ASSET MANAGEMENT OF ROADS
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ABSTRACT

The World Bank's initial approach to road project / network evaluation was to develop a program to do project evaluation. Over the years this has gradually been modified to also do testing of maintenance strategies on a single pavement and then more recently to adapt it to also do strategic analysis of a road network to determine budget needs over a long period or to test the effect of a particular budget level over a long period. The National Association of Australian State Road Authorities (NAASRA) started with a set of programs to assess required budget levels over a given period. Later, individual States developed their own project evaluation programs independent of the NAASRA strategic program set. This paper describes the strengths and weaknesses of the two approaches for doing strategic analyses. It illustrates the advantages of using a purpose designed system for strategic evaluation, rather than trying to make one program do all things.

INTRODUCTION

Road project analyses are conducted at three different levels. The basic requirement is for the economic evaluation of a single project. A second requirement closely aligned to this is the need to evaluate alternate strategies of maintaining a road pavement to minimise the costs over the life of the pavement. A third type of analysis is performed to find the level of funding required over a whole network for a specified number of years to maintain a given level of service, or to determine what the level of service will be at the end of the analysis period with a given level of funding.

Road project analysis needs to be accurate on each and every road record. To do this requires a large amount of data and performs extensive calculations for each record. When only a limited number of records are to be processed, the work load is manageable. On the other hand, strategic evaluation of a network needs to be able to process many thousands of records. It can afford to lose some accuracy at an individual record level, provided the total is correct when averaged over a number of records. This reduces the amount of data that is needed and allows for less extensive calculations per record to be performed. These two requirements lead to quite different system designs.

This paper describes two different approaches used to analyse budget requirements or effects of a particular budget level over a whole network over a number of years. In one approach, the program models the deterioration of the pavement and the user provides all other information such as details of the road network, project and maintenance costs, project specification and timing. In the second approach, the user provides the inventory, a set of standards and unit construction costs and the system models the pavement performance, determines when and what size a project will be, and estimates the costs.

About thirty years ago, when road networks in developing countries (and in Australia) were still in the 'expand and construct' phase of development, the World Bank initiated the development of a project evaluation tool to ensure that funding of road projects was justified. This saw the development of the Highway Design and Maintenance Standards program (HDM) (Harral, 1979). This model was further

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developed including using more complex models of pavement performance, and was released as HDM-III (Watanatada 1987). Further work has been done to expand on the capabilities of HDM-III to include traffic congestion, non-motorised vehicles, concrete pavements, drainage, environmental and safety effects and to update the model relationships.

In recent years with the growing maturity of road networks, the emphasis is shifting from construction to maintenance. Budgets for road works are shrinking. In addition to project evaluation, there is now also a need to estimate the long term requirement for road funds to provide a given level of service and to estimate what will be the resulting level of service at some future year with a given budget. To make it a little easier to do strategic-type analyses, some additional features have been added to the program. This model is now released under the name of Highway Development and Management (HDM-4).

THE HIGHWAY DEVELOPMENT AND MANAGEMENT MODEL (HDM-4)

The Highway Development and Management Model is a project evaluation model that has been modified so that the timing of projects can be made conditional on selected events like traffic or roughness reaching a certain figure. It is both a calculator and its own report generator with most of the reports being optional. Traffic volumes and composition are kept in a separate file to the road inventory. All projects have to be completely specified including cost and time of construction. The user also provides the annual routine road maintenance cost. If the user provides a list and cost of alternative work types of pavement preservation, the program will select the optimum combination of preservation work to give the lowest life cycle cost.

Quite intensive calculations based on pavement strength are used to estimate pavement performance. Where alternative methods of pavement preservation are being evaluated, calculations of pavement performance and road user cost are made for each year from work inception to the end of the analysis period. In addition to an economic analysis, the program can also calculate environmental outcomes in terms of the change in the amount of various gases that are generated by road traffic. Different strategies for maintaining pavements to obtain the minimum life cycle cost can be included as part of the evaluation. For each evaluation, the amount of data to be provided and the amount of calculation is considerable. For project evaluation, this is the most accurate approach. As usually only a small number of inventory records are involved when doing a project evaluation, the job can be run without the computation time becoming excessive or the program running out of space to produce the reports.

USE OF HDM-4 IN A STRATEGIC ROLE

When a large number of inventory records are read, run times become large and the program can run out of space if too many reports are requested. As the program is its own report generator, additional reports can only be obtained by rerunning the analysis to redo all the calculations but with a different set of reports requested.

