ASSESSMENT OF GAUTRANS HVS PROGRAMME BENEFITS

Pilot Study Report (Draft)

November, 2004

Gauteng Provincial Government
Department of Public Transport, Roads and Works
Directorate: Design
Private Bag X3
Lynn East
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EXECUTIVE SUMMARY

BACKGROUND

The South African developed Heavy Vehicle Simulator, or HVS, is a test unit capable of evaluating the rate and manner in which roads deteriorate within a short period of time. Whilst road deterioration would normally take place over a period of eight to twenty years, HVS testing can evaluate such deterioration within a period of three to six months.

Since 1978, Gautrans has owned a HVS machine, and contributed to the funding of the HVS technology development programme, which is centred around the various Heavy Vehicle Simulators that have been operating since that time. The HVS technology development programme is aimed at developing innovative and cost-effective solutions to identified problem areas related to road design and construction.

In the face of increasing pressure on the roads budget, it has become essential to proactively define and quantify the benefits arising from the Gautrans HVS technology development programme. Gautrans thus identified a need to develop and execute an appropriate methodology for quantifying the benefits of the HVS technology development programme. This report summarizes the findings of a pilot study aimed at developing and testing a framework for the assessment of benefits (economic and other) arising from HVS technology development projects.

GENERAL CONCEPTS

Some of the basic concepts related to assessment of benefits arising from technology development programmes were described, and a general approach to identify and assess benefits arising from the HVS technology development programme was provided. Key elements presented were:

- To ensure a benefit assessment is relevant, the needs and objectives of the funding agency first need to be understood. In the context of the HVS technology development programme, the overarching objectives of Gautrans and of the South African Research and Development strategy (SA R&D strategy) were deemed to be most relevant;

- The overarching objectives of Gautrans and of the South African Research and Development strategy were evaluated. For the purpose of this study, three main benefit streams, resulting from the HVS technology development programme, and relevant to Gautrans and to the SA R&D strategy, were identified. These are:

  1. Contribution to <u>better business performance</u>;
  2. Contribution to <u>technical progress</u>;
  3. Contribution to the development of <u>Science and Engineering Technology (SET) human capital</u>.

- Not all of the benefits arising from technology development work are quantifiable in economic terms. Because of this, quantified estimates of the returns on investment of technology development programmes provide a lower bound estimate of the real long term benefits arising from such programmes. In other words, quantified economic benefits typically underestimate the true long term benefits of technology development work, since such estimates only take into account those benefits that can be isolated and quantified in economic terms.

- There is a need to distinguish between direct (or "delivery") benefits, and indirect (or "process") benefits arising from technology development programmes.

- Direct ("Delivery") benefits are those benefits that rely primarily on the technical outcomes of technology development projects. In the context of road technology development projects, these benefits arise because of improved technology which leads to more effective design and construction processes, which in turn reduces agency and road user costs. These benefits can to some extent be quantified in economic terms by means of indicators such as benefit-cost ratios.

- Indirect ("Process") benefits arise because of the development *process*. These benefits largely concern human resource development and the development of better understanding of the problems facing a particular development area. In a well-managed research and development program, these benefits should arise even when the project deliverables have only been partially achieved. Process benefits are not readily quantified in economic terms, and are best monitored and evaluated through indicators and trend analysis.

GENERAL ASPECTS RELATED TO DIRECT BENEFIT ASSESSMENTS

General aspects relating to the assessment of direct economic benefits arising from technology development work were discussed. Specifically, difficulties associated with the assessment process were highlighted, and a best practice approach for addressing these difficulties was outlined. It was noted that the assessment of direct economic benefits involves, amongst other issues, the following three difficulties:

1. There is a conceptual and time-related separation between project findings and benefit realization. This diffusion of project findings greatly complicates the identification and isolation of the links between project deliverables and the benefits that arise as a result. Considerable experience of the field of application is needed to identify and isolate the links between realized benefits and the technical findings of technology development projects.

2. Benefits often result from several contributing projects and processes. It is thus essential to ensure that contributions that precede technology development projects, as well as contributions required to refine and implement policy changes, are taken into account in the benefit assessment process.

3. In order to arrive at the assumptions needed to complete an economic assessment of benefits, a significant amount of subjective input is needed. The subjective element of the assessment process impacts negatively on the credibility of the assessment.

A survey was conducted of previous investigations that involved assessments of direct economic benefits arising from research and technology development projects. From this survey, and also from evaluations conducted as part of the present study, a best practice approach was constructed to guide the assessment of direct economic benefits resulting from technology development projects. This approach involves the following guidelines:

- Select the best performing projects for benefit quantification;
- Identify impacts and benefits through interviews with technology development workers;
- Collect information on actual benefits and contribution ratios from the users of the system (i.e. client body representatives and practitioners);
- Acknowledge all contributions to the realized impact, and
- Use confidence intervals to assess benefits.

DIRECT ECONOMIC BENEFITS: A GENERAL ASSESSMENT

Examples were presented to illustrate the direct economic benefits that can typically be expected from a technology development project such as the Gautrans HVS programme. It was shown that the benefits that can be derived from technology development projects related to the roads industry generally yield information that fall into the following three impact categories:

1. Optimized materials and pavement design, which lead to reduced construction costs;
2. More reliable design and maintenance practices, which reduces the likelihood of costly early failures, and
3. More cost effective materials and pavement design, which optimizes the time between maintenance interventions, thereby reducing pavement life cycle costs.

An economic evaluation was performed to assess the direct economic benefits that can be derived from each of the above three impacts. This evaluation was performed by means of two approaches. These were:

1. A conventional life cycle cost comparison approach in which a benchmark case - without the benefit of technology development findings - was compared to an improved alternative which incorporated the impacts of a technology development project.
2. An approach which incorporated Bayesian statistics and is aimed at evaluating the value of information that can assist in making decisions which have economic impacts.

Conclusions: Life Cycle Cost Comparison Approach

Generalized examples of each impact type were presented and discussed. In all cases, the economic benefit of the impact was calculated over a period of 10 years. This benefit was then compared to the cost of a typical HVS technology development project lasting two years, and with a total cost of R8 million. For each example, an outline of the example situation was provided, and key assumptions were listed. The example calculations were then shown and discussed. It was noted that certain subjective assumptions had a significant impact on the calculated economic benefits. However, since all calculations were shown explicitly, the interested reader could easily re-construct the calculations using a spreadsheet, and then re-evaluate the benefits using different assumptions. The examples evaluated for each of the three impacts showed similar results. For all three examples, the findings were as follows:

- For the stated assumptions, any network on which more than 150 km of road is rehabilitated per year will have a benefit cost ratio in excess of 1.0.

- For a network such as that operated by Gautrans, the calculations suggest that, *for each of the three impacts*, Gautrans will realize a benefit-cost ratio of 1.6 or more, with a total discounted saving over a 10 year period of between R12 million and R16 million per impact (in terms of 2004 Rand), depending on the discount rate.

- All three examples show that*, if the impacts are considered in isolation*, then a benefit-cost ratio of 2.0 or more will be realized for any road network that requires roughly 320 km of rehabilitation work per year. For larger networks that require in excess of 500 km of rehabilitation per year, the expected return on the technology investment will be roughly between R25 million and R33 million per impact (in terms of 2004 Rand), which - for the assumed development costs - equates to a return of more than three Rand for every one Rand invested in technology development.

In the examples, the benefits of each impact were evaluated in isolation. If two or more impacts are combined (i.e. if two impacts arise from the same technology development project), there is a significant increase in the savings and benefit-cost ratios.

For the examples considered, and for a network such as that operated by Gautrans, a combination of impacts for a single project could lead to combined savings of between R24 million and R36 million (in terms of 2004 Rand), depending on the discount rate assumed. For a technology development project with a cost of R8 million, these savings would result in a benefit-cost ratio of between 3.0 and 4.5. For a larger network that rehabilitates roughly 500 km of roads per year, the savings and benefit-cost ratios would be doubled (i.e. benefit cost ratios of 6.0 to 9.0 would apply).

Conclusions: Value of Information Approach

The concept of the Expected Value of Perfect Information (EVPI) stems from Bayesian statistics and can be used to assess the relative value of information that is used to drive decisions that will have an economic impact. An example was used to illustrate the expected value information that could assist a roads agency in the decision to either implement or disregard a network wide implementation of a new pavement technology.

The EVPI example used inputs and assumptions that are based on actual costs, and assumes that information – relevant and significant to the decision making process – would be provided by a one-year HVS technology development project. The example clearly showed that, for the assumed decision making scenario, the EVPI was in excess of R25 million. When this relatively high EVPI is compared to the cost of gathering the information (estimated at roughly R4 million), it is clear that a substantial economic benefit could be derived from the information that would be provided by the technology development project.

The concept of EVPI provides a rational way of evaluating the value of information that would typically stem from the Gautrans HVS programme. For the example considered, the EVPI indicates that significant economic benefit could be derived from technology development projects such as the Gautrans HVS programme. This benefit arises mainly from the relatively large scale on which benefits can be realized for a typical road network.

DIRECT ECONOMIC BENEFITS: SPECIFIC PROJECTS

Benefits arising from HVS technology development projects were evaluated for two specific projects. These were: (a) development of the high quality Crushed Stone called G1; and (b) development of Foamed Bitumen materials technology. In the case of the G1 development project, a full assessment of technical impacts and direct economic benefits was made. In the case of the Foamed Bitumen project, only the major findings and technical impacts were evaluated.

G1 TECHNOLOGY DEVELOPMENT BENEFITS

The key impacts of HVS investigations on G1 base pavements were identified as:

- The suitability for G1 base pavements for the 12 to 50 MESA design class was clearly proven;
- The feasibility of G1 base pavements in wet regions was proven (provided an impervious surfacing could be maintained);
- It was found that the damage exponent (or n-value) of pavements with a G1 base over a thick cemented subbase was close to 3, and not 4.2, as was commonly assumed;
- It was proven that a 150 mm thick G1 layer is optimal for G1 base layers;
- The difference between the high quality G1a, and lower quality G1b or G2 material was clearly shown;

After consideration of the identified impacts (and specifically of the data and assumptions needed to convert the impacts to economic benefits) it was decided to combine the identified impacts into the following three main benefits:

<u>Benefit 1:</u> Increased use of G1 Base Pavements for higher design classes and wet regions;

<u>Benefit 2:</u> Use of 150 mm thickness for G1 base layers, and

<u>Benefit 3:</u> Improved maintenance and construction practices.

The savings derived from these three benefits were evaluated using a probabilistic approach to aggregate the likely unit savings that typically resulted from the above three benefits. The overall savings were calculated for the Gautrans and SANRAL networks, by using the unit cost savings which were scaled to an absolute savings value. This scaling of benefits used the total lane-km of G1 base pavements constructed by Gautrans and SANRAL in the period between 1980 and 1990. The assessment of economic benefits showed the following:

- The overall benefit cost ratio (i.e. for Gautrans and SANRAL) varies from 2.4 to 6.1, depending on the contribution ratio and discount rate selected. For a nominal discount rate of 8 per cent, the overall benefit cost ratio varies between 2.9 and 5.1, depending on the contribution ratio selected. This range of estimated benefit cost ratios is similar to the range of 3.8 to 4.9 reported for accelerated pavement testing performed in Australia (ARRB, 1992).

- For Gautrans, the estimated direct benefit derived between 1980 and 1990 from the HVS investigations on G1 base pavements is roughly between R2.2 and R14.8 million (in 2004 Rand terms). Taking into account the contribution made by Gautrans to the funding of HVS investigations on G1 pavements, this results in a benefit cost ratio of between 1.4 and 3.6, depending on the discount rate and contribution ratio selected.

- For SANRAL, the estimated direct benefit is roughly between R3.4 and R25.2 million (in 2004 Rand terms). This results in a benefit cost ratio of between 4.2 and 10.2. This benefit cost ratio is higher than that realized by Gautrans, mainly because of the greater scaling of benefits provided by the larger SANRAL pavement network.

It is important to note that these economic benefits include only those aspects which can be converted to economic savings with reasonable confidence and assumptions. There are several other benefits resulting from the HVS investigations on G1 base pavements, which cannot easily be converted to economic savings, yet are sure to impact positively on the Gautrans and SANRAL budgets and networks over the long term. Because of this, the above noted benefit-cost ratios represent a lower bound estimate of the benefits of HVS investigations on G1 base pavements.

FOAMED BITUMEN TECHNOLOGY DEVELOPMENT BENEFITS

To date, the key findings and deliverables that emerged from the test programme on foamed bitumen treated materials were:

- It was confirmed that recycling with foamed bitumen treatment reduces the sensitivity of the material to moisture and density;

- Permanent deformation accumulated at a low rate on well-designed foamed bitumen treated materials - especially when in a dry state.

- Despite the decreased sensitivity to moisture and density of foamed bitumen treated materials, the test programme showed that the material can fail prematurely at low density and high moisture saturation levels.

- It was found that traditional material strength indicators such as Unconfined Compressive Strength (UCS) and Indirect Tensile Strength (ITS) were not always appropriate to evaluate the benefits of foamed bitumen treatment. The real benefit of foamed bitumen treatment seems to lie in the increase in long term durability which is not always properly evaluated with conventional strength indicators;

- A balance between the bitumen and cement content is essential to ensure both flexibility and resistance to permanent deformation. Too much bitumen or cement effectively nullifies the benefit of the other, leading to wasted costs. It was specifically found that too much cement renders the bitumen ineffective.

- It was found - owing to the short time available before the foamed bitumen collapses to a normal bitumen state - that traditional laboratory mixers are too slow to effectively simulate the field mixing process. Because of this finding, a high speed laboratory mixer was specifically developed for the laboratory design of foamed bitumen treated materials;

- The HVS and laboratory tests yielded typical material stiffness and strength parameters that can be used as inputs for the mechanistic-empirical design method;

- Structural capacity evaluation models (i.e. Transfer Functions) were developed to evaluate the structural capacity of pavement layers treated with foamed bitumen;

- Classes of foamed bitumen treated material were identified and defined. These classes provide practitioners with an easy way to group foamed bitumen treated materials into classes from which similar behaviour and performance can be expected;

- A design catalogue and design approach was developed for pavements that incorporate foamed bitumen treated materials. This catalogue and methodology has since been published in the TG2 guidelines (Asphalt Academy, 2002).

