Benefits from Research Investment: Case of Australian Accelerated Loading Facility Pavement Research Program

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Since 1984 the Accelerated Loading Facility (ALF) has played a central role in a major Australian pavement research program. Results from an economic evaluation of this research program are reported. Benefits are quantified in terms of the reductions in road authority costs, reflecting a direct hard dollar return on the research investment. The overall benefit-cost ratio depends on the selected inflation-free discount rate and ranges from 4.0 at 8 percent to 5.0 at 4 percent. A number of significant, but unquantifiable benefits were also identified, including ALF's role as a catalyst for pavement research and field innovation, improved cooperation between researchers and practitioners active in the pavements area, and enhancement of Australia's technical reputation overseas. Overall, the results indicate that a healthy return is being obtained on the investment in this pavement research program.

Since 1984 the Australian road authorities, through the Australian Road Research Board Limited (ARRB) and AUSTROADS (the national association of road and traffic authorities in Australia), have supported a major pavement research program centered around the Accelerated Loading Facility (ALF). ALF (Figure 1) is a relocatable road testing machine that applies full-scale rolling wheel loads to a test pavement. To date eight trials have been completed on different pavement types in four mainland Australian states (Figure 2), and the ninth trial, which is being undertaken for the U.S. Army Corp of Engineers, is currently in progress on the Beerburrum test site in Queensland. Technical aspects of the Australian ALF research program have been reviewed elsewhere, (*1*).

Between 1984 and 1992 expenditures on the program totaled approximately $11 million (1992 Australian dollars), and although there is continued interest in the ALF program, an evaluation process was initiated to assess the benefits obtained from this research expenditure. Addressing the issue of value for money is of fundamental importance to research organizations like ARRB as they strive to provide accountability for their expenditures in response to increasing pressures on their budgets. The aim of this study was to produce a credible, justifiable evaluation of the ALF trials on the basis of the dollar value assessments of their benefits and costs. The study focuses on the first seven trials because it was undertaken while the eighth trial was in progress.

The structure of this paper is as follows. Initially, general issues associated with evaluating research benefits are addressed and then the methodology used in this study is outlined. The evaluation of the individual ALF trials is then described before the evaluation of the ALF program as a whole is considered. Finally, the conclusions are presented.

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METHODOLOGY

The general steps in this, as in other economic evaluations, are to

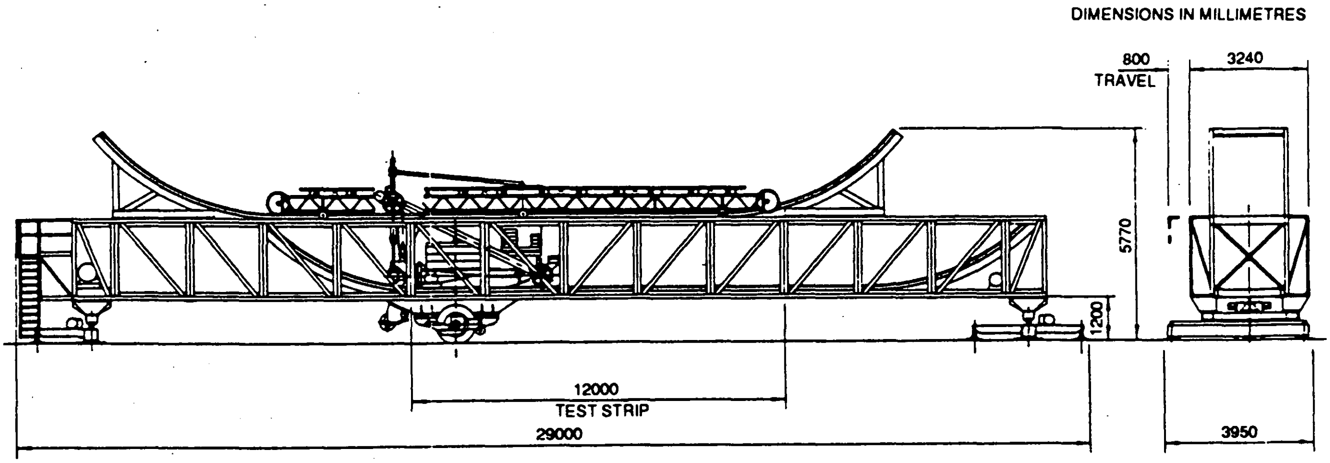
1. Identify the range of benefits and costs associated with the ALF program,
2. Value the benefits and costs in dollar terms, and
3. Determine the values of appropriate benefit-cost criteria.

In a relative sense, costs were easier to quantify than benefits. These costs refer to the actual expenditures involved in conducting each trial. Costs are generally split between the host state road authority (SRA) and ARRB, with the SRA covering construction of the test pavement and staff costs associated with monitoring the test, whereas ARRB costs include those associated with data collection and analysis.

The measurement and dollar valuation of benefits presented the greatest challenge in the evaluation of the ALF program. It is important to appreciate the manner in which benefits are realized. Benefits may be reflected in reduced road authority costs or in terms of reductions in road user costs (Thorensen, unpublished data). (The term *road authority* is used here to cover both state and local government interests.) In the current economic climate, reductions in road authority costs are regarded as the most appropriate measure of benefits. This benefit measure is clearly of interest to road authorities because it reflects a direct hard dollars return on the investment made in pavement research through the ALF program. Although the use of this measure of benefit could be debated, it is important to appreciate that it would not have been feasible to develop justifiable measures of road user benefits given the time frame for this project.