With shrinking budgets for road works, users also need to look at the strategic view of what level of funding is likely to be needed over a long period of years to maintain a given level of service over a whole road network and to be able to assess the effect on the road network of working with a more limited level of funding. In recent years HDM has been used in this role. To assist in this, some modifications have been implemented in later versions of HDM to initiate user specified work types when one or more of the variables describing the road segment reach a user specified value

such as adding a second carriageway when the traffic volume reaches 14000 vpd, or rehabilitating the pavement when the level of road roughness reaches a user specified value of IRI. The user must provide the specification and cost of each possible project that may be required. The user also must indicate which work types are permitted on each road section plus any conditions on the timing of each project.

With long evaluation periods of the order of 50 years, each input inventory record will require the pavement to be rehabilitated at least once plus up to three reseals. If alternative work types are allowed, this will increase the number of projects per record that will need to be specified, costed and entered into the system. In addition, maintenance costs for each year of analysis must be provided. If one attempts to use all the sections representing a road network, (this can be of the order of 20000 plus records) the workload is huge. Setting up alternate strategies may require a large amount of preparation work. For instance, if one wanted to test the effect of alternate width standards, all the project and maintenance costs would have to be re-estimated and re-entered. This workload plus the program run time and limitations of space on report generation imposes a practical limit on the total number of records that can be used to represent the whole network. For project evaluation, the use of a single total job cost per km reduces the amount of data entry, as the individual project cost is available off line. However, it means that for a strategy type analysis, the user has to estimate and input the job cost for every project, as the program is not able to estimate job costs. Clearly, a user is not going to attempt to process 20 000+ records for a network.

METHODS OF REDUCING THE NUMBER OF RECORDS TO REPRESENT A NETWORK

The number of records needed to represent the inventory can be reduced by either of two methods. One way is to increase the range of one or more of the variables used to sectionize the inventory. With this method, a particular piece of road can be identified with each record. Project costs can be correctly estimated for the area. An alternative method is to amalgamate inventory records into the total length of road with inventory characteristics in ranges. Each record can no longer be linked to a particular piece of road or area. Given that there are up to eight variables that can be used to describe a road network (traffic volume, pavement strength, seal type, seal age, pavement roughness, gradient, curvature and climate), the number of subdivisions of each variable has to be kept small in order to limit the number of representative records. For instance, if we leave out gradient and curvature from the above list and subdivide the rest according to the numbers in **Table 1**, even with the expectation that half the cells will be empty, the number of records still comes to 2000.

Table 1. Possible number of Groups for each Network Variable

Network variable	No. of subdivisions
Traffic volume	5
Pavement strength	5
Seal type	2
Seal age	4
Road roughness	5
Climate	4
Gradient	1
Curvature	1

Considerable loss of accuracy results from having to use the length-weighted average value of the variable contained within each cell to represent all the length of road therein. The unit costs of each work type also become a representative figure. When representative road records are used, some of the road length could be in areas where pavement material is only available on very long leads (upwards of 100 kms) while in other areas the pavement material may be available on very short leads (less than 5 kms). The problem is compounded even further by the variation in the pavement thickness required as a result of variations in subgrade soil strength and the variation in traffic loading. In a large State where the construction cost index in the most remote region is approximately 50% higher than in the cheapest region, this averaging is a further loss of accuracy. This gives rise to the anomaly that very detailed calculations of pavement performance are being performed on data that has lost considerable accuracy in the averaging process. This then raises the question of whether the study results bear any relation to reality.

EFFECT OF AVERAGING DATA ON THE ACCURACY OF THE OUTPUT

The author has personal experience in one study of the effect of averaging. The study was to estimate the additional cost to the road authority if one train load of timber per week over a distance of approximately 300 kms was to be moved by road instead of rail as a result of some relaxation of Government controls (the project evaluation program being used also had a feature to calculate the annualised cost of the alteration in pavement life resulting from a change in the traffic load between project and base case). When the study started, there was no direct means of taking data from the road inventory and passing it to the evaluation program. Inventory data was being summarised manually into uniform segments averaging about 10 kms in length and then manually entered into the evaluation program. Before the study finished, a process to extract all records from the inventory between nominated start and finish points to set up the evaluation input file was implemented and the study re-run (the average segment length in the inventory was about 0.5 kms). The road authority cost from using the actual records was double the cost from using the amalgamated records. This is because the pavement performance relationships are non-linear and averaging the pavement data distorts the results.

This leaves the user with the difficult choice of an impossible workload to use all the records describing the network, or to accept questionable results by aggregating records. One compromise would be to compare using all records with using aggregated records on a portion of the network for one scenario to gauge the relative error in the aggregate works total. This correction could then be applied to scenarios run on the whole network using aggregated records to improve confidence in the results. However this still involves a lot of work.