Based on interviews with the principal investigators on the foamed bitumen test programme, it was established that the findings of the programme and the information dissemination process had the following impacts on the southern African road building industry:

- Better understanding of the relative contributions or roles of bitumen and cement. In particular, the development work showed that too much cement nullifies the effect of bitumen. This has lead to improved project specifications. The emphasis on obtaining a balance between the cement and binder contents prevents materials wastage.

- The development of a materials classification approach, together with the understanding of differences in behaviour and performance of different materials classes, ensure that materials are appropriately designed for specific situations. This leads to more cost effective and reliable designs;

- An improved laboratory mix design procedures (including the development of a new high speed mixer) which ensures a better agreement between materials prepared in the laboratory and the field. This leads to optimized mixes and minimizes the risk of premature failure owing to inappropriate materials design;

- The development of structural design models for use in the mechanistic-empirical design method, combined with a design catalogue (as part of the TG2 Guidelines), ensure optimized and reliable designs using Foamed Bitumen materials.

The HVS programme and associated laboratory tests have significantly accelerated understanding of the behaviour and performance of foamed bitumen treated materials. This factor, together with the technical impacts noted above, translates to the following three benefits:

Benefit 1: More cost-effective design of foamed bitumen treated *materials*;

Benefit 2: More cost-effective design of *pavements* incorporating foamed bitumen treated materials;

Benefit 3: More *reliable* design of pavements incorporating foamed bitumen treated materials;

Conceptual frameworks for evaluating economic returns from these benefits were defined and presented. Because of the emerging nature of the technology associated with foamed bitumen treatment (and in fact with deep in-situ recycling technology in general), and specifically since the results of the tests on foamed bitumen treated materials have not been finalized, it was felt that an evaluation of the economic benefits arising from the test programme on foamed bitumen treated materials would be premature. It was therefore decided to postpone the benefit calculation until such time that the scaling of the benefits can be approached with more clarity and confidence.

INDIRECT BENEFITS

The indirect benefits associated with the HVS technology development programme were outlined and discussed. It was shown that these benefits contribute to (a) Technical Progress; and (b) development of a critical mass of Science and Engineering Technology (SET) human capital. These elements form two of the three key processes that serve the South African Research and Development (R&D) strategy goals (RSA, 2000).

The contribution of the HVS technology development programme to Technical Progress was discussed. It was shown how the HVS programme contributed through the following aspects:

- Technical publications (local and international);
- International alliances formed and international interest attracted, and
- High-Tech developments and imports;

The contribution of the HVS technology development programme to SET human capital was discussed. It was shown how the HVS programme contributed to the development of South Africa's SET human capital through the following aspects:

- Educational opportunities created;
- Improvement in Science and Technology Excellence by advancing critical technical aspects of South African pavement technology;
- Creation of employment and career growth opportunities;

FRAMEWORK FOR BENEFIT ASSESSMENT

A framework for evaluating the benefits arising from technology development projects was presented, with specific emphasis on HVS centred projects. The framework was developed on the basis of the best practice elements outlined in earlier sections as well as the experience gained during the execution of this benefit assessment pilot study. It was shown that the benefit assessment framework consists of the following four steps:

1. Summarize the key technical findings and impacts
2. Identify main impacts and develop a benefit assessment strategy
3. Refine assumptions and calculate benefits
4. Validate impacts and assumptions through interviews

Guidelines were provided for the identification and design of benefit-centred technology development process. Key elements highlighted in these guidelines are:

- An overarching, policy-oriented strategic plan is needed to guide the selection and design of candidate projects. The strategic plan should be aligned to the needs of the funding agency.
- The objectives of candidate projects should be evaluated against those of the strategic plan. Proposals or execution plans for candidate projects should show - in a specific manner - how the project findings will impact on and contribute towards the objectives of the strategic plan.
- Potential benefits that are expected to be derived from a candidate project should be clarified at the project design stage. A counter-factual or alternative situation that will develop without the benefit of the project findings should be stated.
- A plan to facilitate technology transfer should form part of the project execution plan. A technology development project which does not contribute to the implementation of findings cannot reasonably claim a high contribution of the realized benefits. Thus, a technology development project should incorporate plans for the transfer of findings to practice. This will ensure a larger contribution ratio and will also greatly speed up the realization of benefits.

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1 INTRODUCTION

1.1 BACKGROUND

The South African developed Heavy Vehicle Simulator (HVS) is a test unit capable of evaluating the rate and manner in which roads deteriorate within a short period of time. Whilst road deterioration would normally take place over a period of eight to twenty years, HVS testing can evaluate such deterioration within a period of three to six months.

Since 1978, Gautrans has owned an HVS machine, and contributed to the funding of the HVS Technology Development Programme, which is centred on the various Heavy Vehicle Simulators that have been operating from that time. From the early 1990's, the Gautrans HVS has been the only operational HVS in South Africa.

The HVS technology development programme is aimed at developing innovative and cost-effective solutions to identified problem areas related to road design and construction. Although the HVS technology development programme (hereafter also referred to as the *HVS programme*) is to a large extent focussed around the HVS machine, a significant portion of the work is focussed on data analysis and transmission of findings to the industry. The transmission of findings is typically effected through conference papers, presentations, seminars and workshops as well as through manuals and guidelines to aid designers in the implementation of technologies that were tested and improved through HVS projects.

The combined efforts and results of: (i) data gathering through HVS testing, (ii) analysis and interpretation of data, and (iii) transmission of findings, has played a pivotal role in furthering road design and construction technology for Gautrans and South Africa in general. There can be no doubt that every road design undertaken in South Africa, at present and in future, will be influenced by results that were generated by the HVS programme over the past two decades.

By contributing to the establishment of a cost effective road infrastructure, the implementation of HVS test related findings and products undoubtedly has a positive, if sometimes indirect, impact on the people of South Africa. Furthermore, HVS technology exported overseas has led to international recognition of the excellence of South African road design and construction technology.

1.2 THE NEED FOR QUANTIFYING BENEFITS

As can be expected, the cost of owning and operating the HVS machine and sustaining the analysis and transmission of findings is not insignificant. In the face of increased pressure on the roads budget, it has become essential to proactively define and quantify the benefits of the Gautrans HVS programme. Such a quantification of benefits serves two purposes:

- It will ensure that a rational and defendable justification for HVS related funding is in place;
- It will facilitate a quantification of the effectiveness of the HVS test programme, as measured against overarching Gautrans policy objectives.

Gautrans thus identified a need to develop and execute an appropriate methodology for quantifying the benefits of the HVS programme. *To this end, Gautrans, in October 2003, initiated an independent investigation into the benefits (economic and other) arising from the HVS technology development work.* Apart from the identification of benefits, the study objective was also to prepare a framework against which the benefits and economic performance of future HVS projects could be evaluated.

1.3 FRAMEWORK FOR QUANTIFYING BENEFITS

As part of the study to evaluate benefits arising from HVS development work, an inception report was completed in January, 2004 (Jooste et al., 2004). In this report, a framework was presented for evaluating the benefits from HVS technology development projects. The framework recommended that the evaluation should be performed in two stages, as shown in Figure 1.

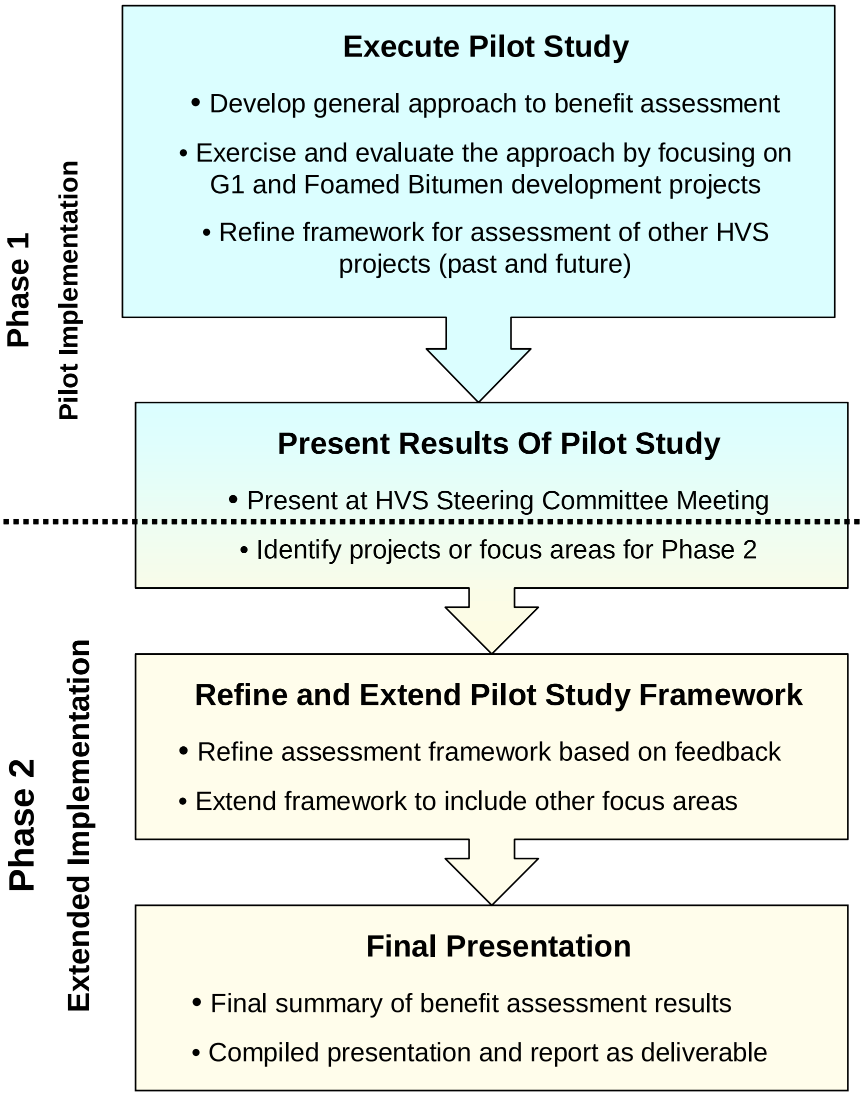


Figure 1: Proposed framework for evaluating the benefits arising from HVS Technology Development

The aim of the pilot study is to clarify, exercise and refine the benefit assessment method. The second phase will then refine and extend the methodology to other development focus areas. This report then documents the findings of Phase 1 of the implementation framework shown in Figure 1.

1.4 OBJECTIVES AND SCOPE

The key objective of the framework for the assessment of benefits arising from the Gautrans HVS technology development programme is as follows:

> *To identify and, where appropriate, quantify, all benefits stemming from the Gautrans HVS technology development programme that are relevant to the Gautrans mission and that are congruent with the South African National Research and Development (R&D) Strategy. Also, to formulate all identified benefits in a presentation format that is suitable for both political and strategic decision makers.*

For this study, which comprises the first phase of the longer term benefit assessment study, the following specific objectives apply:

The first stage, of which this report forms part, comprises a pilot study with the following objectives:

- To clarify the elements associated with the determination of benefits arising from technology development work;
- To develop a general approach for benefit assessment;
- To implement and evaluate the approach by focussing on two technology development programmes (G1 and Foamed Bitumen development projects were selected for evaluation);
- To refine and document a framework for the assessment of other (past or future) HVS technology development projects.

As determined in the inception study (Jooste et al., 2004), the scope of the investigations will not be limited to Gautrans alone, but will include those benefits that impacted on roads agencies and the broader population across South Africa. The study will not, however, consider impacts outside South Africa.

1.5 STRUCTURE OF THE REPORT

The structure of the report is summarized in Figure 2. Section 1 of the report is this introduction which also outlines the background and project objectives. Sections 2 to 7 deal specifically with the process of evaluating benefits stemming from technology development work. Section 2 outlines the general concepts associated with benefit assessment, and highlights the need to differentiate between direct and indirect economic benefits (these benefit types are defined in Section 2).

1. Introduction
2. Benefit Assessment: Concepts and Approach
3. General Aspects Related To **Direct Benefit** Assessment
4. **Direct Economic Benefits**: A General Assessment
5. **Direct Economic Benefits**: Specific Projects
6. **Indirect Benefits**
7. Framework for Benefit Assessment
8. Summary and Conclusions
9. References

Figure 2: Structure of the Report

Sections 3 to 5 then deal with the evaluation of *direct economic benefits*. Section 3 illustrates the typical benefits that can be derived from technology development projects in the road sector. Section 4 applies some of the approaches that are illustrated in Section 3 to specific HVS projects.

Section 6 deals with the *Indirect Benefits* stemming from HVS technology development projects. Section 7 contains a framework or methodology for the assessment of benefits arising from HVS technology development projects. This section also provides some recommendations for the selection and design of benefit-oriented projects.

Section 8 summarizes the project elements and key observations and conclusions. Section 9 contains the references while supporting information is provided in the Appendices.

2 BENEFIT ASSESMENT: CONCEPTS AND APPROACH

2.1 IDENTIFYING RELEVANT BENEFITS

The first step in the assessment of benefits derived from publicly funded research and development work is the understanding and definition of the overarching objectives of the funding agency. Given the nature and impact of the Gautrans HVS technology development work, the missions and objectives of Gautrans Department of Public Transport, Roads and Works, as well as the South African National Research and Development Strategy are deemed most relevant and important in the present context.

It is recognized at the outset that these objectives are defined to address a broad range of social and economic issues. Undoubtedly, any well-managed technology development programme will to some extent address policy centred objectives within a system that recognizes the need for research and innovation. However, the benefits that arise from such work are often realized so far downstream from the actual work, that they cannot realistically be quantified *at the political level*.

This effect is illustrated schematically in Figure 3, which shows how the HVS technology development programme contributes to the two high level goals of the National Research and Development (R&D) Strategy (RSA, 2002):, namely:

- Quality of Life, and
- Growth and Wealth Creation.