The reference point against which benefits are to be measured must also be defined. As illustrated in Figure 3, the outcomes of the ALF trials, that is, the knowledge that is gained, affect the decisions and practices of road authorities, and these determine authority costs. Because the focus here is on road pavement research, the relevant road authority costs are those that relate ultimately to either the establishment or preservation of roadway assets. The benefit of the ALF trial is then the difference in the authority's costs with and without the ALF trial. These benefits may arise, for example, because an ALF trial results in accelerated introduction into practice of an asphalt additive that reduces maintenance costs or because ALF provides reassurance that a cheaper pavement design will provide adequate service life.

The linkages between ALF trial outcomes and road authority costs are illustrated in greater detail in Figure 4. Here a distinction is made between whether the outcome of the trial affects authority



Test wheel	Dual tyres, 12 - 22.5 Michelin 'X' type, ZA pattern, 16 ply rating, tubeless
Mass of Test wheel assembly	4 to 8 tonne in 1 tonne steps
Suspension for variable mass	Air bag
Power drive to wheel	2 x 11 kW electric geared motors, uni-directional operation, wheel off pavement on return
Transverse movement of test wheel	User programmable
Test speed	20 km/h
Cycle time	9 seconds
Pavement test length	12 metres
Overall length of ALF	26.3 metres
Overall width of ALF	4.0 metres (operating) 3.2 metres (transport)
Overall height of ALF	5.7 metres (operating) 4.4 metres (on transporter)
Total mass of ALF	45 tonne approx.

FIGURE 1 Description of ALF.

decisions/practices in the areas of pavement design, construction, or maintenance. These decisions/practices in turn determine the magnitude and timing of asset establishment and preservation costs. These cost categories should be interpreted broadly, so that, for example, expenses associated with laboratory testing of materials or conventional field trials could be classified as part of the asset establishment cost.

The first step in the assessment of the benefits of ALF is to develop qualitative descriptions of the linkages between each outcome of each trial and authority costs. Some linkages are direct, whereas others are much more indirect. The trial conducted at Benalla, Victoria, illustrates a fairly direct linkage in which one outcome was the confirmation of the strength of a particular pavement design which led to a decision to proceed with that design, thereby determining the construction cost. A less direct linkage is illustrated by the trial conducted at Callington, South Australia, in which one outcome was the cross-referencing, within a short time period, of laboratory tests on materials with their field performance. This calibration of the laboratory tests will enable the field performance of other combinations of materials to be predicted from the laboratory tests. Those subsequent laboratory tests could then influence decisions on the selection of maintenance treatments that could ultimately translate through to authority maintenance costs.

As the linkages between the outcome of an ALF trial and the authority's costs become less direct it becomes more difficult to develop credible and justifiable quantitative estimates of the corresponding authority costs. Comparing the Benalla and Callington examples cited, a broader range of assumptions would have to be made to quantify the final authority costs in the second case. It is important to emphasize that this discussion is focused on a particular outcome of each trial. There is no implication that all outcomes of the Callington trial are difficult to translate through to authority costs.

In keeping with the objective of producing a credible analysis, emphasis has been on quantifying those outcomes of each ALF trial that have fairly direct linkages through to authority costs. These outcomes will lead to benefits that are clearly recognizable and whose magnitudes can be readily justified.

As noted in Figure 3 it has also been necessary to assess authority costs in the absence of the ALF trial to estimate the benefits. This involved consideration of authority decisions/practices and their links to asset establishment and preservation costs in a manner similar to that illustrated in Figure 4. An additional difficulty arises, however, because it is not known for certain which decisions/practices would have been adopted in the absence of a particular ALF trial. For example, in the absence of the ALF trial conducted in Benalla, the Victorian State road authority (VIC ROADS) could have proceeded with the proposed pavement design or selected one of a number of alternative pavement designs. It would be incorrect to simply select the most expensive alternative pavement design and attribute all of the cost savings to ALF.

The methodology recognizes the importance of uncertainty about the outcome, in the absence of the ALF trial, by including it explicitly in the analysis process by using techniques developed in the field of decision analysis (*2,3*). The relative importance of this issue of uncertainty of outcomes in the absence of ALF varies across trials, so further discussion is held until individual trials are considered in the following section.

Another important issue that must be addressed in the context of each trial is over what period of time benefits can be directly attributed to that trial. In some cases an ALF trial may have accelerated the introduction of a new material by 3 to 5 years, whereas in other cases design procedures may have remained unchanged for 10 years or more, and therefore the benefits from the trial are likely to be realized over an extended period. Since each ALF trial is unique they must be assessed individually to determine the time period over which benefits are realized.

Once the benefits and costs are valued in dollar terms, the economic evaluation is relatively straightforward and involves the use of evaluation criteria such as the benefit-cost ratio to compare the magnitudes of the benefits and costs. Results of the economic evaluation are reported for values of the discount rate of 4, 6, and 8 percent per annum. The analysis of each trial is conducted in constant dollars so that these represent real, or inflation-free, discount rates. Given that that average inflation rate over the period of the ALF trials is about 7 percent, these discount rates would be equivalent to market interest rates of approximately 11, 13, and 15 percent, respectively.

EVALUATION OF INDIVIDUAL ALF TRIALS

Within the space limitations of a technical paper it is not possible to fully describe the evaluation of each trial. However, to adequately illustrate the application of the methodology, one trial, conducted at Benalla, Victoria, is examined in detail. The discussion of the other trials is brief, but in each case the primary outcomes of the trial, the nature of the benefits, and the results of the economic evaluation are reviewed. Readers are referred to the final report of the ALF program evaluation (*4*) for additional details.