STRATEGIC EVALUATION USING PURPOSE-WRITTEN SOFTWARE

Australia started down the path of strategic assessment in the early 1970's. At the time, the two requirements were
- To assess the five year need for road funds in each State as input into the five yearly agreements between the Federal Government and the States for the amount of Road Funds being distributed by the Commonwealth.
- To test the effect of differing road design standards to see what could be afforded.

The move into project assessment came later. The end result is that separate systems are used for strategic assessment and for project and strategy assessment. For strategic assessment, a suite of programs is used. The reporting function is kept separate from the main calculation program. The suite of programs is commonly referred to by the name of the main calculation program. The first application of this process was the use of the **N**ational **H**ighway **P**roject **A**ssessment and **C**osting program (NHUPAC) by the Commonwealth Bureau of Roads for the National Highway Study in 1972. Following this application NAASRA set up a team to further develop the concept. This led to the development of the **N**AASRA **I**mproved **M**odel for **P**roject **A**ssessment and **C**osting (NIMPAC) in the late seventies. The underlying philosophy of NIMPAC is the use of engineering standards to generate and design projects and to use the total road authority costs and the total cost of transportation for assessment of scenarios. The system treats roads and bridges.

NIMPAC is designed to permit exploration of the consequences of choice of particular road improvement standards and strategies, in terms of changes in the costs of transportation. Maximum flexibility is provided for ease of alteration of standards and sensitivity testing. It can generate network expansion type projects as well as asset preservation type projects. It works on the assumption that no diversion of traffic arises from any project. Availability of data in a particular continuous inventory format is a prerequisite for its use.

Starting with road inventory records in continuous format, programs were written to
- Sectionize the inventory using changes in from 8 to 27 variables (at user's discretion) as section determinants to convert the continuous inventory to a fixed format inventory with values for all variables present on each record (SECIDF)
- Adding unit cost group numbers to the fixed format records (SETCOG)
- Editing, updating and reporting of the unit cost file (UCEDIT)
- The main calculation program (NIMPAC). In addition to the initial inventory record, NIMPAC writes out a work cost record for each analysis year (contains maintenance and road user costs for each year and capital works costs when work is generated) followed by a new inventory record at the end of the elapsed project construction time
- A program to create an inventory only file at the user nominated future year by extracting the relevant records from the NIMPAC output file. (SNAP) – enables summary tabulations of the inventory at the future date for comparison with similar tabulations of the inventory at the starting date.
- A tabulation program to produce all the reports that the user chooses to output (XTAB)

NIMPAC uses assessment standards to determine if and when any work is required, design standards to determine the project specification, and deferral rules to defer particular work types if they are followed too closely by pavement rehabilitation. Unit quantities for the generated work type are calculated and then the project is costed using unit costs. Five area classes are used as the prime index into the standards. The area classes are defined in **Table 2.**

Table 2 Area Classes

Area	No.	Definition
C.B.D	1	The central business district of major cities
Urban	2	The contiguous built up portion of cities or major towns in which interrupted traffic flow predominates
Outer urban	3	The outer suburban areas of major cities in which uninterrupted flow generally predominates
Town	4	Minor population centres in which commercial activity is undertaken and traffic flow is predominantly uninterrupted
Rural	5	The rest of the State not included within any of the above

The second level of indexing is the road classification. Five levels are used for roads in the two rural area classes (4 and 5) and four levels are used for the three urban area classes (1, 2 and 3). Road width standards are further indexed by carriageway number, general terrain and traffic volume.

Deferral rules are indexed by area class and road classification. These are used to cancel the first occurring work type if it is followed too closely by the need to rehabilitate the pavement e.g. a reseal in year n followed by pavement rehabilitation in year n+2 can be cancelled by a user specified rule. In the case of a widening in year n followed by pavement rehabilitation in year n+4, the widening can be cancelled and the rehabilitation to the new width done anywhere between the two dates based on the user's specified rule of how much to bring the rehabilitation forward, or the user can choose to accept all projects when they fall due.

Unit costs are indexed by area class, local government area and road classification. There is no limit on the number of sets of unit costs that can be used as only one set is held in memory at any one time. The unit cost file also contains the hourly flow rate distribution of traffic throughout the year, the coefficients of the equation relating road roughness to pavement age and the strength of the subgrade soil expressed in terms of the Californian Bearing Ratio. This level of indexing means that the program is able to estimate project costs with reasonable accuracy if the correct unit costs are provided.