Through its contribution to safe, affordable road transport, which in turn leads to better infrastructure and economic growth, the HVS programme contributes to the R&D objectives by furthering the key processes that serve the R&D strategy goals (RSA, 2002).

Gautrans Policy Objectives (Gautrans, 2001)

Mission:

To promote accessibility and the safe, affordable movement of people, goods and services and to render client-centred and developmental public works service in Gauteng.

Some Focus Areas:

- Accelerated infrastructure development, with an emphasis on job creation;
- Quality social service delivery

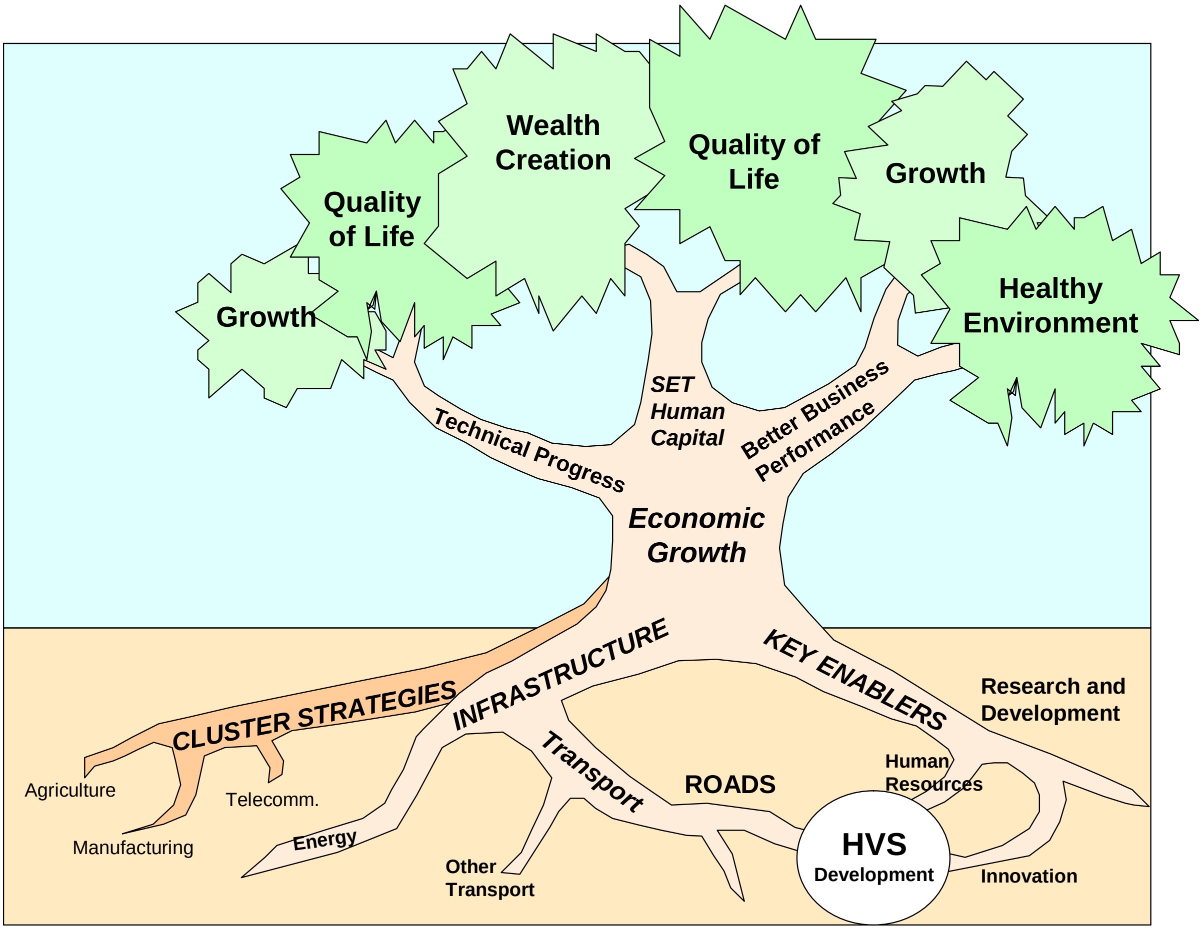


Figure 3: Relevance of the HVS Development Programme with respect to national research and development objectives

Within the context of the South African national R&D strategy objectives and the Gautrans mission to deliver safe, affordable movement of goods and people, and recognizing the limitations of what can be quantified in terms of these objectives, three main benefit streams were identified. These are:

- Contribution to better business performance (including performance of public service departments such as Gautrans);
- Contribution to technical progress;
- Contribution to the development of SET human capital.

Figure 4 shows these three benefit streams in context, and also shows suggested measures for assessing benefits in these streams. It should be noted that the benefits arising from better business performance are generally those that are directly quantifiable in economic terms, while the other two main benefit streams result in benefits that are more intangible and indirect in nature. The concept of direct and indirect benefits is discussed in more detail in the following section.

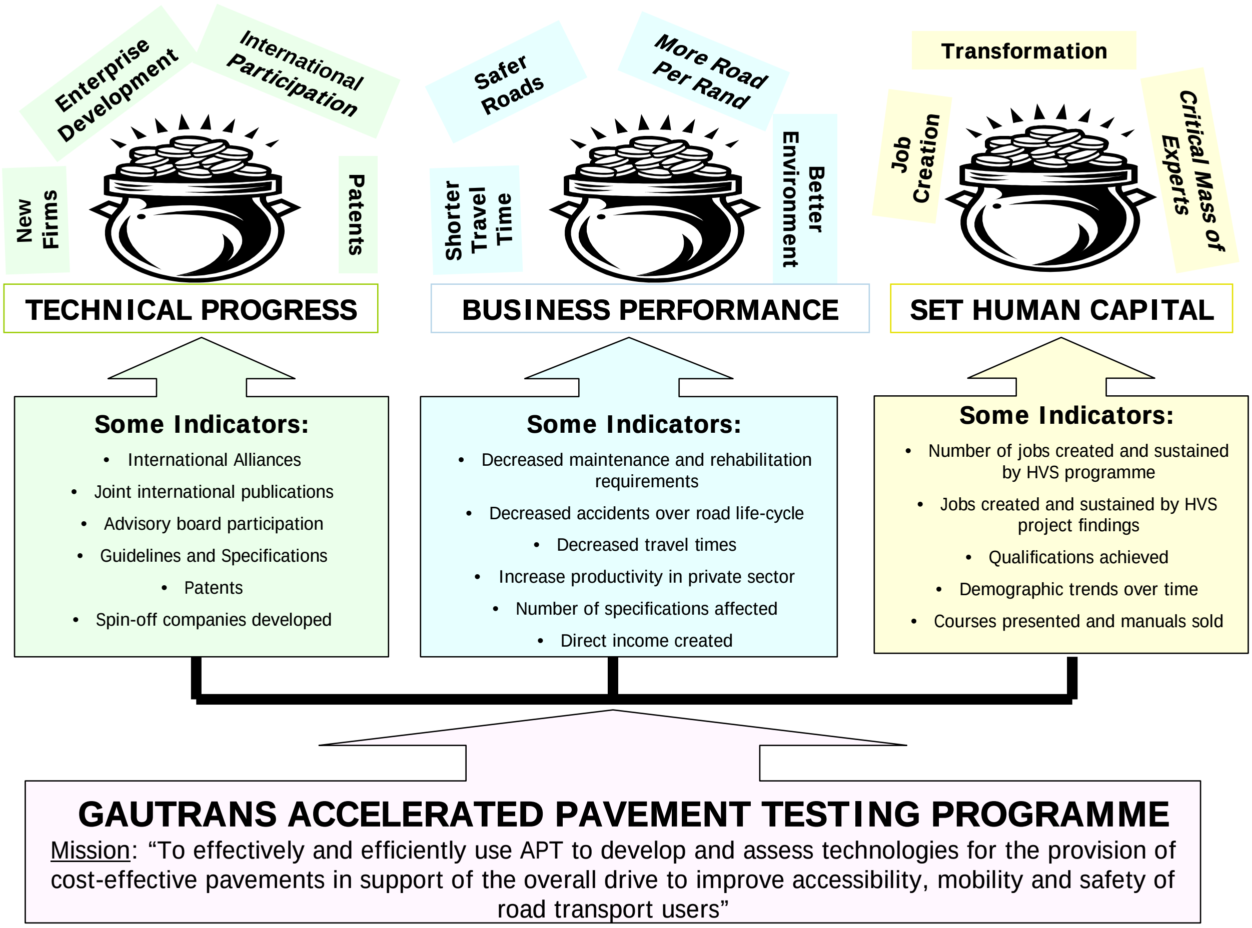


Figure 4: Contribution of the HVS technology development programme to three policy-centred benefits

2.2 DIRECT AND INDIRECT BENEFITS

An evaluation of approaches to the quantification of benefits stemming from research and technology development work was performed as part of earlier work of the study (Jooste et al, 2004). This evaluation recommended that the assessment of benefits stemming from the Gautrans HVS Technology Development programme should take cognisance of the following aspects (summarized conceptually in Figure 5):

- Benefits stemming from technology development efforts should be relevant to the basic mission and objectives of the agency (i.e. Gautrans). This means that the mission and objectives of the funding agency should first of all be understood and summarized (this was done in Section 2.1).
- The benefit assessment should be formulated for presentation at different levels, so that benefits can be communicated effectively at a technical as well as a political level.
- Benefit assessment should take cognisance of the intangible nature of many technology development benefits, and should not only focus on technical benefits.

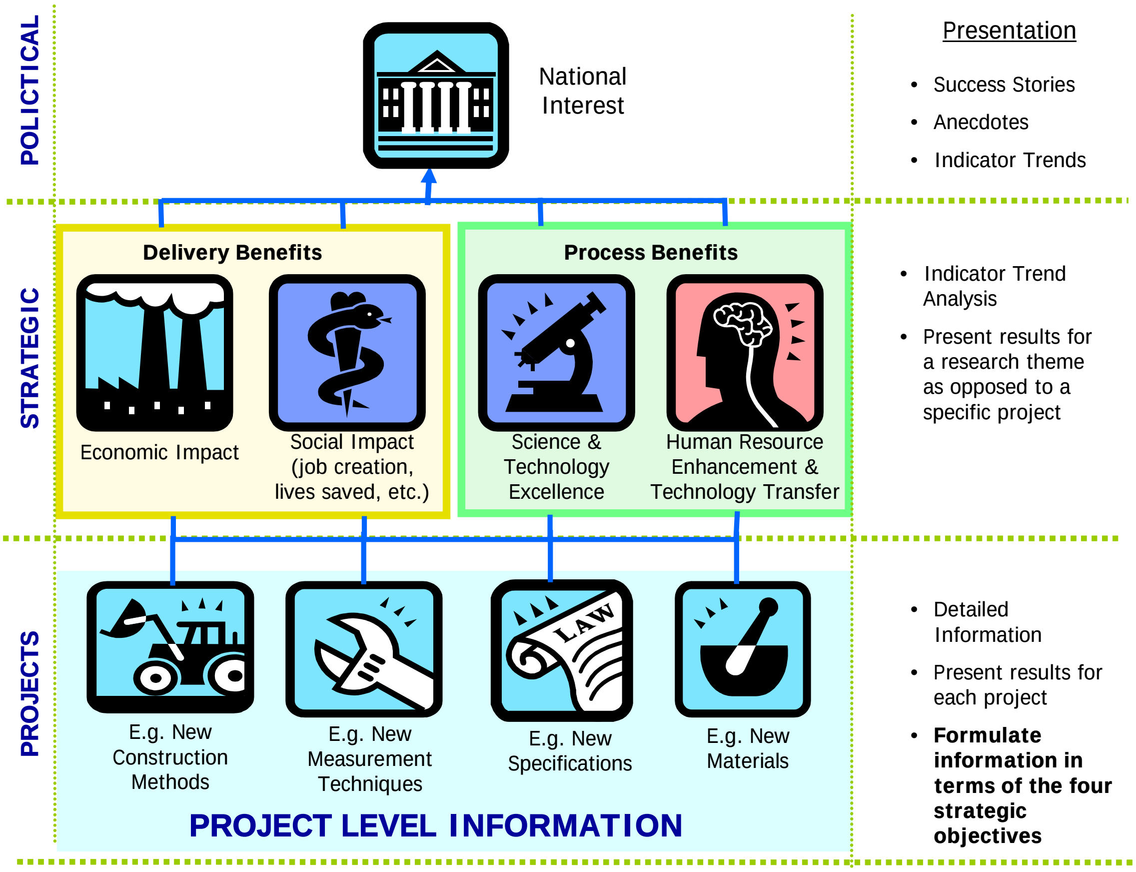


Figure 5: Key elements of Assessment and Presentation of Technology Development Benefits

Owing to the intangible nature of many technology development benefits, the quantification of benefits arising from publicly funded work such as the Gautrans HVS technology development programme is not a simple analytical exercise. Indeed, there seems to be some acceptance that there are limits to the quantification of technology development benefits. In general, such benefit quantification centres around the assumption of new and freely available information. This information is assumed to impact positively on policies which in turn lead to measurable economic benefits.

Approaches centred on the assumption of new and freely available information have been implemented with success in the field of Accelerated Pavement Testing (APT) (ARRB, 1992). However, this “simple linear model” as it is called by Scott et al. (2002), fails to adequately take into account the complex relationships between development, innovation and government policy objectives. The failure of a simple benefit quantification to take into account further downstream benefits and the impact of these on quality of life of the population at large means that the benefits of publicly funded technology development are probably greatly underestimated. One way in which the more diffuse benefits of technology development work can be incorporated into a benefit assessment is by identifying and grouping benefits into two main categories, which can be termed direct (or “delivery”) benefits, and indirect (or “process”) benefits. These two benefit categories can be defined as follows:

- Delivery benefits are those benefits that rely primarily on the project outcomes. In the context of road technology development projects, these benefits arise because of improved technology which leads to more effective design and construction processes, which in turn reduces agency and road user costs. These benefits can to some extent be quantified in economic terms by means of indicators such as benefit-cost ratios.