Benalla, Victoria

The Benalla ALF trial, conducted between June 1985 and February 1986, examined a new section of the Hume Highway before it was opened to traffic. The Hume-Highway is a major interstate highway with a design traffic load of 3×10^7 equivalent single axles (ESAs) that connects Australia's two largest cities: Melbourne and Sydney. A heavy-duty unbound pavement comprising a double seal over 400 mm of crushed rock base and 170 mm of ripped sandstone subbase was tested. The granular material was compacted to a high density, thereby achieving a relatively stiff layer that would be expected to

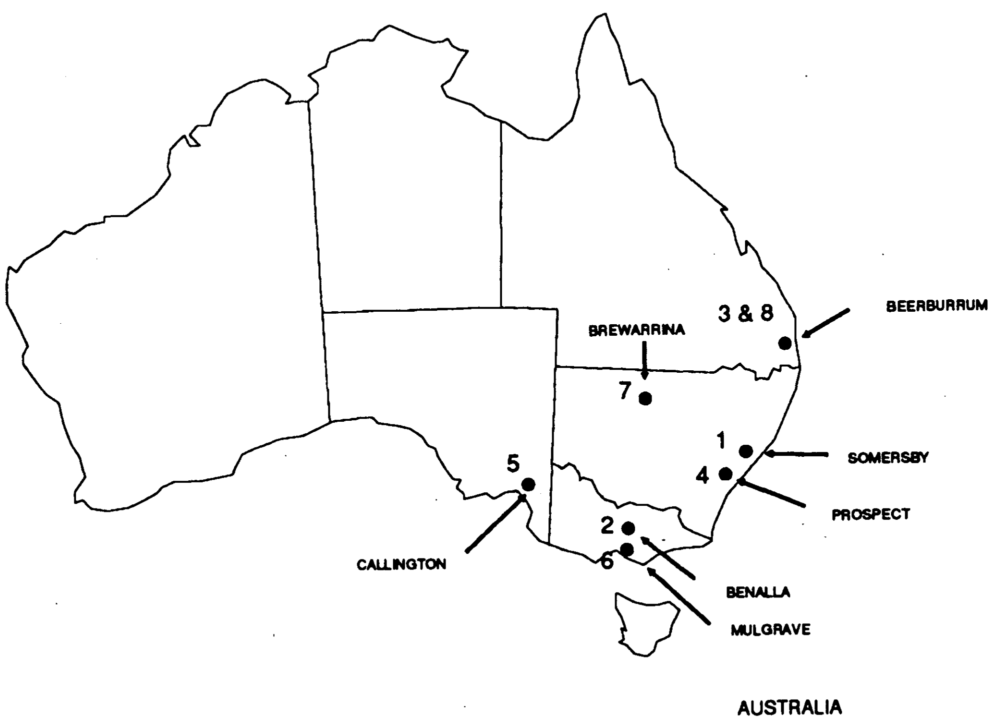


FIGURE 2 Locations of ALF trials in Australia.

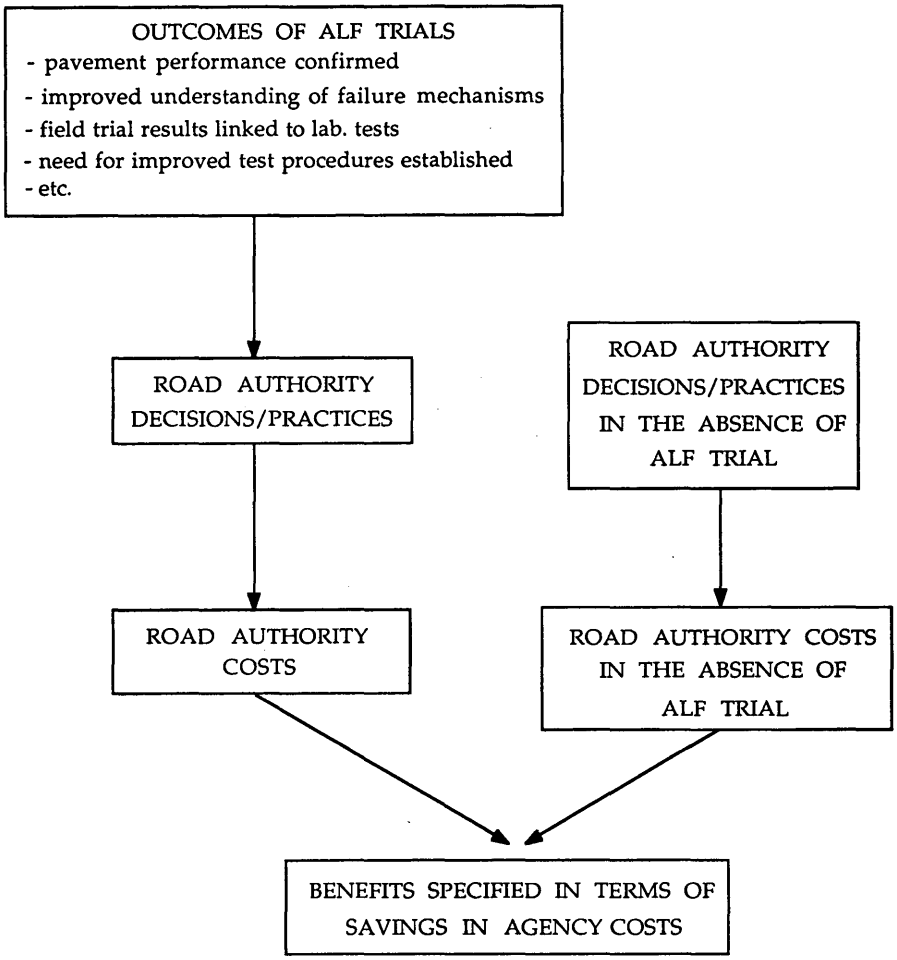


FIGURE 3 Effects of outcomes of ALF trials.

enhance pavement performance. Significantly, the Victorian State road authority has a national reputation for its ability to achieve a high degree of compaction in road pavements. The use of natural materials and a sprayed surface seal challenges overseas experience in which pavements of a different design would be standard for heavily trafficked situations.