NIMPAC uses engineering assessment standards by area class to assess the road section. The roughness is assessed to calculate in what year the pavement will need rehabilitation. Pavements are rehabilitated when the roughness reaches a user specified value. The speed rating of the road geometry, both horizontal and vertical is checked. Next the road section is checked to see if it has the correct surface type and width for the traffic volume. Finally, the seal is checked to see if a reseal is needed. Reseals are due based on seal age.

All geometric failures are triggered in the first year. These can be deferred at any interval up to the next pavement rehabilitation provided the interval between the two failures does not exceed a user specified value. Most widening failures are triggered in the first year (some widening failures occur later as a result of traffic growth). These can be deferred anywhere between the present and the next pavement rehabilitation work, again providing the interval does not exceed a user specified value. For widening failures, a section that fails by 0.1 m by 1 vpd has the same priority as a section that fails by 7.0m by 10000 vpd. All projects that are triggered, pass the deferral rules and can be constructed within the time period are accepted.

If the section fails any of the checks, an appropriate work type is flagged. If a failure is flagged, the program changes to design standards using traffic at a user specified time interval into the future to determine the project specification. Unit quantities of work required are calculated and costed. The total project cost is used to calculate pre-construction and construction time. Depending on the size of the project, this time can be as much as four years (maximum). When the construction is estimated to take more than one year, the capital cost is spread evenly across the construction years.

The maintenance cost is estimated from formulae, itemised road user costs (including fuel consumption) and road crash costs for the section are calculated and a cost record is written. At the time of project completion, the inventory is updated with the new project and a new inventory record is written. The analysis year is incremented and the process repeated until the inventory record is processed through all years. The program then moves on to the next inventory record. Because of the application of the deferral rules, it is usual to run NIMPAC beyond the last year of interest by a few years. The reporting is then restricted to the analysis years. The assessment year increment can be one or two years. If two years is used to save time, the total program capital cost is barely affected, but the user then has to interpolate for the missing years for the maintenance cost in order to arrive at the total budget cost.

Bridges are assessed for width and load rating. Narrow bridges are widened. Where a bridge occurs on a single carriageway that is being duplicated, the length and height above the waterway for the new bridge is copied from the existing bridge. For a bridge that fails the load rating, a new bridge is designed and costed. The new length is a user specified increase on the existing length, and similarly for the height above the waterway. The new width comes from the design standards. Costing of the substructure is based on the height above the waterway times the width, while the costing of the superstructure is based on the deck area. A separate road crash rate is used for bridges to account for vehicles hitting the crash barrier at entry to the bridge. Apart from the case of a carriageway being duplicated, NIMPAC cannot construct a bridge where there is not one currently, or construct a road where there isn't one. These cases can be dealt with by putting into the inventory an existing bridge (or road) that is substandard and has to be replaced. NIMPAC will then be able to estimate the project costs.

NIMPAC is used to estimate all road authority costs in rural areas and to estimate rehabilitation and maintenance costs in urban areas where traffic diversion occurs. The urban traffic forecasting and evaluation system is used for urban network expansion projects.

NIMPAC has no means of restricting the need in any period to a budget. The user does this by adjusting the standards by trial and error until the total need in the analysis period matches the required budget within a selected percentage (say +- 2%). Changing the standards may remove (add) projects or it may change the project cost because the required road width has changed, thus altering the unit quantities, which in turn alters the cost. To decide what to change and make the changes takes a few hours. Unless the assessment standards are chosen carefully, the need arising in the first year is often more than 50% of the total ten year requirement because of all the widening and geometric failures that are triggered in the first year. This could be changed by the addition of some form of economic analysis of capital works before the project is accepted. This would then allow the program to be restrained to a year by year budget and make the program more useful as a strategic analysis tool. For a fuller description of NIMPAC see Both et al (1976).

The number of tables that the report program can produce in any one run is only limited by the total table space required. If the user requests more tables than can fit within memory, the program gives a warning message and then continues to run to produce all those tables that do fit starting with the first table requested and working in sequence. It is usual to have four or five runs set up to produce tables for a strategic study.

ADDITION TO NIMPAC

Once NIMPAC is set up, it is relatively easy to set up an alternative scenario for testing and it produces reasonably accurate estimates of project costs. A limitation is that it does not have any means of restraining generated needs to a budget other than by adjusting the standards. As it already calculates road user costs on each record for each year of the analysis it would be relatively easy to add some form of economic analysis of each project that passed the engineering and deferral criteria. This would provide the ability to restrain needs in each year to a budget. A test for the first year rate of return would fail any widening projects that just failed the assessment standards for either width or traffic volume. A benefit cost ratio (BCR) could then be calculated for projects passing this test. By allowing the user to input a minimum cut-off BCR for each year, the need could be restrained to the available annual budget. Maintenance strategies to give minimum life cycle costs would be determined within the project assessment system and then that strategy would be followed within NIMPAC. Most of the projects requiring widening by small amounts or where the traffic was not far over the limit would not be accepted so that the resulting widening work would be both much less and more evenly spread over the analysis period. Determining needs that are unrestrained by budget would be done by setting all cut-off BCR's to a low value. Working to a restrained budget would require several runs on a trial and error basis to give needs within an acceptable percentage of the budget.