- Process benefits arise because of the development *process*. These benefits largely concern human resource development and the development of better understanding of the problems facing a particular development area. In a well-managed research and development program, these benefits should arise even when the project deliverables have only been partially achieved. Process benefits are not readily quantified into economic terms, and are best monitored and evaluated through indicators and trend analysis.

In the context of the three main benefit streams that were identified in the previous section (see Figure 4), direct benefits are mostly (but not exclusively) associated with Better Business Performance. Indirect benefits, on the other hand, contribute largely toward technical progress and growth of South Africa's Science and Engineering Technology (SET) human capital.

Since direct or delivery benefits can to some extent be quantified in economic terms, it is understandable that this benefit category is of immediate importance to an agency such as Gautrans. However, it is critical to understand that indirect (or process) benefits that contribute to SET Human Capital and Technical Progress are as valuable as the more direct benefits, for these reasons: (a) the indirect benefits are directly aligned with the objectives of Gautrans and of the National R&D Strategy; (b) indirect benefits undoubtedly lead to significant economic returns. These returns, however, are not readily quantified owing to the diffuse nature of the impacts.

Owing to the large scale of most roads infrastructures, the economic benefits of well executed technology development programmes focussed on pavement technology development are easy to determine beyond reasonable doubt. Sections 3 to 5 document such assessments in both a general and specific manner. Section 6 then focuses on indirect benefits, and as such summarizes indicators of contribution towards Technical Progress and SET human capital.

2.3 SUMMARY

In this section, some of the basic concepts related to assessment of benefits arising technology development were described. The general approach to identify and assess benefits arising from the HVS technology development programme was also provided. Key elements presented in this section are:

- To ensure a benefit assessment is relevant, the needs and objectives of the funding agency first need to be understood. In the context of the HVS technology development programme, the overarching objectives of Gautrans and of the South African Research and Development strategy (SA R&D strategy) were deemed to be most relevant;

- The overarching objectives of Gautrans and of the SA R&D strategy were evaluated. For the purpose of this study, three main benefit streams, resulting from the HVS technology development programme, and relevant to Gautrans and to the SA R&D strategy, were identified. These are:

A. Contribution to better business performance;

B. Contribution to technical progress;

C. Contribution to the development of SET human capital.

The manner in which the HVS technology development programme contributes towards these benefit streams is summarized schematically in Figure 3 and Figure 4.

- Not all of the benefits arising from technology development work are quantifiable in economic terms. Because of this, quantified estimates of the returns on investment of technology development programmes provide a lower bound estimate of the real long term benefits arising from such programmes. In other words, quantified economic benefits typically underestimate the true long term benefits of technology development work, since such estimates only take into account those benefits that can be isolated and quantified in economic terms.

- There is a need to distinguish between direct (or “delivery”) benefits, and indirect (or “process”) benefits arising from technology development programmes.

- Delivery benefits are those benefits that rely primarily on the technical outcome(s) of technology development projects. In the context of road technology development projects, these benefits arise because of improved technology which leads to more effective design and construction processes, which in turn reduces agency and road user costs. These benefits can to some extent be quantified in economic terms by means of indicators such as benefit-cost ratios.

- Process benefits arise because of the development *process*. These benefits largely concern human resource development and the development of better understanding of the problems facing a particular development area. In a well-managed research and development program, these benefits should arise even when the project deliverables have only been partially achieved. Process benefits are not readily quantified into economic terms, and are best monitored and evaluated through indicators and trend analysis.

3 GENERAL ASPECTS RELATED TO DIRECT BENEFIT ASSESSMENTS

3.1 INTRODUCTION

In Section 2.2, the two main categories of benefits (i.e. direct and indirect benefits) that derive from technology development programmes were identified and defined. Direct benefits (also called *delivery* benefits) were defined as those benefits that are a result of technical project deliverables. These benefits are more readily assessed in economic terms than the indirect benefits (i.e. those that are mainly a result of the development *process*) which – although they have definite economic benefits – are more difficult to assess by means of conventional indicators such as cost-benefit ratios.

In this section, the focus is on the evaluation of *direct benefits*. Best practice elements of economic benefit assessment are outlined, where after a general approach to the assessment of economic benefits that result from technology development projects is described. Examples are provided to illustrate the typical benefits that can be derived for road networks of various sizes.

3.2 DIFFICULTIES ASSOCIATED WITH BENEFIT ASSESSMENT

Although indirect benefits such as employment opportunities created, technical progress etc. are important, it can be argued that, at the strategic level (as opposed to a political level), a favourable economic benefit quantifier such as a benefit-cost ratio is the most powerful motivation for continued technology development funding. Because of this, a significant part of this study was focussed on the evaluation of direct economic benefits arising from the HVS technology development programme. However, quantified estimates of the direct economic benefits arising from technology development work are very difficult to obtain. This is not because of the complexity of the calculations involved, but rather because of the vague and subjective nature of the task.

Amongst the many difficulties associated with such a benefit assessment are the following three aspects:

1. <u>Conceptual and time-related separation between project findings and benefit realization</u>

   Whilst the findings of technology development projects may be quite specific, the manner in which those findings are implemented in practice are often more diffuse and general. This effect is illustrated in Figure 6 , which shows that several stages of information transfer as well as a period of implementation are required before benefits are actualized. This process diffuses and obscures the link between the technology development project and the benefits thereof. Considerable experience of the field of application is needed to identify and isolate the links between realized benefits and the technical findings of technology development projects.

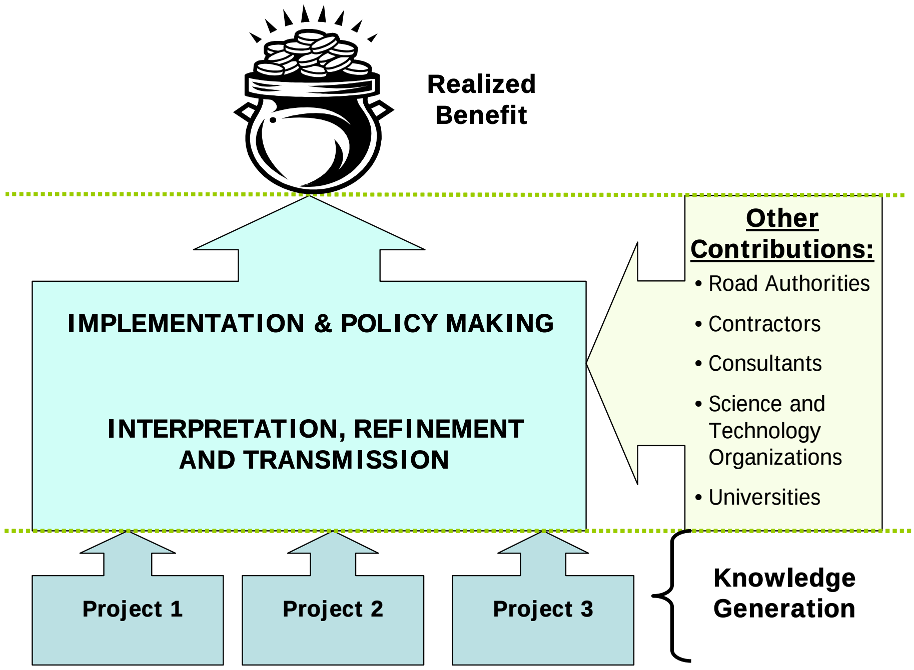


Figure 6: Pattern of Benefit Evolution from Knowledge Created by Technology Development Projects

2. Benefits often result from several contributing projects and processes

It is seldom that a single technology development project is solely responsible for a realized benefit. As shown in Figure 6, most often several other role players and processes are needed to transform technical findings into policy changes that will result in economic benefits. Furthermore, technology development projects – and specifically projects that involve accelerated pavement testing – are seldom solely responsible for the technical findings. Rather, technology development projects are often identified based on results of earlier work. As such, technology development projects often refine and complete a technology that was “ripened” by earlier (often informal or anecdotal) evidence, as shown in Figure 7. It is thus essential to ensure that contributions that precede technology development projects, as well as contributions required to refine and implement policy changes, are taken into account in the benefit assessment process.

3. Benefit assessment involves a significant subjective component

Because of the difficulties noted in the preceding two paragraphs, a purely objective assessment of economic benefits derived from technology development projects is almost impossible to obtain. In order to arrive at the assumptions needed to complete an economic assessment of benefits, a significant amount of subjective input is needed. This is further complicated by the fact that these subjective inputs are sometimes provided by the technology workers who are involved in the technology development project itself. This situation creates a conflict of interest which can impact negatively on the credibility of the assessment. The approach proposed by Zilberman and Heimer (1999), and also implemented in ARRB (1992) partly overcomes this challenge by collecting evidence and estimates from the users of the system (e.g. client bodies and practitioners), and not from the technology development workers themselves.

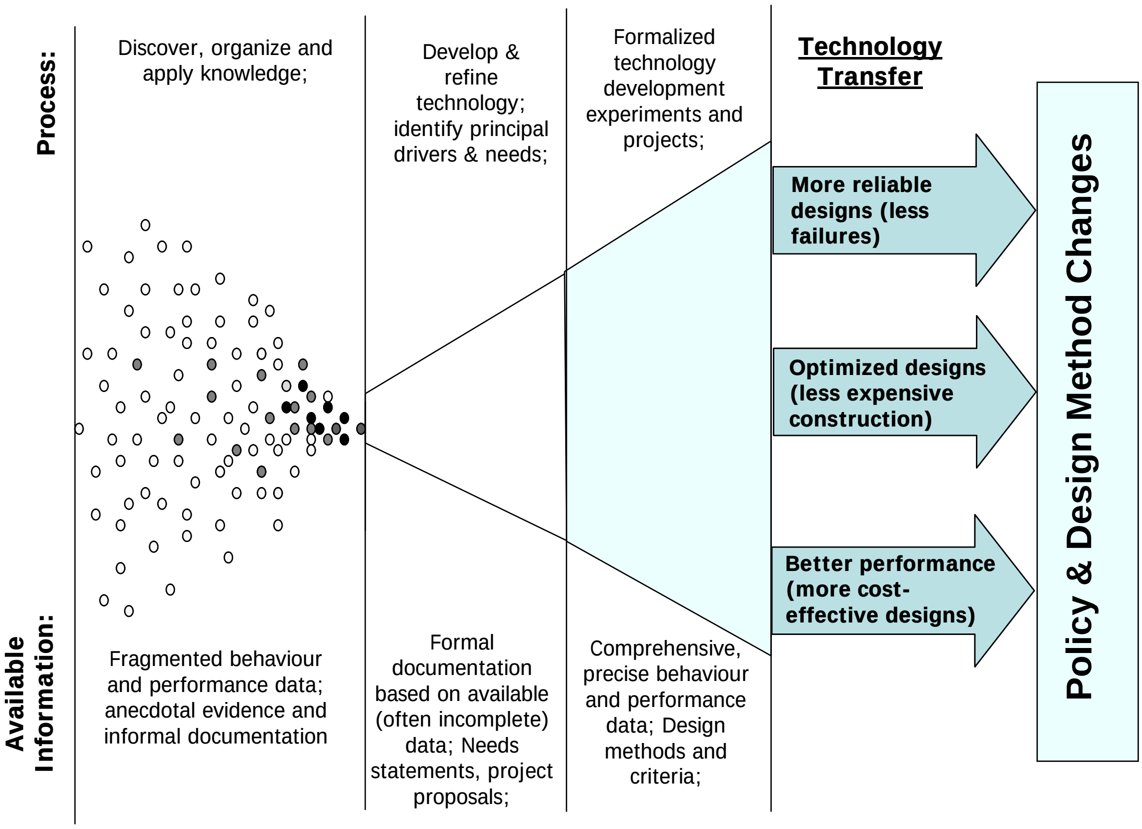


Figure 7: Technology Development to Policy Change (concept after Ounjian and Carne, 1987; and Horak et al., 1992)

3.3 A BEST PRACTICE APPROACH

To address the difficulties that were raised in the preceding section as effectively as possible, a survey was performed of other studies that involved benefit assessment from research and development projects. From this survey, several best practice elements for economic benefit assessment were identified and adhered to during this study. These best practice elements are defined below, and are principally based on the work of Zilberman and Heimer (1999), ARRB (1992), and Jooste et al. (2004):

- **Select the Best Performing Projects for Benefit Quantification**

  According to Zilberman and Heiman (1999), the distribution of benefits from research programs comprising several separate projects, is skewed. This means that a small number of projects may account for most of the benefits of a research program. For example, Parker, Zilberman and Castillo (1998) found that out of several hundred royalty-generating research projects at the University of California, the top two generated 70 percent of the technology transferred in 1994 (study quoted in Zilberman and Heiman [1999]). This effect suggests that it may be more effective to identify and then focus on the best performing projects within a research program, as opposed to trying to evaluate the entire research programme over a long term.

- **Identify Impacts and Benefits Through Interviews with Technology Development Workers**

  The selection of best performing projects can be based on assessments provided by the project workers. *Researchers or primary investigators are asked to provide basic assessments of the impacts resulting from the research. These should be as specific as possible, and should include a list of policies, guidelines or specifications affected. Where possible, examples of implementation should be provided and the extent of possible implementation should be quantified*. Selection of the best performing projects within a programme can then be made based on these technical assessments.

- **Collect Evidence From The Users Of The System**

  It is important to note that the benefit assessments made by project leaders and researchers are used only for initial screening to determine best performing projects and to identify associations between technical project outcomes and realized benefits (arising from policy changes etc.). *Estimates of the actual realised benefits should come from the users of the system and not from the researchers.* Although this presents an “empirical challenge”, it ensures transparency and credibility. While the initial assessment of benefits made by project workers is not used in the actual quantification, it should contribute to clarify the potential benefits and assist in formulating an approach for collecting estimates of benefits from users of the system.

- **Acknowledge Other Contributions**

  The realized benefit from an improved policy, specification or design method is invariably a result of several development stages, and includes contributions by many role players, as shown in Figure 6 and Figure 7. The credit for the benefit should thus be proportionally assigned to the different role players. The contribution ratio assigned to the development process itself should ideally be assigned by practitioners and clients, as opposed to the workers responsible for technology development.