This trial was not expected to cause the test pavement to fail. Sufficient load repetitions were applied to prove that the pavement would provide a long service life and to demonstrate that massive maintenance problems would not arise so long as the integrity of the seal was maintained. Fundamentally, then, this trial provided reassurance in the performance of this heavy-duty unbound pavement. This outcome has implications for the cost of establishing roadway assets (Figure 4) because the cost of other proven pavement designs for heavily trafficked situations is generally higher than that for the type of pavement tested at Benalla.

The greatest benefit from the Benalla trial has been realized in Victoria, where extensive lengths of roadway with this heavy-duty unbound pavement have been constructed since the ALF trial. Therefore, additional costs have been avoided by not adopting the more expensive designs.

Within Victoria, the Benalla ALF trial had most relevance to the selection of the pavement for the Hume Highway. Substantial proportions of the Hume Highway were still to be constructed in the decade following the ALF trial. The flexible granular pavement, costing approximately \$25/m^2 (1986 Australian dollars) to construct, offered substantial savings over alternative pavement types, with the cheapest alternative adding \$15/m^2 to the cost of the pavement. The long-term performance of this pavement was of special concern because Victoria had experienced failures in granular pavements with thin surfacings elsewhere in the state. In contrast to the Victoria practice, New South Wales was constructing rigid pavements on its portions of the Hume Highway. These factors may have created a perception, perhaps at the political level, that the remaining portions of the Hume Highway in Victoria should be constructed by using a rigid pavement.

At the very least there was pressure on the Victoria state road authority to consider other types of pavements for the Hume Highway. The ALF trial confirmed the performance of the granular pavement, and this type of pavement has now been used on the remaining sections of the Hume Highway and on one part of the Calder Highway, northwest of Melbourne, Victoria. It will never be known with certainty what choice would have been made in the absence of the ALF trial; however, there is a real chance that a more expensive pavement would have been selected to reduce the risk associated with the future performance of the pavement. The benefit of the ALF trial to Victoria is the expected savings in costs resulting from continued use of the low-cost granular pavement.

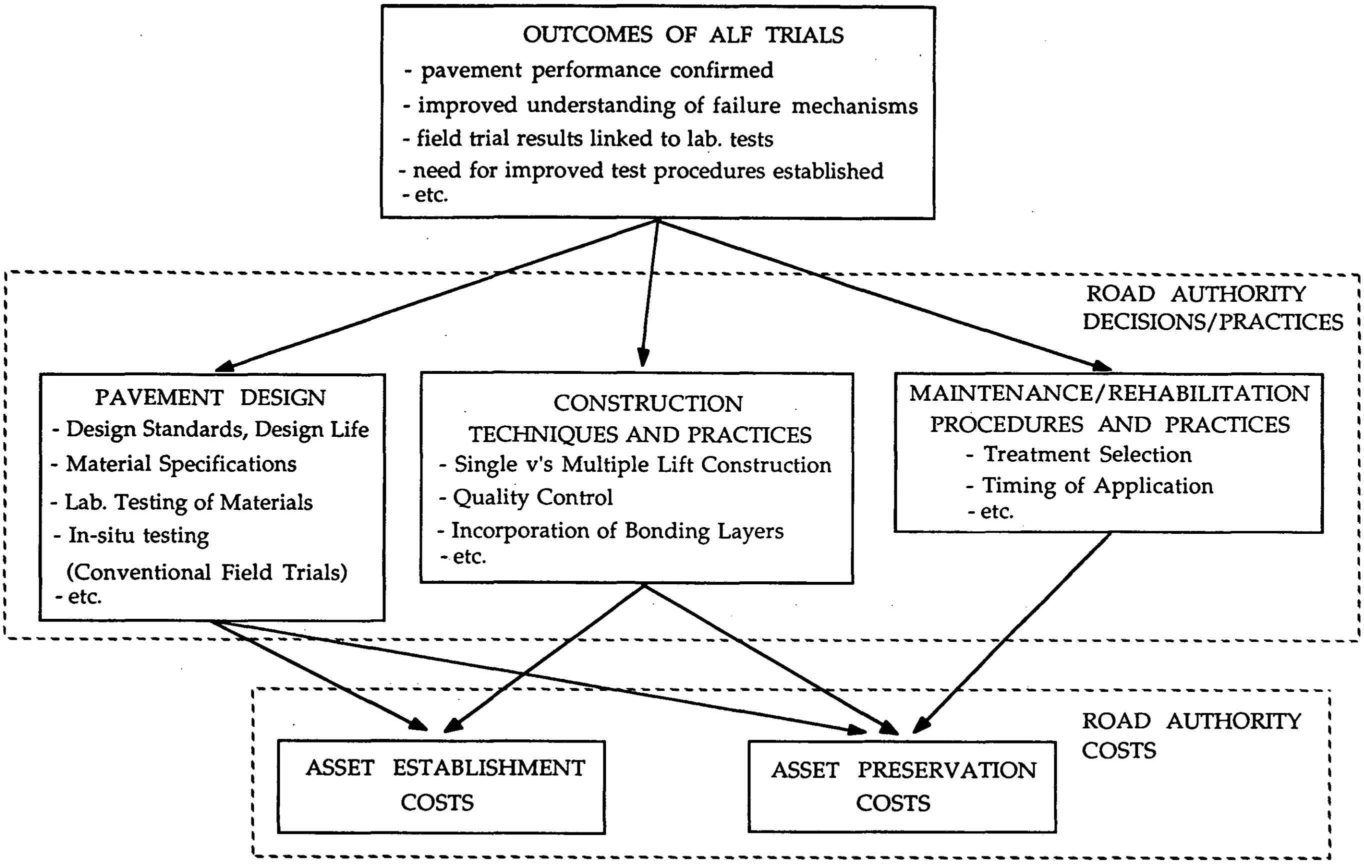


FIGURE 4 Linkages between ALF trial outcomes and road authority costs.