CURRENT POLICY CONTEXT

The recent Auslink Green Paper set out some specific requirements for 'improved and consistent evaluation' (DoTARS, 2002, p58), including:
♦ capable of being implemented at different levels of detail, from a high-level scan to an in-depth study;
♦ capable of providing a holistic assessment of the project, including whole-of-life analysis and incorporating the best elements of cost-benefit analysis and other assessment techniques to ensure that the widest possible range of relevant information is available to decision-makers on costs and benefits;
♦ defensible in that it is comprehensive, transparent, rigorous and offers consistency across decisions;
♦ able to be used to compare different types of projects … with no inherent bias towards any particular solution or geographic region;
♦ capable of ensuring that a mix of projects of national and regional importance receive assistance; and
♦ able to be tailored to fit the Government's objectives (economic, social, safety, environmental and regional).

The models described provide a substantial and proven basis for evaluation of road projects in these terms, but further development is required to meet the other stated Auslink criterion of being able to be used to compare different types of projects, including in different modes of transport and alternative approaches.

Whilst these criteria were set out in the context of the requirements of a *National* land transport plan, they are equally applicable at the State/Territory level, where governments are increasingly seeking to establish transport programs on an integrated, multi-modal basis, with evaluation on the basis of triple-bottom-line outcomes.

CONCLUSION

HDM-4 is a project analysis system that can also be used for strategic analysis, providing one is either prepared to put in a lot of work, or one accepts possible loss of accuracy by reducing the inventory into representative sections. It will deal with both asset preservation of the existing sealed / paved area and with projects that add additional lane kms to the network. Testing the effect of changing construction standards involves a lot of data preparation and data entry work.

NIMPAC is a strategic analysis system that processes the sectionized inventory without any need to reduce the number of records. It does not require much time to set up alternate scenarios. It is not a project analysis tool. It can be used to calculate pavement preservation needs in an urban network, but as the system does not allow for traffic diversion, urban network expansion projects have to be dealt with outside of the system. In a rural setting (where the assumption of no diversion of traffic is acceptable), network expansion and pavement preservation works compete against each other for available funds. The addition of economic analysis of projects before acceptance can fairly easily be added to NIMPAC and would be very beneficial.

The needs of project assessment are so different to the needs of strategic assessment that trying to make one program do both is not satisfactory. It is preferable to have separate systems for project evaluation and for strategic assessment. Of the two systems reviewed, NIMPAC is the most flexible for setting alternate scenarios, and does not require any compromise on accuracy by having to reduce the number of inventory records. The addition of economic assessment of projects before acceptance would make it the most suitable tool for strategic analysis.

The current focus on sustainability and 'triple bottom line' evaluation adds to the importance of road system evaluation that is technically robust, flexible, able to be applied at various levels of detail and capable of providing estimates of an appropriate range of outcomes. The two models described in this paper provide a substantial basis for this. It is equally important that the development of the broader decision-support models required by governments comprehends and includes such models, rather than reinventing the wheel.

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The author has over 30 years experience in traffic forecasting and transport modelling covering such items as traffic forecasting models, road safety analysis, asset management and economic analysis of road projects. In addition to model calibration, traffic forecasting included development of an incremental assignment method that allowed for separate analysis of the effects of intersections on travel times and the variation in traffic flow throughout the day. Another project was summarising daily traffic volume data into actual travel speed ranges so that it could be integrated into a model for estimating vehicle emissions. Asset management encompassed pavement life and seal life prediction, estimating the change in road authority and road user costs if freight transferred from rail to road and development of a model to predict annual road maintenance costs. Road project analysis covered vehicle operating cost models and the development of a system for analysing road projects in an urban network that also included the effects of intersections and used the same assumptions about the spread of traffic throughout the day and the effect of intersections as used in forecasting the traffic. Road safety analysis covered such topics as developing road crash rates by road stereotype for rural roads and separate crash rates for intersections and for mid block by road type for urban network analysis. Recent work has looked at the safety of heavy vehicles relative to other traffic, the residual effect of speed camera enforcement, the likelihood of drivers being involved in crashes by age group and gender, data analysis and presentation of driver fatigue monitoring data and analysis and presentation of skid resistance data.