- **Use Confidence Intervals To Assess Benefits**

  The expected benefits of a research programme can seldom be known with any certainty and are typically obtained through subjective estimates that are highly uncertain (this includes the assigned contribution ratios noted above). Zilberman and Heiman (1999) note that the credibility of a benefit assessment will increase if the analysis provides some indication of the randomness of the estimated benefit. It may therefore be useful to calculate a range or interval rather than a point estimate of economic benefits. Such a range can be based on probability measures (as used in ARRB [1992]) or on estimates from different models or approaches.

3.4 SUMMARY

In this section, elements of the assessment of direct economic benefits arising from technology development work were discussed. Specifically, difficulties associated with the assessment process were highlighted, and a best practice approach for addressing these difficulties was outlined. It was noted that the assessment of direct economic benefits involves, amongst other issues, the following three difficulties:

1. There is a conceptual and time-related separation between project findings and benefit realization. This diffusion of project findings greatly complicates the identification and isolation of the links between project deliverables and the benefits that arise as a result. Considerable experience of the field of application is needed to identify and isolate the links between realized benefits and the technical findings of technology development projects.

2. Benefits often result from several contributing projects and processes. It is thus essential to ensure that contributions that precede technology development projects, as well as contributions required to refine and implement policy changes, are taken into account in the benefit assessment process.

3. In order to arrive at the assumptions needed to complete an economic assessment of benefits, a significant amount of subjective input is needed. The subjective element of the assessment process impacts negatively on the credibility of the assessment.

A survey was conducted of previous investigations that involved assessments of direct economic benefits arising from research and technology development projects. From this survey, and also from evaluations conducted as part of the present study, a best practice approach was constructed to guide the assessment of direct economic benefits resulting from Gautrans technology development projects. This approach involves the following guidelines:

- <u>Select the Best Performing Projects for Benefit Quantification</u>
  Earlier investigations found that it may be more effective to identify and then focus on the best performing projects within a research program, as opposed to trying to evaluate the entire research programme over a long term.

- <u>Identify Impacts and Benefits Through Interviews with Technology Development Workers</u>
  This approach quickly identifies the impacts resulting from technology development work, and helps to identify links between purely technical outcomes and downstream benefits.

- <u>Collect Evidence From The Users Of The System</u>
  Whilst technology development workers are interviewed to identify impacts and potential benefits, estimates of the actual benefits are obtained through interviews with the more impartial system users (e.g. client body representatives and practitioners). This ensures transparency and credibility.

- <u>Acknowledge Other Contributions</u>
  A technology typically has to develop through several stages before its benefits are realized through changes in policy, design methods or specifications. To realize such benefits, contributions from other role players are needed. The benefit assessment process should acknowledge such contributions, and a contribution ratio should be assigned to technology development projects when calculating benefits.

- <u>Use Confidence Intervals To Assess Benefits</u>
  The expected benefits of a research programme can seldom be known with any certainty and are typically obtained through subjective estimates that are highly uncertain. The credibility of benefit assessment can be increased if the analysis provides some measurement of the randomness of the estimated benefit. It may therefore be more useful to use a range or interval rather than a point estimate of economic benefits.

4 DIRECT ECONOMIC BENEFITS: A GENERAL ASSESSMENT

4.1 INTRODUCTION

This section presents an assessment of the typical returns on investment in technology development projects in the road building sector. The methodology followed here is based on the best practice elements highlighted in Section 3, and uses assumptions that are based on typical pavement rehabilitation projects in the Gauteng province.

It should be noted that the assessment presented in this section is based on general impacts from technology development projects, and not on specific projects or impacts. An evaluation of the benefits arising from some specific projects is presented in Sections 5 and 6. The primary objective of this section is to demonstrate that – owing to the vast scale of most road infrastructures – the benefits that can be realized from technology investment projects in the road building sector are significant.

4.2 GENERAL IMPACTS OF ROAD RELATED TECHNOLOGY DEVELOPMENT PROJECTS

A survey of the technical impacts of road related technology development work, and specifically of those that involve accelerated pavement testing, has shown that the technical impacts of such development work can be generalized into the following three categories (ARRB, 1992; Jooste and Sampson, 2004, Gillen et al. 2002):

1. Optimized materials and pavement design, which lead to reduced construction costs;
2. More reliable design and maintenance practices, which reduces the likelihood of costly early failures, and
3. More cost effective materials and pavement design, which optimizes the time between maintenance interventions and reduces pavement life cycle costs.

Direct economic benefits that can typically be derived from these impacts are evaluated in the following sections.

4.3 BENEFITS ARISING FROM OPTIMIZED DESIGN

Technology development projects often result in rationalized design methods which improve on earlier, more empirical, methods. Specifically, Accelerated Pavement Tests, such as those conducted with the HVS, are often used to validate and calibrate newly developed methods. Similarly, the findings of technology development tests are often used to improve and optimize materials design. These improvements in materials and pavement design methodologies often lead to optimized designs that either involve reduced layer thicknesses in pavements, or reduced use of costly additives in materials.

Although the savings from such optimization may be small when expressed in unit costs (typically Rand per square metre), the economic benefit becomes clear when these unit costs are applied on a network-wide basis over the course of a decade or more.

Examples of Design Optimization Effected Through Pavement Technology Development

- In the late 1970's and early 1980's the use of a high quality Crushed Stone base over a cemented subbase was increasingly implemented in South Africa. At the time, a 150 mm thick Crushed Stone layer was typically used, but for heavier traffic applications engineers would often increase the thickness of the Crushed Stone to 200 mm or more. The HVS technology development programme conducted in South Africa during the early 1980's validated the hypothesis – derived from analytical calculations – that for a Crushed Stone base over a stabilized subbase, higher shear strength could be achieved by limiting the layer thickness to 150 mm. This conclusion prevented further use of 200 mm thick crushed stone base layers, thus effecting a significant saving in natural resources and construction cost.

- Prior to the completion of the first phase of the Gautrans technology development programme for Foamed Bitumen Treated Materials, existing design methods for pavements using foamed bitumen recycling technology were based mostly on laboratory measurements. The findings of the Gautrans technology development programme facilitated the development of a mechanistic-empirical design method that was calibrated using full-scale accelerated testing. This method is published as part of the guidelines for the design and use of foamed bitumen treated materials (Asphalt Academy, 2002), and allows engineers to optimize foamed bitumen layer thicknesses for specific design situations.

To evaluate the potential benefits from such optimization for the HVS technology development programme, consider the example of a 3 per cent reduction in the overall cost of heavy rehabilitation work, arising from the results of a two year HVS technology development project[♣].

Example Outline:

The example assumes a 20 year design period. In the first year, a heavy rehabilitation is performed. In year 9, a surface seal is placed, and in year 15, a resurfacing with light rehabilitation work is performed. The example considers a benchmark scenario in which the unit cost for the rehabilitation actions is based on those summarized in Appendix A. The benchmark case is then contrasted with the case in which a 3 per cent saving on the initial heavy rehabilitation is achieved (e.g. by optimizing layer thicknesses) through the impacts of a two year technology development project.

Key Assumptions:

[♣] Unit costs for different treatment types used in all examples included in this section were obtained from the Committee of Land Transport Officials (COLTO) tender rates database (www.coltodatabase.co.za), and are outlined in more detail in Appendix A.

- It is assumed that the findings which lead to the three per cent saving are the result of a two year HVS technology development project. The annual budget for the HVS technology development programme is approximately R 4 million, which means the total cost of arriving at the benefits is approximately R 8 million.
- The impact of the technology development project findings that will lead to the three per cent saving in rehabilitation cost is accumulated over a ten year period. This means that the "credit" for the optimization is assigned to the technology development project only for a period of 10 years.
- It is assumed that the optimized pavement or materials design approach will affect 30 per cent of the rehabilitation work undertaken on the network over the next ten years.
- A 60 per cent contribution ratio is assigned to the technology development project which resulted in the three per cent saving. In effect, this means that other role players and other developments, not funded by the technology development project, contributed roughly 40 per cent to the findings which resulted in the three per cent saving.

Observations:

The calculation of the life cycle costs and unit savings that can be effected by a three per cent saving, as assumed in this example, is shown in Figure 8 . These scaled total savings and benefit-cost ratios are summarized in Figure 9 for road networks of various sizes. The highlighted line in Figure 8 represents an annual pavement rehabilitation length that is roughly appropriate for the Gautrans network. The resulting savings and benefits are discussed in Section 4.6.

Evaluation of Optimized Design Resulting in a 3 Per Cent Saving in Initial Construction Cost

Benchmark Scenario

Year	**0**	
Action: Initial Rehabilitation	**R / m²**	**R / lane-km**
Heavy Rehabilitation	R 145.00	R 609,000
Ancillary Works & Contingencies (20%)		R 121,800
Total Cost of Construction		**R 730,800**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 730,800
	8%	R 730,800
	12%	R 730,800

Year	**9**	
Action: Surface Maintenance	**R / m²**	**R / lane-km**
Surface Seal	R 25.00	R 105,000
Ancillary Works & Contingencies (20%)		R 21,000
Total Cost of Construction		**R 126,000**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 88,526
	8%	R 63,031
	12%	R 45,437

Year	**15**	
Action: Light Rehabilitation	**R / m²**	**R / lane-km**
Light Rehabilitation	R 70.00	R 294,000
Ancillary Works & Contingencies (20%)		R 58,800
Total Cost of Construction		**R 352,800**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 195,897
	8%	R 111,217
	12%	R 64,455

Scenario with Optimized Design

Year	**0**	
Action: Initial Rehabilitation	**R / m²**	**R / lane-km**
Heavy Rehabilitation	R 140.65	R 590,730
Ancillary Works & Contingencies (20%)		R 118,146
Total Cost of Construction		**R 708,876**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 708,876
	8%	R 708,876
	12%	R 708,876

Year	**9**	
Action: Surface Maintenance	**R / m²**	**R / lane-km**
Surface Seal	R 25.00	R 105,000
Ancillary Works & Contingencies (20%)		R 21,000
Total Cost of Construction		**R 126,000**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 88,526
	8%	R 63,031
	12%	R 45,437

Year	**15**	
Action: Light Rehabilitation	**R / m²**	**R / lane-km**
Light Rehabilitation	R 70.00	R 294,000
Ancillary Works & Contingencies (20%)		R 58,800
Total Cost of Construction		**R 352,800**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 195,897
	8%	R 111,217
	12%	R 64,455

Benchmark Scenario

Life Cycle Cost per Lane-Km for a Discount Rate of	4%	R 1,015,223
	8%	R 905,049
	12%	R 840,692

Scenario with Optimized Design

Life Cycle Cost per Lane-Km for a Discount Rate of	4%	R 993,299
	8%	R 883,125
	12%	R 818,768

Summary of Savings Per Lane-Km

Lane-Km Saving for Optimized Design	**4%**	**R 21,924**
	8%	**R 21,924**
	12%	**R 21,924**

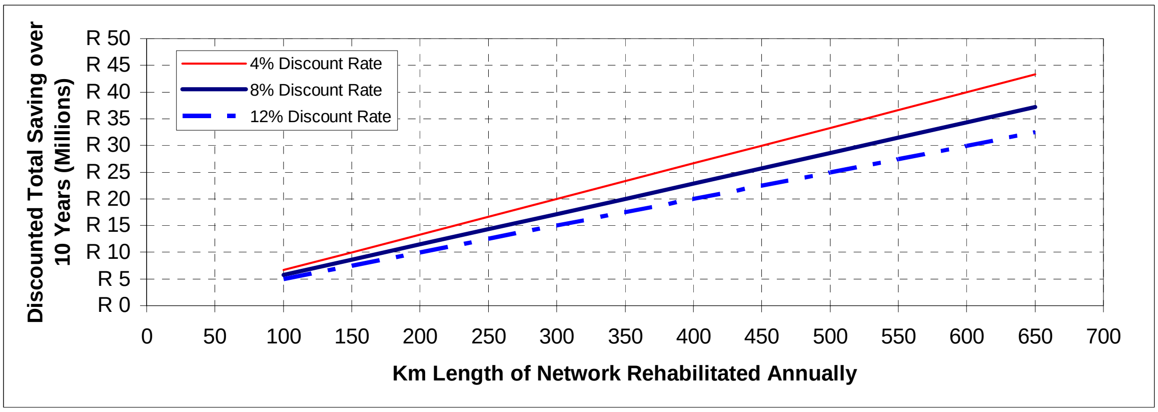
Note: A lane width of 3.7 m is assumed, plus an effective shoulder width of 0.5 m. This effective lane width is 4.2 metres.