A decision tree representation of the Benalla ALF trial is shown in Figure 5. This decision tree highlights the uncertainty associated with the choice of pavement in the absence of the ALF trial. The options range from constructing an unbound, sprayed seal pavement or an asphalt-surfaced pavement through to a rigid (concrete) pavement. Options connected to a circular, chance node have a probability of occurrence. As will be described, these probabilities were assessed on the basis of discussions with representatives of road authorities.

The ALF trial tested and confirmed the performance of the unbound, sprayed seal pavement, and as a consequence of the trial, VIC ROADS proceeded with this flexible granular (FG) pavement at a life cycle cost of $26/m². (The life cycle cost reflects initial construction, maintenance, and rehabilitation costs over the economic life of the pavement.) Without the ALF trial VIC ROADS could have continued to use the flexible granular pavement, or one of three alternative, more expensive, pavements (Bethune, unpublished data) could have been selected. These alternatives and their associated life cycle costs were as follows:

1. AS, asphalt surfaced, costing $A41/m²,
2. DS, deep-strength asphalt, costing $A46/m², and
3. R, rigid pavement, that is, a jointed unreinforced concrete pavement, costing $A48/m².

Clearly, the flexible granular pavement offers considerable cost savings over alternative pavement designs.

As noted in Figure 5 there is a probability of selecting each pavement type in the absence of the ALF trial. The expected cost of the pavement, in the absence of the ALF trial, is simply the sum of the pavement costs multiplied by their respective probabilities of selection. The benefit, expressed as the saving in cost owing to the ALF trial, is the difference between the pavement cost after the ALF trial and the expected cost in the absence of the ALF trial.

Although hard data were available to quantify costs, the assessment of the probabilities was, of necessity, subjective. Discussions were held with a number of individuals who were working in the pavements area of the Victoria state road authority around the time of the Benalla ALF trial. Very consistent opinions were expressed by these individuals indicating that in the absence of the ALF trial there was still a 70 to 80 percent chance (i.e., $P_{FG} = 0.7$ to 0.8) that the flexible granular pavement would have continued to be used on the Hume Highway. There was a perception that there would need to have been evidence that the unbound pavement "would not work" rather than evidence that the other pavements "would work" for the design to be changed, given its considerable cost savings over the alternatives. In the results presented in this paper P_{FG} was set equal to 0.8. From the discussions with present and former VIC ROADS employees, it seems reasonable to expect that the probability of selecting the other pavement types would decline with increasing cost, and this expectation guided the selection of their probabilities. The other values used in the analysis were P_{AS} equal to 0.12, P_{DS} equal to 0.06, and P_R equal to 0.02. Because the estimation of benefits depends directly on the values of the probabili-

