whilst useful for identifying the full range of feasible outcomes, the information gained does not necessarily assist in determining whether the effects of alternatives are significantly different, and hence, with the making of decisions" (TAM, para 12.4.4.2).

TAM also notes that "work is at present being examined on systematic sensitivity testing" (as at May 1984). However, this work has not yet resulted in improved analysis methods being incorporated in either TAM or COBA.

APPENDIX A2. DEVELOPMENTS IN NEW ZEALAND

A2.1 Introduction

As at 1992, reported experience in the use of uncertainty analysis for the appraisal of transportation projects in New Zealand seems to be limited to three studies.

A2.2 Clark Study

This study (Clark 1982) involved sensitivity testing for six case studies; three involved substantial highway realignments and three bridge replacements. Both traffic and economic variables were considered, and the effect of arbitrary variation in each variable was estimated. The accuracy of predictions of the variables was subjectively assessed.

A2.3 Tai and Nicholson Study

This study (Tai and Nicholson 1989) involved sensitivity testing for ten projects (e.g. passing lane construction, road realignment, town by-pass construction, with capital costs ranging from $0.08 to $2.35 million (1982 figures)). Only traffic variables were tested and they were those considered most important by Clark: traffic flow, traffic composition, vehicle occupancy, proportion of occupants working, speed increase, and accident reduction. The variations in the variables were somewhat arbitrary. The study revealed that the sensitivity to a variable varies substantially according to the nature of the project.

For two projects, a risk analysis was undertaken using the Monte Carlo simulation method. Correlation between uncertain variables was taken into account, and probability distributions for the B/C ratio were obtained, based upon probability distributions derived from data describing the variability of the uncertain variables.

A2.4 Butcher, Brown and Copeland Study

This study (Butcher 1985) discussed the application of risk analysis and demonstrated its application to the Arthur's Pass route. The main emphasis was upon the reliability of the route, which is subject to natural hazards (floods, washouts, subsidence, slips, avalanches, snow and ice) caused by storms and earthquakes, and the social and economic impacts of closure. The aim was to evaluate a proposal for upgrading the route, taking account of uncertainty in the traffic flow, the capital costs and the duration of road closure. Monte Carlo analysis was used to derive a probability distribution for the NPV.

APPENDIX A3. SUMMARY OF VIEWS FROM CONSULTATION WORKSHOP (28 MAY 1992)

A3.1 Introduction

As Task 2 of the project, a workshop was held "to elicit opinions on what features and outputs of the sensitivity analysis (SA) process would be of greatest assistance to enable better project evaluations and decisions to be taken".

This appendix provides a summary (as interpreted by Travers Morgan) of the views emerging from the workshop. In many cases no clear consensus was reached, and the notes do not attempt to cover all views expressed, or to attribute views to individuals. The list of people attending the workshop is attached.

A3.2 The Present Procedures

- PEM procedures for Sensitivity Analysis (SA) have been developed since the production of TR9 in 1986.

- Some support exists in Transit New Zealand for more sophisticated risk analysis, but concerns also exist about complexity. Hence it was decided to use a simpler SA approach in the present PEM.

- The selection of variables in SA was said to be based on a Works Consultancy review of its project database results over the last 5-10 years.

- SA procedures are not required when using PEM Simplified Procedures. When using Full Procedures, SA is optional. (The Manual states that "The project analyst does not need to do a sensitivity analysis for each project." .... "This will be done by Transit New Zealand when considering projects for funding under the National Land Transport Programme".)

A3.3 Present Application Practice

- Some districts have undertaken SA in developing their Land Transport Programmes (LTP), often using the standard ranges for the nominated variables. Others use their own ranges and variables as an aid in developing the Programme, but do not include the results in their LTP submissions.

- Some authorities only use the SA procedures in cases where the B/C ratio for a project is marginal (using the standard ranges) and they wish to both justify the deviations from the procedures and enhance the justification for the project.

- Regional Councils would have difficulty in handling the LTP results if they were given a range of outcomes. At regional and national levels, it is generally impractical to deal with each project in detail (except for very large or controversial projects).