Figure 8: Evaluation of Life Cycle Cost Savings as a Result of Design Optimization

Key Assumptions
Percentage Projects on Which Optimization is Applied = 30%
Contribution Made By Findings of Technology Development Project = 60%
Period over which savings are contributed to Technology Development = 10 Years
Annual cost of Technology Development work = R 4 million
Technology Development Period needed to deliver findings = 2 Years

Discount Rate	4%			8%			12%		
Savings / Lane-Km	R 21,924			R 21,924			R 21,924		
Annual	Savings		Benefit Cost Ratio	Savings		Benefit Cost Ratio	Savings		Benefit Cost Ratio
Annual Km of 2 Lane Road Rehabilitated	Annual	Total Discounted Over 10 Years		Annual	Total Discounted Over 10 Years		Annual	Total Discounted Over 10 Years	
100	R 789,264	R 6,657,704	0.8	R 789,264	R 5,719,708	0.7	R 789,264	R 4,994,660	0.6
150	R 1,183,896	R 9,986,555	1.2	R 1,183,896	R 8,579,562	1.1	R 1,183,896	R 7,491,990	0.9
200	R 1,578,528	R 13,315,407	1.7	R 1,578,528	R 11,439,415	1.4	R 1,578,528	R 9,989,319	1.2
250	R 1,973,160	R 16,644,259	2.1	R 1,973,160	R 14,299,269	1.8	R 1,973,160	R 12,486,649	1.6
300	R 2,367,792	R 19,973,111	2.5	R 2,367,792	R 17,159,123	2.1	R 2,367,792	R 14,983,979	1.9
350	R 2,762,424	R 23,301,962	2.9	R 2,762,424	R 20,018,977	2.5	R 2,762,424	R 17,481,309	2.2
400	R 3,157,056	R 26,630,814	3.3	R 3,157,056	R 22,878,831	2.9	R 3,157,056	R 19,978,639	2.5
450	R 3,551,688	R 29,959,666	3.7	R 3,551,688	R 25,738,685	3.2	R 3,551,688	R 22,475,969	2.8
500	R 3,946,320	R 33,288,518	4.2	R 3,946,320	R 28,598,539	3.6	R 3,946,320	R 24,973,299	3.1
550	R 4,340,952	R 36,617,370	4.6	R 4,340,952	R 31,458,393	3.9	R 4,340,952	R 27,470,629	3.4
600	R 4,735,584	R 39,946,221	5.0	R 4,735,584	R 34,318,246	4.3	R 4,735,584	R 29,967,958	3.7
650	R 5,130,216	R 43,275,073	5.4	R 5,130,216	R 37,178,100	4.6	R 5,130,216	R 32,465,288	4.1

Note: The discounted saving over 10 years assumes the saving is realized at the start of each year



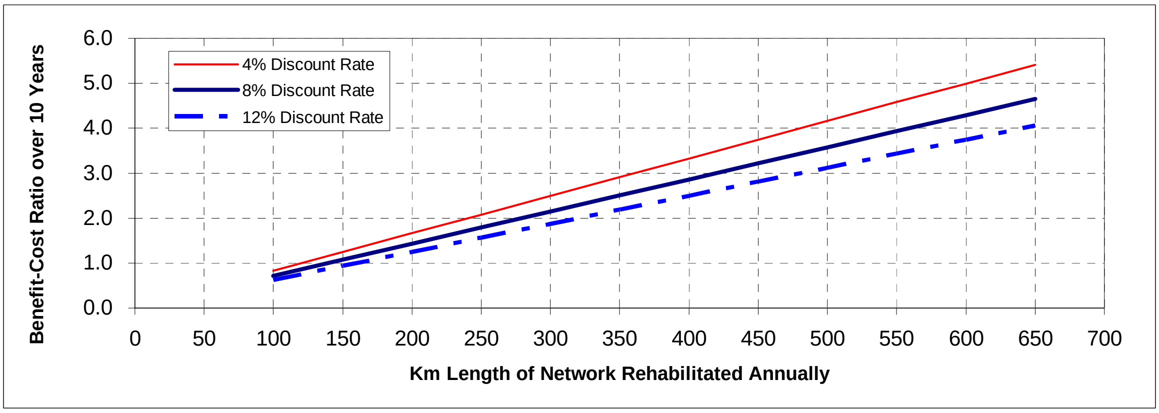


Figure 9: Scaling of Savings Resulting from Design Optimization

4.4 BENEFITS ARISING FROM MORE COST EFFECTIVE MATERIALS OR CONSTRUCTION PRACTICES

Technology development projects often result in improvements in materials design or improved construction practices. These improvements are typically the result of improved materials design methods or special modifications (i.e. through addition of modifiers such as cement or bitumen rubber) which result in more durable materials. Such modifications are, however, frequently more costly than conventional approaches, and may require a deviation from established practice not easily implemented by engineers.

In such situations, an accelerated full scale testing facility such as the HVS is ideal to evaluate and quantify the benefits (if any) that can be achieved with such modifications. Thus a programme such as the Gautrans HVS technology development programme can be used to evaluate whether a proposed modification to existing materials or design practice does indeed increase the durability and cost-effectiveness of a design. Irrespective of the findings, the clarification provided by the test will result in significant savings.

For example, if a more expensive - *but ineffective* - modified material is implemented on several projects across a road network, the cost associated with the modification will be wasted. HVS testing can thus be used to prevent such waste by identifying ineffective modifications within a short period of time. Similarly, if an *effective* modified material or procedure is prevented from being implemented because of the perceived increase in construction cost, then the potential to achieve significant savings will be lost. In such a situation, an HVS test project can be used to validate the improved performance from the modified material or process. Such validation will provide engineers with the confidence to implement the modified material or process.

The following paragraphs describe an example which illustrates the potential benefits that can be derived from the implementation of a material or construction practice that – because of greater durability - increases the time between required maintenance interventions.

Examples of Improved Cost Effectiveness of Pavement and Materials Design

- The HVS centred technology development programme conducted in the early 1980's clearly showed that the structural capacity of a well-constructed, high quality Crushed Stone base over a thick cement stabilized subbase could be as high as 50 million standard axles. The validation of the structural capacity of this pavement type established a cost-effective alternative to the more expensive concrete and asphalt base pavements used at the time in South Africa for heavy traffic applications. This cost-effective, validated and locally relevant pavement technology thus led to significant savings in construction costs in all areas of Southern Africa.

- The Australian Accelerated Loading Facility (ALF) was used to assess the benefits of polymer modified binders for specific applications that involved the repair of distressed intersections. Tests on modified asphalt validated the improvement in fatigue and deformation properties for these materials. As a result, the depth of repair (milling depth as well as overlay thickness) as well as the frequency of repair on intersections could be significantly reduced. In addition, the frequency of repairs could be reduced. Taking into account this as well as other benefits derived from this specific ALF test, a benefit-cost ratio of 2.5 to 3.5 was calculated for the technology development project (ARRB, 1992).

- The Gautrans technology development programme for Foamed Bitumen Treated Materials led to significant improvements in the understanding of the manner in which the stabilizers (bitumen and cement) interact. Specifically, it was shown that too much cement nullifies the effect of the bitumen binder. The technology development programme assisted in the development of guidelines for the design of foamed bitumen treated materials. As a result of the optimized materials design method, which prevents excessive use of cement or bitumen binder, significant savings can be achieved on projects which implement foamed bitumen materials.

Example Outline:

The example compares the life cycle costs of two scenarios over a 20 year design period. In the benchmark scenario, a heavy rehabilitation is performed in the first year, followed by a resurfacing in year 9, and a light rehabilitation in year 15. The life cycle cost of this situation is compared to the alternative in which an improved material or construction practice - validated through a test program such as the HVS technology development programme - is included in the initial rehabilitation.

A two per cent increase in overall construction cost is assumed owing to the modified material or process. The impact of the modified material or process is assumed to be an increase in the time between maintenance interventions. Specifically, in the scenario with the modified material or process, the surface seal is now placed in year 12 (instead of year 9), and the final light rehabilitation is placed in year 19 (instead of year 15). The net effect of the increased interval between interventions (assumed to be a result of more durable materials) is a reduced pavement life cycle cost.

Key Assumptions:

- It is assumed that the findings which lead to the validation and refinement of the modified material or process are the result of a two year HVS technology development project. The annual budget for the HVS technology development programme is approximately R 4 million, which means the total cost of arriving at the benefits is approximately R 8 million.
- The impact of the technology development project findings that refined and validated the modified material or process is accumulated over a ten year period. This means that the "credit" for the modification is assigned to the technology development project only for a period of 10 years.
- It is assumed that the modified material or process will be implemented on 30 per cent of the rehabilitation work undertaken on the network over the next ten years.
- A 60 per cent contribution ratio is assigned to the technology development project which validated and refined the modified material or process. This means that other developments and role players, not funded by the technology development project, contributed roughly 40 per cent to the developments which resulted in the modified process or material.

Observations:

The calculation of the life cycle costs and unit savings that can be effected by the modified material or process which results in increased time between interventions, is shown in Figure 10. These scaled total savings and benefit-cost ratios are summarized in Figure 11 for road networks of various sizes. The highlighted line in Figure 11 represents an annual pavement rehabilitation length that is roughly appropriate for the Gautrans network. The resulting savings and benefits are discussed in the Section 4.6.

Evaluation of Cost Effective Materials Resulting in an Increased Period Between Maintenance Actions

Benchmark Scenario

Year		**0**	
Action: Initial Rehabilitation	**R / m^2**	**R / lane-km**	
Heavy Rehabilitation	R 145.00	R	609,000
Ancillary Works & Contingencies (20%)		R	121,800
Total Cost of Construction		**R**	**730,800**
Discounted Cost for Discount Rate of	4%	R	730,800
	8%	R	730,800
	12%	R	730,800

Year		**9**	
Action: Surface Maintenance	**R / m^2**	**R / lane-km**	
Surface Seal	R 25.00	R	105,000
Ancillary Works & Contingencies (20%)		R	21,000
Total Cost of Construction		**R**	**126,000**
Discounted Cost per Lane-Km for Discount Rate of	4%	R	88,526
	8%	R	63,031
	12%	R	45,437

Year		**15**	
Action: Light Rehabilitation	**R / m^2**	**R / lane-km**	
Light Rehabilitation	R 70.00	R	294,000
Ancillary Works & Contingencies (20%)		R	58,800
Total Cost of Construction		**R**	**352,800**
Discounted Cost per Lane-Km for Discount Rate of	4%	R	195,897
	8%	R	111,217
	12%	R	64,455

Scenario with Increased Time Between Interventions

Year		**0**	
Action: Initial Rehabilitation	**R / m^2**	**R / lane-km**	
Heavy Rehabilitation	R 147.90	R	621,180
Ancillary Works & Contingencies (20%)		R	124,236
Total Cost of Construction		**R**	**745,416**
Discounted Cost for Discount Rate of	4%	R	745,416
	8%	R	745,416
	12%	R	745,416

Year		**12**	
Action: Surface Maintenance	**R / m^2**	**R / lane-km**	
Surface Seal	R 25.00	R	105,000
Ancillary Works & Contingencies (20%)		R	21,000
Total Cost of Construction		**R**	**126,000**
Discounted Cost per Lane-Km for Discount Rate of	4%	R	78,699
	8%	R	50,036
	12%	R	32,341

Year		**19**	
Action: Light Rehabilitation	**R / m^2**	**R / lane-km**	
Light Rehabilitation	R 70.00	R	294,000
Ancillary Works & Contingencies (20%)		R	58,800
Total Cost of Construction		**R**	**352,800**
Discounted Cost per Lane-Km for Discount Rate of	4%	R	167,454
	8%	R	81,748
	12%	R	40,962

Benchmark Scenario

Life Cycle Cost per Lane-Km for a Discount Rate of	4%	R	1,015,223
	8%	R	905,049
	12%	R	840,692

Scenario with Increased Time Between Interventions

Life Cycle Cost per Lane-Km for a Discount Rate of	4%	R	991,569
	8%	R	877,200
	12%	R	818,720

Summary of Savings Per Lane-Km

Lane-Km Saving for Increased Period Between Interventions	**4%**	**R**	**23,654**
	8%	**R**	**27,848**
	12%	**R**	**21,973**

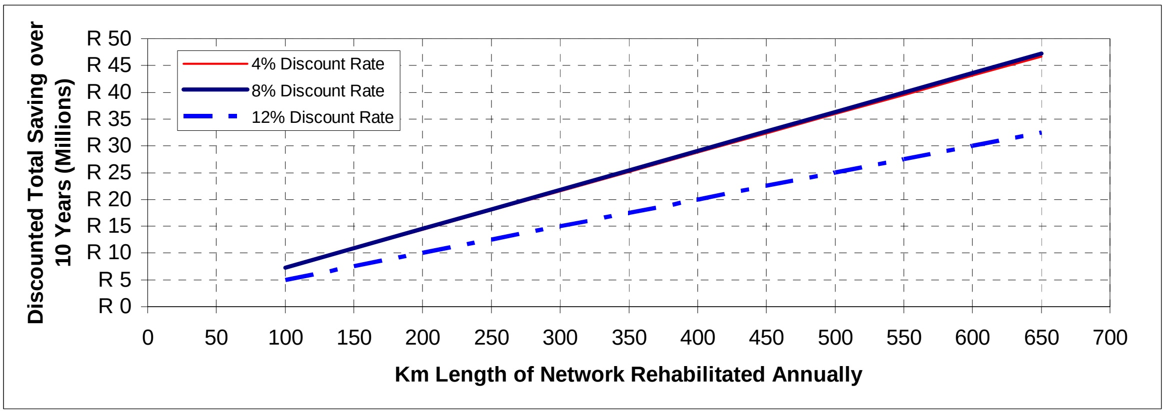
Note: A lane width of 3.7 m is assumed, plus an effective shoulder width of 0.5 m. This effective lane width is 4.2 metres.