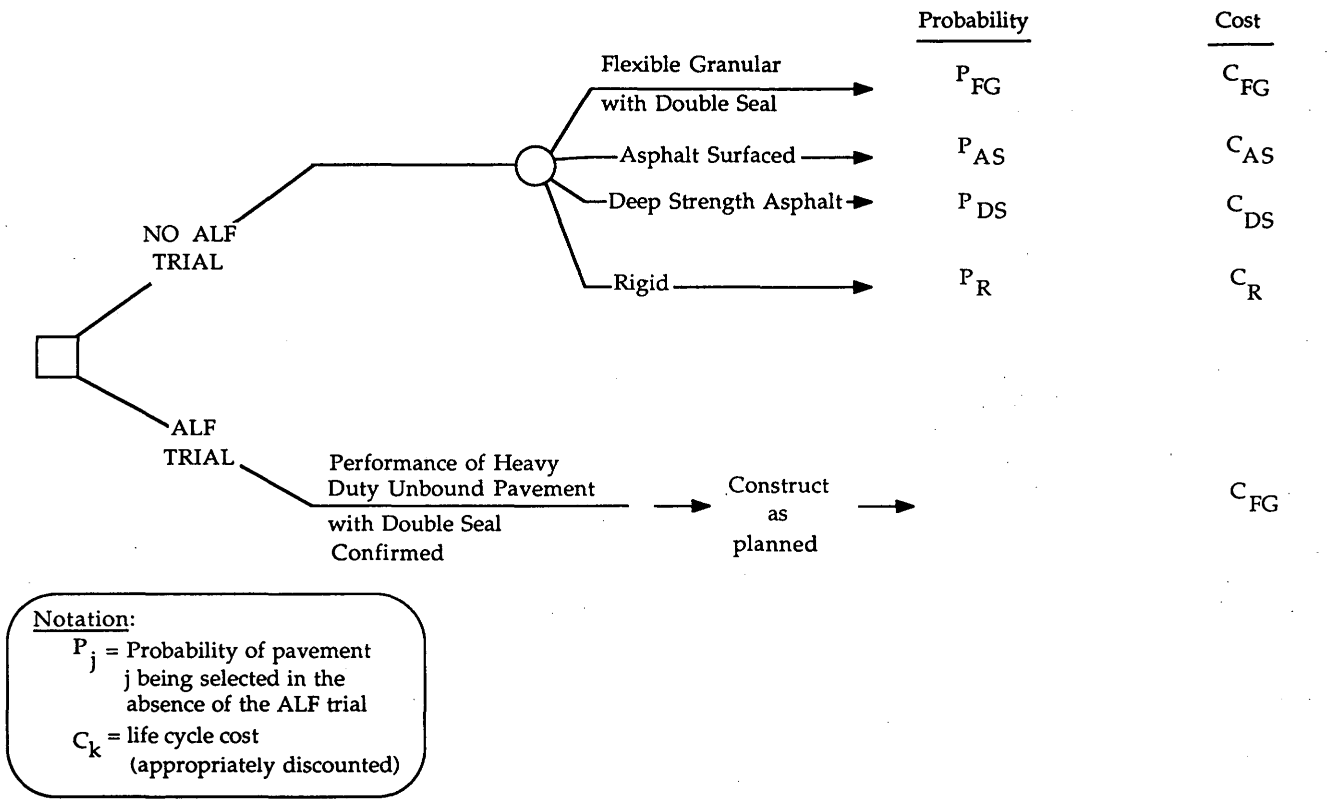


FIGURE 5 Decision tree representation of Benalla ALF trial.

ties, a sensitivity analysis approach was adopted in the study by repeating the analysis with three sets of probabilities; however, in this paper results are reported only for the probability values cited above.

On the basis of the cost and probability data mentioned above the expected cost savings associated with the ALF trial can be calculated at $3.44/m^2 (1986 Australian dollars).

To estimate the total benefits to Victoria of the Benalla ALF trial, the savings per square meter must be multiplied by the number of square meters and discounted to account for the time lag between the ALF trial and the completion of a particular portion of pavement. It is not regarded as appropriate to assume that the Benalla ALF trial would influence pavement choice for an indefinite period. Early sections of the Hume Highway constructed as flexible pavements would provide indications of field performance, which would influence subsequent pavement decisions. In the present study the perhaps conservative assumption has been made that the ALF trial could only be regarded as having an influence on pavement choice for about 7 years after the trial (i.e., up to about the time that this evaluation was being undertaken, since the trial was completed in 1986). During this period extensive sections of the Hume Highway have been completed, and it is regarded as appropriate to assume that the ALF trial would also have influenced the choice of pavement for one portion of the Calder Highway. In all approximately 90 carriageway km of road was identified in which the choice of pavement type could have been influenced by the ALF trial.

The present value of the benefits was estimated to be $3.4 million (1986 Australian dollars) when a 6 percent discount rate was used. Given that the total cost of the Benalla ALF trial was estimated to be $630,000 (1986 Australian dollars), the resulting benefit-cost ratio is 5.4.

As noted discussions with VIC ROADS staff identified that the most likely scenarios, in terms of the probability of still constructing the flexible granular pavement in the absence of the ALF trial, are represented by the probabilities underlying the figures presented above. These produce benefit-cost ratios in excess of 5 even at an 8 percent discount rate. Although there is inherent uncertainty associated with all estimates obtained in this type of analysis, even when using more conservative assumptions about the probabilities, the Benalla trial would still be economically justified. Results of the sensitivity analysis have been previously reported (*4*).

As noted an important factor that contributed to the high level of performance of the pavement tested at Benalla was the high density achieved in the granular layer. In individual ways pavement design procedures and specifications in Queensland, New South Wales, and South Australia have been influenced by the Benalla ALF trial to explicitly include the benefits of higher compaction. South Australia was close to making these changes in any case, and since ALF may have accelerated the introduction by at most 1 or 2 years, no benefits were quantified. The use of high-density granular bases offers the potential for savings in construction costs in Queensland and New South Wales; however, given the time that has elapsed since the ALF trial, it is difficult to assess whether these design changes could have been introduced as a result of field experience in other states, particularly Victoria. Therefore, no benefits were attributed to the ALF trial in these states. In the remaining states and territories heavy-duty granular pavements of the type tested at Benalla see rare application, and so no benefits were quantified.

Summary of Benefits from Individual ALF Trial Evaluations

As noted previously, this evaluation covered the first seven ALF trials. Table 1 summarizes the focus, outcomes, and primary benefits of these trials. In this section the nature of the benefits resulting from the trials is reviewed. The results of the economic evaluation are summarized in the following section.

Of necessity the first ALF trial, which was conducted at Somersby, New South Wales, had more to do with testing ALF than it did with testing a particular pavement. As a result of the proof testing that ALF underwent at Somersby, it emerged as a reliable testing machine for future trials. No mechanisms that would enable estimates of direct benefits from the Somersby trial to be quantified were identified. In the economic evaluation of the ALF program, the costs of undertaking the Somersby trial are regarded as part of the development costs of ALF and are therefore classified as "sunk" costs.

The second trial was conducted at Benalla, and as described in the previous section, the benefits were identified and quantified. The benefits related to savings in pavement construction costs relative to more expensive alternatives.

The trials that followed Benalla were guided by a more explicit experimental design. As noted in Table 1, these later trials examined a variety of pavement types, including cement-treated base and deep-strength asphalt and a range of materials including polymer-modified asphalt, geotextile seals, and blast furnace slag.

The primary benefits have accrued through savings in construction costs and maintenance and rehabilitation costs. For each trial conservative assumptions were made about the duration over which the benefits could be attributed to the trial.

A number of trials have led to improvements in pavement design, which in turn have produced construction cost savings. For example, the Prospect trial facilitated the design of more cost-efficient slag-based roads by designing them as heavily bound instead of lightly bound, resulting in a reduction of typical base course thicknesses from 450 to 350 mm. The Mulgrave trial found that significantly higher modulus values were achieved in the cement-treated crushed rock (CTCR) examined in the trial than are normally assumed in the design process and also that the existing fatigue relationships for CTCR were conservative. Revision of the design guides for CTCR and achievement of higher modulus values will lead to construction cost savings through a reduction in pavement thickness.