A3.4 Potential Roles of Uncertainty Analysis in Project Evaluation

- Two potential main areas of application of uncertainty analysis exist:
  1. Developing and selecting the best option to address a problem and to assist in scheme definition and design, etc.
     - applied by evaluators.

  2. Prioritising projects which address different problems
     - applied by Transit New Zealand (HO/regions).

- A view was raised that PEM Appendix A9 is not very helpful for either of these applications. Better guidelines on the general use of the SA approach are needed to assist evaluators, rather than a mechanical method that is applied after the evaluators have finished.

- Any procedures should focus on those variables to which the results are most sensitive, and these are not likely to be the same for all types of projects. The variables in the present procedures may not always be the appropriate ones, nor are the ranges given always wide enough (e.g. accident savings).

- Uncertainty analysis procedures can never be a substitute for carrying out careful and sensitive basic project evaluations by skilled evaluators, but should be an integral part of the overall evaluation procedures.

- A view was held that risk analysis procedures should be used to examine the potential distribution of B/C ratio values, using an automated process (e.g. "@ RISK" package). It may be appropriate to undertake a pilot project (on Transit New Zealand schemes) to develop and prove appropriate methods and software.

- The largest areas of weakness in present project evaluations are:
  - treatment of intangibles,
  - evaluation with congested networks.

  Uncertainty analysis methods do not help directly in either of these areas, although they could be used to assist in the treatment of intangibles (by assessing the sensitivity of the B/C ratio to plausible variations in the valuation of the intangibles).

- There was discussion of "Ranking B/C ratios" in the Land Transport Programmes: these are supposed to allow for valuation of intangibles, but in practice often just seem to reflect local political preferences (thus bringing the system into disrepute).

A3.5 Possible Directions for Development

- For "large" projects (see below), there was a general consensus that:
  - An independent review/audit of the evaluation should be made.
  - Uncertainty analysis should be applied to ensure that the optimum option/design was selected.
  - This uncertainty analysis could involve sensitivity analysis (but ensuring the variables/ranges were most appropriate to the project) or possibly risk analysis (or "systematic sensitivity analysis", as provided in the MVA studies).
  - Before adopting risk analysis, it would need first to be piloted by Transit New Zealand using selected schemes.

- "Large" projects in this context might be defined as those:
  - Over $2.0M capital cost (in general),
  - Over $1.0M capital cost (in the case of safety-oriented projects).

  These definitions would need to be considered further.

- For smaller projects (below the above thresholds):
  - Any uncertainty analysis would generally be using sensitivity analysis.
  - Such analysis would be at the option of the District, but could be stipulated by Transit New Zealand regional office as required for specified projects. The regional office could also refer specific projects back for sensitivity analysis.
  - Sensitivity analysis is likely to be particularly important for safety projects.

- Procedures should be the same for Transit New Zealand (State Highway) projects and local council projects.

- The following comments were made in relation to computerised packages for economic evaluation:
  - Spreadsheet-based software has been developed (by Beca) for TR9. Transit New Zealand now has a version (copyright).

  - An **appropriate** package could give significant benefits to both users and Transit New Zealand regions.

  - Transit New Zealand has not yet decided whether to develop and disseminate a spreadsheet system for general use (though consultants could develop and market such a product independently if they wished).

A3.6 Workshop Participants

Transit New Zealand Policy & Planning:	Ian Melsom (Project Manager) David Young Ted van Geldermalsen
Transit New Zealand Land Transport:	Paul Dobbs
Transit New Zealand Wanganui:	Mike Haywood
MoT Land Transport:	Jagadish Guria
Christchurch City Council:	Gary Huish
Wellington City Council:	Brian Hodge David Niven
Manukau City Council:	Don Hayward
Wellington Regional Council:	John Allard
Works Consultancy, Wellington office:	Fergus Tate
Consultants:	Ian Wallis (Travers Morgan) Alan Nicholson (Canterbury University)