Figure 10: Evaluation of Life Cycle Cost Savings as a Result of More Cost Effective Materials or Construction Processes

Key Assumptions
Percentage Projects on Which Optimization is Applied = 30%
Contribution Made By Findings of Technology Development Project = 60%
Period over which savings are contributed to Technology Development = 10 Years
Annual cost of Technology Development work = R 4 million
Technology Development Period needed to deliver findings = 2 Years

Discount Rate	4%			8%			12%		
Savings / Lane-Km	R 23,654			R 27,848			R 21,973		
Annual	Savings			Savings			Savings		
Annual Km of 2 Lane Road Rehabilitated	Annual	Total Discounted Over 10 Years	Benefit Cost Ratio	Annual	Total Discounted Over 10 Years	Benefit Cost Ratio	Annual	Total Discounted Over 10 Years	Benefit Cost Ratio
100	R 851,550	R 7,183,108	0.9	R 1,002,539	R 7,265,285	0.9	R 791,013	R 5,005,725	0.6
150	R 1,277,325	R 10,774,661	1.3	R 1,503,808	R 10,897,927	1.4	R 1,186,519	R 7,508,588	0.9
200	R 1,703,100	R 14,366,215	1.8	R 2,005,077	R 14,530,569	1.8	R 1,582,025	R 10,011,450	1.3
250	R 2,128,875	R 17,957,769	2.2	R 2,506,346	R 18,163,212	2.3	R 1,977,531	R 12,514,313	1.6
300	R 2,554,650	R 21,549,323	2.7	R 3,007,616	R 21,795,854	2.7	R 2,373,038	R 15,017,175	1.9
350	R 2,980,425	R 25,140,877	3.1	R 3,508,885	R 25,428,496	3.2	R 2,768,544	R 17,520,038	2.2
400	R 3,406,200	R 28,732,430	3.6	R 4,010,154	R 29,061,139	3.6	R 3,164,050	R 20,022,901	2.5
450	R 3,831,976	R 32,323,984	4.0	R 4,511,424	R 32,693,781	4.1	R 3,559,557	R 22,525,763	2.8
500	R 4,257,751	R 35,915,538	4.5	R 5,012,693	R 36,326,423	4.5	R 3,955,063	R 25,028,626	3.1
550	R 4,683,526	R 39,507,092	4.9	R 5,513,962	R 39,959,066	5.0	R 4,350,569	R 27,531,488	3.4
600	R 5,109,301	R 43,098,645	5.4	R 6,015,231	R 43,591,708	5.4	R 4,746,075	R 30,034,351	3.8
650	R 5,535,076	R 46,690,199	5.8	R 6,516,501	R 47,224,350	5.9	R 5,141,582	R 32,537,214	4.1

Note: The discounted saving over 10 years assumes the saving is realized at the start of each year



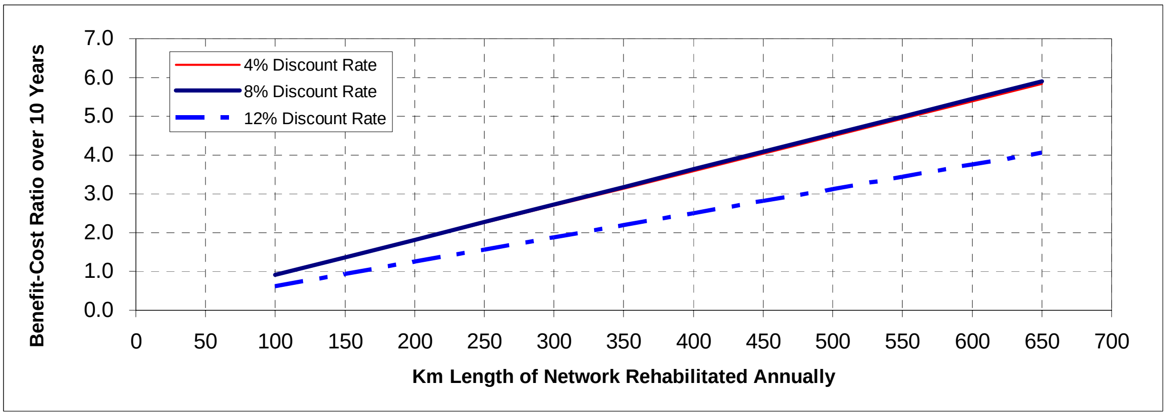


Figure 11: Scaling of Savings Resulting from More Cost Effective Materials or Construction Processes

4.5 BENEFITS ARISING FROM MORE RELIABLE DESIGN AND CONSTRUCTION PRACTICES

Another impact of technology development projects relates to the reliability of design practices. Under the controlled test conditions used in typical accelerated pavement tests, modes of deterioration that would otherwise not be detected can often be identified. Once identified, these modes of failure can be included as part of design methods and can thus ensure more reliable designs.

The following paragraphs describe an example which illustrates the potential benefits that can be derived from a technology development project for which the findings result in a modified design or construction method that decreases the frequency of premature failures on a road network.

Examples of More Reliable Design and Construction Practices

- The HVS technology development programme on high quality Crushed Stone (G1) materials, together with the technology transfer effected by the programme, led to a widespread awareness of the importance of timely maintenance on pavements with crushed stone bases. The technology development programme quantified the differences in the performance of dry and saturated materials and explicitly showed the importance of maintaining an impervious surface seal. These findings greatly assisted in establishing a culture of timely resurfacing amongst road owner agencies in South Africa. The impact of establishing a policy of timely surface maintenance amongst South African road owner agencies is estimated to have lead to significant savings (Jooste and Sampson; 2004).

- The Australian Accelerated Loading Facility (ALF) was used to evaluate cement treated base (CTB) pavements. The study revealed a deterioration mechanism that develops due to de-bonding between two CTB layers, followed by water ingress (ARRB, 1992). The ALF trial on CTB pavements showed the need to include special measures to ensure an adequate bond between CTB layers, and to prevent ingress of water. The recommendations stemming from the ALF investigation lead to improved maintenance and construction policies, which in turn reduced the number of incidences in which early maintenance was needed owing to the effects of CTB de-bonding and water ingress. Taking into account the savings in maintenance cost, as well as the cost of the ALF investigations, a benefit-cost ratio of roughly 4 to 9 was calculated for the impacts from the ALF trial.

- HVS tests conducted on CTB pavements in South Africa during the 1980's revealed a previously unidentified deterioration mechanism in CTB layers. This distress mechanism consisted of crushing which occurs at the top of CTB layers which these layers have inadequate crushing strength to withstand the pressures imposed by traffic (De Beer, 1990). Data collected during the HVS investigations facilitated the incorporation of a method to evaluate the potential for crushing failure in CTB layers. This evaluation method is now incorporated as part of the South African mechanistic-empirical design methodology. This improvement has undoubtedly increased the reliability of the design procedure for CTB pavements, which in turn reduced – and continues to do so – the incidence of premature failures on CTB pavements.

Example Outline:

The example compares the life cycle costs of two scenarios over a 20 year design period. In the benchmark scenario, a heavy rehabilitation is performed in the first year, followed by a resurfacing in year 9, and a light rehabilitation in year 15. The life cycle cost of this situation is compared to the alternative in which a premature failure is assumed to occur after the first two years. It is further assumed that the premature failure requires rehabilitation in year three, after which the life cycle continues with a light rehabilitation in year 12. By comparing the life cycle cost of these two scenarios, the typical cost of a premature failure can be determined. It is then assumed that the findings of a test program such as the HVS technology development programme are used to reduce the frequency of a specific type of premature failure. Detailed assumptions are defined below.

Key Assumptions:

- It is assumed that the findings which lead to the improved design and construction practices are the result of a two year HVS technology development project. The annual budget for the HVS technology development programme is approximately R 4 million, which means the total cost of arriving at the benefits is approximately R 8 million.
- The impact of the technology development project findings that lead to the more reliable design and construction practice is accumulated over a ten year period. This means that the “credit” for the more reliable methodologies is assigned to the technology development project only for a period of 10 years.
- It is assumed that, before implementation of the methodology that increases design or construction reliability, roughly 5 per cent of the annual rehabilitated length showed some form of premature distress. It is further assumed that – owing to the implementation of findings of the technology development project – the percentage of rehabilitated km length showing premature distress is decreased by 2 per cent;
- A 60 per cent contribution ratio is assigned to the technology development project which validated and refined the modified material or process. This means that other developments and role players, not funded by the technology development project, contributed roughly 40 per cent to the developments which resulted in the increased reliability of the design or construction process.

Observations:

The calculation of the life cycle costs and unit savings that can be effected by decreasing the likelihood of premature failure is shown in Figure 12. The scaled total savings and benefit-cost ratios are summarized in Figure 13 for road networks of various sizes. The highlighted line in Figure 13 represents an annual pavement rehabilitation length that is roughly appropriate for the Gautrans network. The resulting savings and benefits are discussed in the following section.

Evaluation of the Cost of Premature Failure

Benchmark Scenario

Year	0	
Action: Initial Rehabilitation	**R / m^2**	**R / lane-km**
Heavy Rehabilitation	R 145.00	R 609,000
Ancillary Works & Contingencies (20%)		R 121,800
Total Cost of Construction		**R 730,800**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 730,800
	8%	R 730,800
	12%	R 730,800

Year	9	
Action: Surface Maintenance	**R / m^2**	**R / lane-km**
Surface Seal	R 25.00	R 105,000
Ancillary Works & Contingencies (20%)		R 21,000
Total Cost of Construction		**R 126,000**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 88,526
	8%	R 63,031
	12%	R 45,437

Year	15	
Action: Light Rehabilitation	**R / m^2**	**R / lane-km**
Light Rehabilitation	R 70.00	R 294,000
Ancillary Works & Contingencies (20%)		R 58,800
Total Cost of Construction		**R 352,800**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 195,897
	8%	R 111,217
	12%	R 64,455

Scenario with Premature Failure

Year	0	
Action: Initial Rehabilitation	**R / m^2**	**R / lane-km**
Heavy Rehabilitation	R 145.00	R 609,000
Ancillary Works & Contingencies (20%)		R 121,800
Total Cost of Construction		**R 730,800**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 730,800
	8%	R 730,800
	12%	R 730,800

Year	3	
Action: Correct Premature Failure	**R / m^2**	**R / lane-km**
Medium Rehabilitation	R 100.00	R 420,000
Ancillary Works & Contingencies (20%)		R 84,000
Total Cost of Construction		**R 504,000**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 448,054
	8%	R 400,091
	12%	R 358,737

Year	12	
Action: Light Rehabilitation	**R / m^2**	**R / lane-km**
Light Rehabilitation	R 70.00	R 294,000
Ancillary Works & Contingencies (20%)		R 58,800
Total Cost of Construction		**R 352,800**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 220,358
	8%	R 140,102
	12%	R 90,555

Benchmark Scenario

Life Cycle Cost per Lane-Km for a Discount Rate of	4%	R 1,015,223
	8%	R 905,049
	12%	R 840,692

Scenario with Premature Failure

Life Cycle Cost per Lane-Km for a Discount Rate of	4%	R 1,399,212
	8%	R 1,270,993
	12%	R 1,180,092

Summary of Costs Per Lane-Km

Lane-Km Cost for Premature Failure	**4%**	**R 383,989**
	8%	**R 365,945**
	12%	**R 339,400**

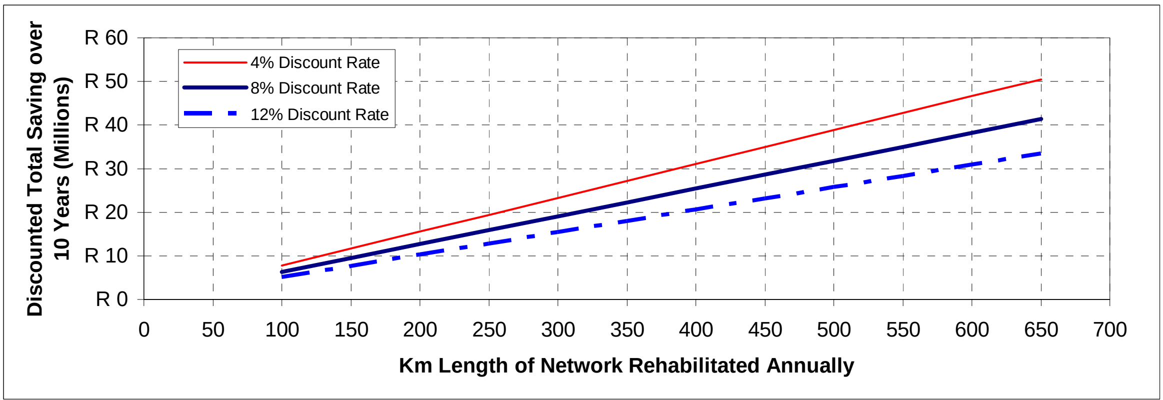
Note: A lane width of 3.7 m is assumed, plus an effective shoulder width of 0.5 m. Thus the effective lane width is 4.2 metres.

Figure 12: Evaluation of Life Cycle Cost Savings as a Result of More Reliable Design and Construction Processes

Key Assumptions
Percentage of rehabilitated length that failed before Technology Development Project findings were implimented = 5%
Percentage of rehabilitated length that failed after Technology Development Project findings were implemented = 3%
Contribution made by the findings of the Technology Development Project = 60%
Period over which savings are contributed to Technology Development = 10 Years
Annual cost of Technology Development work = R 4 million
Technology Development Period needed to deliver findings = 2 Years

Discount Rate	4%			8%			12%		
Savings / Lane-Km	R 383,989			R 365,945			R 339,400		
Annual	Savings		Benefit Cost Ratio	Savings		Benefit Cost Ratio	Savings		Benefit Cost Ratio
Annual Km of 2 Lane Road Rehabilitated	Annual	Total Discounted Over 10 Years		Annual	Total Discounted Over 10 Years		Annual	Total Discounted Over 10 Years	
100	R 921,573	R 7,773,774	1.0	R 878,267	R 6,364,702	0.8	R 814,560	R 5,154,741	0.6
150	R 1,382,360	R 11,660,661	1.5	R 1,317,400	R 9,547,053	1.2	R 1,221,840	R 7,732,111	1.0
200	R 1,843,146	R 15,547,548	1.9	R 1,756,534	R 12,729,404	1.6	R 1,629,121	R 10,309,482	1.3
250	R 2,303,933	R 19,434,435	2.4	R 2,195,667	R 15,911,754	2.0	R 2,036,401	R 12,886,852	1.6
300	R 2,764,719	R 23,321,322	2.9	R 2,634,801	R 19,094,105	2.4	R 2,443,681	R 15,464,223	1.9
350	R 3,225,506	R 27,208,209	3.4	R 3,073,934	R 22,276,456	2.8	R 2,850,961	R 18,041,593	2.3
400	R 3,686,292	R 31,095,096	3.9	R 3,513,068	R 25,458,807	3.2	R 3,258,241	R 20,618,964	2.6
450	R 4,147,079	R 34,981,983	4.4	R 3,952,201	R 28,641,158	3.6	R 3,665,521	R 23,196,334	2.9
500	R 4,607,865	R 38,868,870	4.9	R 4,391,334	R 31,823,509	4.0	R 4,072,801	R 25,773,704	3.2
550	R 5,068,652	R 42,755,757	5.3	R 4,830,468	R 35,005,860	4.4	R 4,480,081	R 28,351,075	3.5
600	R 5,529,438	R 46,642,644	5.8	R 5,269,601	R 38,188,211	4.8	R 4,887,362	R 30,928,445	3.9
650	R 5,990,225	R 50,529,531	6.3	R 5,708,735	R 41,370,561	5.2	R 5,294,642	R 33,505,816	4.2