In some cases construction practices have been altered as a result of an ALF trial, resulting in savings in rehabilitation costs through extended pavement life. The Beerburrum trial, for example, focused attention on the importance of achieving an adequate bond between layers of cement-treated base (CTB) material to reduce water infiltration and thereby reduce the rate of pavement deterioration. Without the knowledge provided by this trial, a number of states would have continued to construct CTB pavements that would have experienced premature failure because of layer debonding. The benefit of the ALF trial is therefore measured by the savings in rehabilitation expenses made possible by revising construction practices to prevent debonding. It seems reasonable to expect that the debonding mechanism would have been identified by selected excavation

TABLE 1 Overview of Individual ALF Trials

Trial Location (Duration)	Pavement type/ trial focus	Primary Outcomes	Primary Benefits	Assumed Duration of Benefits
Somersby (7/84 to 4/85)	Heavy duty unbound, asphalt surfaced	Pavement did not fail	Proof testing of ALF	
Benalla (6/85 to 7/87)	Unbound, sprayed seal	Pavement did not fail	Lower pavement construction cost relative to alternatives	7 years
Beerburrum (2/86 to 7/87)	Cement treated base	Failure through layer debonding rather than fatigue	Reduced rehabilitation expenses through improved construction practices which bonded layers	5 years
Prospect (8/87 to 6/88)	Blast furnace slag as base material & stabilising agent	Performance of blast furnace slag confirmed	Construction cost savings relative to conventional materials	5 years
Callington (7/88 to 10/89)	Asphalt surfacings in pavement rehabilitation	Improved design procedures for overlays	Reductions in rehabilitation costs due to reduced depth and extended life for overlays and intersection reinstatements	5 years
Mulgrave (6/90 to 3/91)	Asphalt fatigue life	Shell Asphalt Fatigue relationship found to be conservative	Existing relationships still used pending probabilistic design process therefore no benefits quantified	
	Cement Treated Crushed Rock fatigue life	Higher modulus for CTCR than assumed in design Fatigue life relationship for CTCR found to be conservative	Construction cost savings possible through reduced pavement thickness due to less conservative fatigue life and higher modulus for CTCR	10 years
Brewarrina (7/91 to 2/92)	Geotextile seals for low volume all weather roads	Performance confirmed	Construction cost savings relative to alternatives	5 years

or drilling of boreholes in in-service CTB pavements that exhibited cracking and pumping, so it was therefore assumed that benefits could be attributed to ALF for only 5 years.

Of all the ALF trials conducted up to early 1992, Callington had perhaps the widest relevance across Australia. That trial addressed the relative performances of a variety of asphalt surfacings in the context of pavement rehabilitation. In particular, it compared a number of polymer-modified asphalt (PMA) overlays, investigated different binders in open-graded friction courses (OGFCs), and examined the effect of flexible stress-alleviating membrane interlayers (SAMIs) and the use of a high-binder mix in the tensile zone in the bottom of full-depth asphalt pavements. The primary savings resulting from the Callington trial arose from decreases in frequencies and reductions in reinstatement depths for rut repairs at urban intersections because of the use of PMAs and reduced frequencies and thicknesses of general road rehabilitations.

Although most of the trials focused on pavements for heavily trafficked applications, the Brewarrina trial demonstrated that research on pavements for lightly trafficked roads can also produce significant benefits. That trial examined the structural performance of an expansive clay pavement with a geotextile reinforced seal wearing surface. The knowledge gained from Brewarrina is relevant to roads carrying very low traffic volumes, in which road user cost savings may not justify sealing but the provision of all-weather access is seen as a community service obligation. The benefits from the Brewarrina trial arise simply from savings in road construction costs. The geotextile seal road was consistently estimated to cost around $A60,000/km less to construct than the most probable all-weather road alternative—the placement on the black clay subbase of 300 to 350 mm of gravel, to which a spray seal was then applied.

OVERALL ALF PROGRAM

In this section the ALF research program as a whole is placed into perspective. The performances of individual ALF trials are compared, the viability of the entire program is assessed, and some of the broader benefits, which are attributable to the program as a whole instead of to any one trial, are described.

Overall Economic Viability

Table 2 summarizes the economic evaluation results for all trials, with the benefits and costs expressed in the common units of 1992 Australian dollars. For each trial these figures represent the best estimates of the benefits. Prospect is the only trial in which the benefit-cost ratios were close to 1.0. For all other trials the benefit-cost ratios tend to be greater than 3.0, with the Brewarrina result higher at around 11.0.

On the right side of Table 2 the total column shows a combined result for all the trials from Benalla to Brewarrina. The overall benefit-cost ratios range from 4.0 to 5.0 depending on the discount rate. These results suggest that the internal rate of return would exceed 20 percent, indicating that a healthy return is being obtained on the investment in this pavement research program.

As noted earlier no mechanisms that would enable estimates of the benefits from the Somersby trial to be quantified were identified, so the costs of that trial have been regarded as "sunk" in the context of the economic evaluation. The Somersby trial cost approximately $A1 million at the time, which is equivalent to $A1.7 million in 1992 Australian dollars. If this cost was added to the cost of the other trials shown in Table 2, the benefit-cost ratios for the entire program would remain in the range from 3.0 to 4.0 even if no benefits are attributed to the Somersby trial. Clearly, the overall conclusion about the economic viability of the ALF program is robust with respect to the treatment of the costs of the Somersby trial.

Also of interest is the distribution of benefits. Some trials, for example, the Callington trial, have produced significant benefits in a number of states, whereas others, most notably the Prospect trial and to a lesser extent the Benalla trial, have tended to produce the

TABLE 2 Summary of Economic Evaluation Results

	Trial Location and Focus						
	Benalla Heavy Duty Unbound	Beerburrum Cement Treated Base	Prospect Blast Furnace Slag	Callington PMA, OGFC SAMI's	Mulgrave Asphalt & CTCR	Brewarrina Geotextile Reinforced Seal	TOTAL
Cost ($M, $1992)	0.9	2.2	1.8	2.4	1.8	0.7	9.8
Benefits ($M, $1992) given a discount rate of							
4 %	5.4	13.9	2.5	8.3	10.1	8.1	48.3
6 %	4.8	11.4	2.3	6.9	9.3	7.7	42.4
8 %	4.6	9.0	2.1	5.8	8.7	7.3	37.5
Benefit-Cost Ratio given a discount rate of							
4 %	6.0	6.2	1.4	3.5	5.7	11.6	4.9
6 %	5.4	5.1	1.3	2.9	5.2	11.0	4.3
8 %	5.1	4.0	1.2	2.5	4.9	10.4	3.8

Notes: PMA = Polymer Modified Asphalt
OGFC = Open Graded Friction Course
SAMI = Stress-alleviating Membrane Interlayer
CTCR = Cement Treated Crushed Rock

most benefits for the host state. Most benefits have accrued to those states that have hosted ALF trials. Western Australia, Tasmania, and the Northern Territory have derived limited direct benefits from the trials conducted to date.

Broader, Nonquantified Benefits

The past decade has seen an acceleration in the rate of advancement of pavement technology. Pavement design has advanced from crude empirical approaches to a more theoretically rigorous design process. Throughout this period ALF has acted as a focus for pavement research, bringing together researchers and practitioners from ARRB, the SRAs, and industry.

By its nature and scale of operation ALF has generated interest in pavement engineering research, and it has acted as a catalyst for field innovation. Cases were reported relating to the Beerburrum and Brewarrina trials in which regional engineers were motivated by these trials to experiment with cement slurries to bond cement-treated bases or to construct sections of geotextile sealed pavements. ALF's ability to have an impact on road authority practices has been enhanced by conducting the trials in different states. This generates a sense of local ownership, which provides an incentive to implement the results within the host SRA. The greater spirit of cooperation in road pavement research fostered by the ALF program has contributed to an increased willingness on the part of SRA staff to assess interstate innovations and practices on their merits.

ALF's credibility in accelerated pavement testing has established Australia as an international leader in pavement research. In 1987 the U.S. manufacturing rights were purchased by FHWA, and its ALF is currently stationed at the Turner-Fairbanks Research Station, McLean, Virginia. A second ALF has just been manufactured for the Louisiana Highways Department, and testing is expected to commence later this year. Another ALF was built in Australia and transported to the Peoples' Republic of China for use by the Research Institute of Highways. This overseas use of ALF has enhanced Australia's technical reputation. It is impossible to place a dollar benefit on these kudos; however, these export initiatives are clearly consistent with the thrust of the Australian federal government's economic strategy, which aims to increase Australia's role as an exporter of high-value-added items.

The accelerated nature of the testing undertaken with ALF produces data that are not only of higher quality but are also more reliable than could be obtained from other forms of full-scale testing. The only real alternatives to the use of ALF are to rely on overseas results or to conduct field trials. Overseas research programs have objectives and priorities that are unlikely to be consistent with Australian pavement research needs, and differences in climatic conditions, particularly the incidence of frost heave, mean that there are very few overseas countries where research results are directly transferable. Field trials have inherent shortcomings because the time required to obtain results has implications for the quality of data obtained. Over the 10 years or more that a major field trial would be conducted, normal staff turnover and retirements may mean that by the time the trial is completed there is no one about who has a thorough understanding of what was being tested or what was being measured. The field trial approach is also an ineffective testing method in which there are rapid changes in technology, for example, in the area of polymer additives for asphalt. One benefit claimed from ALF's success as an accelerated testing device is that expenditures on less effective field trials have been reduced. In New South Wales it was estimated that expenditures on field trials have been reduced by between $A-200,000 and $A-400,000 per year for this reason.

Another important contribution of ALF relates to the link between results obtained from the accelerated field trials and laboratory tests. Once field performance can be reproduced in a laboratory test this provides a capability to predict the field performance of other material combinations from laboratory tests without the need for further costly field trials.

CONCLUSIONS

This study has developed a framework for quantifying the benefits of ALF trials conducted to date. The framework addresses a number of issues relevant to evaluating research benefits. It is incorrect to simply compare the outcome of an ALF trial with the most expensive alternative outcome that could have eventuated by, for example, comparing the cost of the flexible granular pavement with the rigid pavement in the context of the Benalla trial. The methodology highlights that because the outcomes in the absence of an ALF trial are not known with certainty it is essential that the probability of each alternative outcome be recognized in the analysis. It is also important to consider the characteristics of each trial and assess the likely time period over which benefits can be attributed to that trial. Although not described in this paper, the methodology outlined here provides a sound foundation for a priori evaluation of future ALF trials. The framework for evaluating future ALF trials has been described elsewhere (*4*).

The overall benefit-cost ratio for the ALF program is between 4.0 and 5.0. It is important to note that all the trials were found to have benefit-cost ratios in excess of 1.0. The Prospect trial had the lowest benefit-cost ratio, slightly in excess of 1.0, but this is not surprising given that the benefits are predominantly accrued in only two areas of New South Wales. The other trials had benefit-cost ratios ranging from 3.0 to 6.0, with the exception of Brewarrina, where the value was about 11.0.

The present study has identified and quantified substantial economic benefits that are directly attributable to the ALF program. In addition, a number of significant but unquantifiable benefits were identified, including ALF's role as a catalyst for pavement research and field innovation, improved cooperation between researchers and practitioners active in the pavements area, and enhancement of Australia's technical reputation overseas. The results indicate that a healthy return is being obtained on the investment in this pavement research program.

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