Note: The discounted saving over 10 years assumes the saving is realized at the start of each year



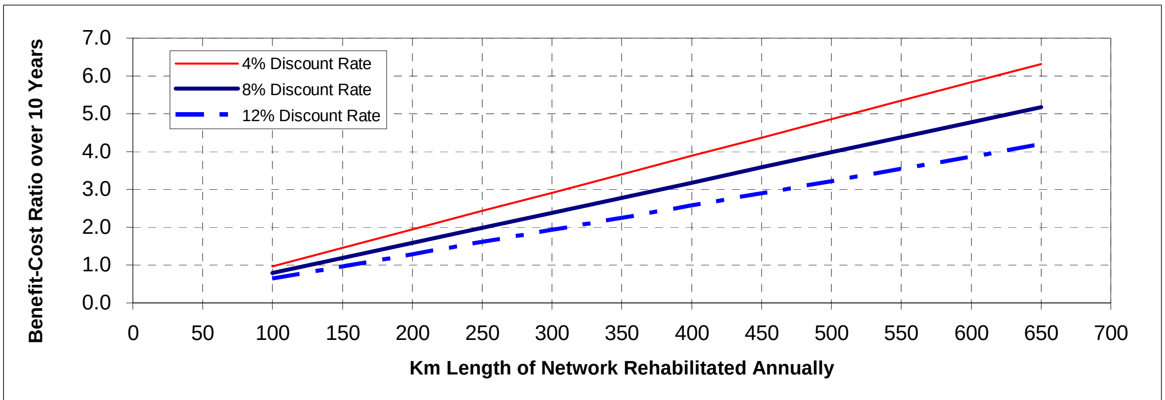


Figure 13: Scaling of Savings Resulting from More Reliable Design and Construction Processes

4.6 DISCUSSION OF EXAMPLE RESULTS

- As expected, the total savings and benefit-cost ratio is in all instances directly proportional to the size of the network. The results for all three examples suggest that, for the stated assumptions, the development work will realize a benefit-cost ratio in excess of 1.0 for any network on which more than 150 km of road is rehabilitated per annum.
- It is expected that Gautrans will, on average, rehabilitate 250 km of the network per annum (see Appendix A for details). Using this figure as an indication, the results shown in Figures 8, 10 and 12 suggest that, for each impact Gautrans will realize a benefit-cost ratio of 1.6 or more, with a total discounted saving over a 10 year period of between R12 million and R16 million *per impact*, depending on the discount rate.
- All three examples show that, *if the impacts are considered in isolation*, then a benefit-cost ratio of 2.0 or more will be realized for any road network that requires roughly 320 km of rehabilitation work per year. For larger networks that require in excess of 500 km of rehabilitation per year, the expected return on the technology investment will be roughly between R25 million and R33 million per impact, which equates to a return of three Rand for every one Rand invested in technology development.
- It will be noted that the expected returns on the technology development investment are quite similar for all three examples. This is a result of the subjective assumptions which were made with respect to aspects such as (a) percentage contribution assigned to the technology development project (b) period over which benefits were calculated; (c) percentage of the network affected by a project impact, and (d) assumed duration and cost of the technology development project. For all three examples these assumptions are the same or similar, and therefore result in similar benefits.
- For all three examples, the benefits of each impact were evaluated in isolation. This effectively implies that the impact considered in each example is the only significant finding of the assumed two year development project. In practice, this is seldom the case, and HVS technology development projects have often resulted in more than one finding that impacted significantly on the South African road network (the HVS test programme on G1 base pavements is one such example, and is discussed in more detail in Section 5).
- If two or more impacts are combined (i.e. if two impacts arise from the same technology development project), then there is naturally a significant increase in the savings and benefit-cost ratios. For example, if a two year technology development project resulted in findings that lead to more cost effective materials as well as more reliable designs, then the combined savings for a network such as that operated by Gautrans would be between R 24 million and R36 million, depending on the discount rate assumed. For a total cost of R8 million for the development project, these savings would result in a benefit-cost ratio of between 3.0 and 4.5. For a larger network that rehabilitates roughly 500 km of roads per year, the savings and benefit-cost ratios would be doubled (i.e. benefit cost ratios of 6.0 to 9.0 would apply).

4.7 EVALUATING THE VALUE OF INFORMATION

It was noted earlier that – apart from the many indirect benefits – the assessment of economic benefits that stem from technology development projects is based primarily on the assumption of new and freely available information. This information is assumed to impact positively on policies which in turn lead to measurable economic benefits. In the preceding section, an evaluation of these economic benefits was performed using the life cycle costs of scenarios with and without the benefit of technology development impacts.

In this section, an alternative approach is presented. This approach aims to establish a rational method for evaluating the *value of information* that can assist to direct and clarify policy decisions. The method used is derived from Bayesian statistics and specifically applies to decision making with experimental information (Lapin, 1983). As in the preceding section, the methodology is best illustrated by means of an example, which is presented and discussed in the following paragraphs.

Example Outline:

The example assumes that a new type of modified thin asphalt surfacing material is presented for consideration to a roads agency such as Gautrans. The material is more expensive than the conventional alternative and use of the material will raise the cost of a typical heavy rehabilitation by five per cent. However, it is claimed that the material is significantly more durable and flexible than conventional asphalt. It is expected that use of the material will increase the time between the initial construction and the first light rehabilitation by at least 5 years. It is also claimed that the material is specifically suited to low to medium volume roads where the support stiffness is low. Although there are no field performance data for the new material, indicator laboratory tests suggest that the claims made regarding the material's flexibility and durability are reasonable. These tests, however, do not represent actual field conditions. Thus the modified material seems promising, but there is still significant uncertainty regarding its overall cost effectiveness.

The client now has to make the decision whether to implement the new technology (i.e. the modified asphalt material) or not. The various options and alternatives are summarized in Table 1. It will be noted that Table 1 does not consider the likely alternative of pilot implementation and long term performance monitoring. The reason for this is as follows: pilot implementation and long term monitoring would require at least 10 years of monitoring before an indication of the effectiveness of the new technology can be obtained. Thus, if the new technology is indeed more cost effective, the potential savings of a network wide application will also be wasted during the first 10 years. Thus, for an analysis period of 10 years, the alternative of a pilot implementation is effectively the same as that of not implementing the new technology.

Assumptions and Cost of Various Consequences

The costs of the various consequences were calculated using typical construction costs (summarized in Appendix A) and assuming a typical life cycle for a rehabilitated pavement in which a heavy rehabilitation is performed in the first year, followed by a reseal in year nine and a light rehabilitation in year 15. To calculate the network wide savings and costs of the various consequences shown in Table 1, the following assumptions were made:

- It is assumed that the new modified asphalt will be appropriate for use on roughly 30 per cent of the annual kilometre length that is rehabilitated using light or heavy rehabilitations.

Table 1: Alternatives and Consequences for the Implementation of a New Technology

Option	Situation	Consequences
Implement new technology on all appropriate projects	New technology is significantly more cost-effective	Network wide savings are realized owing to more cost effective technology
	New technology is not more cost effective	Cost of more expensive but ineffective new technology is wasted
Disregard new technology	New technology is significantly more cost-effective	Potential network wide savings are not realized
	New technology is not more cost effective	Cost of more expensive but ineffective new technology is prevented

- The benefit and cost of the new technology is calculated and accumulated over 10 years.
- The new material is more expensive than the conventional alternative, such that the overall cost of a heavy rehabilitation will be increased by five per cent.
- The new material, if it is more durable, will increase the time to the first resurfacing by five years.

The savings and costs of the possible consequences are summarized in Tables 2 and 3, and in Figure 14 and Figure 15. In Tables 2 and 3, a network for which the size is such that it requires 400 km of rehabilitation per year was highlighted and will be used for further calculations in this example.

Calculation of Expected Payoffs

Once the savings or costs of the various consequences are calculated, a "payoff table" can be constructed using concepts of Bayesian statistics. The payoff table assigns a subjective probability – typically based on experience and engineering judgement - to each consequence, and then calculates the "Net Expected Payoff" by multiplying the probability of each consequence occurring with the cost or savings associated with that consequence. This multiplication yields a probable payoff for each consequence. Adding all of these probable payoffs yields the Net Expected Payoff for the situation. The payoff table for the current example is shown in Table 4.

Savings Realized if Modified Material Is More Durable

Benchmark Scenario

Year	0	
Action: Initial Rehabilitation	**R / m²**	**R / lane-km**
Heavy Rehabilitation	R 145.00	R 609,000
Ancillary Works & Contingencies (20%)		R 121,800
Total Cost of Construction		**R 730,800**
Discounted Cost for Discount Rate of	4%	R 730,800
	8%	R 730,800
	12%	R 730,800

Year	9	
Action: Surface Maintenance	**R / m²**	**R / lane-km**
Surface Seal	R 25.00	R 105,000
Ancillary Works & Contingencies (20%)		R 21,000
Total Cost of Construction		**R 126,000**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 88,526
	8%	R 63,031
	12%	R 45,437

Year	15	
Action: Light Rehabilitation	**R / m²**	**R / lane-km**
Light Rehabilitation	R 70.00	R 294,000
Ancillary Works & Contingencies (20%)		R 58,800
Total Cost of Construction		**R 352,800**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 195,897
	8%	R 111,217
	12%	R 64,455

More Durable Material

Year	0	
Action: Initial Rehabilitation	**R / m²**	**R / lane-km**
Heavy Rehabilitation	R 152.25	R 639,450
Ancillary Works & Contingencies (20%)		R 127,890
Total Cost of Construction		**R 767,340**
Discounted Cost for Discount Rate of	4%	R 767,340
	8%	R 767,340
	12%	R 767,340

Year	14	
Action: Surface Maintenance	**R / m²**	**R / lane-km**
Surface Seal	R 25.00	R 105,000
Ancillary Works & Contingencies (20%)		R 21,000
Total Cost of Construction		**R 126,000**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 72,762
	8%	R 42,898
	12%	R 25,782

Year	20	
Action: Light Rehabilitation	**R / m²**	**R / lane-km**
Light Rehabilitation	R 70.00	R 294,000
Ancillary Works & Contingencies (20%)		R 58,800
Total Cost of Construction		**R 352,800**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 161,013
	8%	R 75,693
	12%	R 36,574

Benchmark Scenario

Life Cycle Cost per Lane-Km for a Discount Rate of	4%	R 1,015,223
	8%	R 905,049
	12%	R 840,692

Scenario with More Durable Material

Life Cycle Cost per Lane-Km for a Discount Rate of	4%	R 1,001,115
	8%	R 885,931
	12%	R 829,696

Summary of Savings Per Lane-Km

Lane-Km Saving for More Durable Material	**4%**	**R 14,108**
	8%	**R 19,118**
	12%	**R 10,996**

Notes: 1. A lane width of 3.7 m is assumed, plus an effective shoulder width of 0.5 m. This effective lane width is 4.2 metres.
2. More durable material is more expensive, so than cost of initial rehabilitation is increased by 5 per cent

Figure 14: Savings per Lane-Km Realized if the Modified Material is more Durable

Cost Incurred if Modified Material Is NOT More Durable

Benchmark Scenario

Year	**0**	
Action: Initial Rehabilitation	**R / m²**	**R / lane-km**
Heavy Rehabilitation	R 145.00	R 609,000
Ancillary Works & Contingencies (20%)		R 121,800
Total Cost of Construction		**R 730,800**
Discounted Cost for Discount Rate of	4%	R 730,800
	8%	R 730,800
	12%	R 730,800

Year	**9**	
Action: Surface Maintenance	**R / m²**	**R / lane-km**
Surface Seal	R 25.00	R 105,000
Ancillary Works & Contingencies (20%)		R 21,000
Total Cost of Construction		**R 126,000**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 88,526
	8%	R 63,031
	12%	R 45,437

Year	**15**	
Action: Light Rehabilitation	**R / m²**	**R / lane-km**
Light Rehabilitation	R 70.00	R 294,000
Ancillary Works & Contingencies (20%)		R 58,800
Total Cost of Construction		**R 352,800**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 195,897
	8%	R 111,217
	12%	R 64,455

NOT More Durable Material

Year	**0**	
Action: Initial Rehabilitation	**R / m²**	**R / lane-km**
Heavy Rehabilitation	R 152.25	R 639,450
Ancillary Works & Contingencies (20%)		R 127,890
Total Cost of Construction		**R 767,340**
Discounted Cost for Discount Rate of	4%	R 767,340
	8%	R 767,340
	12%	R 767,340

Year	**9**	
Action: Surface Maintenance	**R / m²**	**R / lane-km**
Surface Seal	R 25.00	R 105,000
Ancillary Works & Contingencies (20%)		R 21,000
Total Cost of Construction		**R 126,000**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 88,526
	8%	R 63,031
	12%	R 45,437

Year	**15**	
Action: Light Rehabilitation	**R / m²**	**R / lane-km**
Light Rehabilitation	R 70.00	R 294,000
Ancillary Works & Contingencies (20%)		R 58,800
Total Cost of Construction		**R 352,800**
Discounted Cost per Lane-Km for Discount Rate of	4%	R 195,897
	8%	R 111,217
	12%	R 64,455

Benchmark Scenario

Life Cycle Cost per Lane-Km for a Discount Rate of	4%	R 1,015,223
	8%	R 905,049
	12%	R 840,692

Scenario with More Costly Modified Material

Life Cycle Cost per Lane-Km for a Discount Rate of	4%	R 1,051,763
	8%	R 941,589
	12%	R 877,232

Summary of Cost Per Lane-Km

Lane-Km Cost for More Expensive Material (NOT more durable)	**4%**	**R -36,540**
	8%	**R -36,540**
	12%	**R -36,540**

Note: 1. A lane width of 3.7 m is assumed, plus an effective shoulder width of 0.5 m. This effective lane width is 4.2 metres.
2. More durable material is more expensive, so than cost of initial rehabilitation is increased by 5 per cent

Figure 15: Cost per Lane-Km of Implementing a More Expensive Material that is NOT More Durable

Table 2: Network Wide Savings Realized if the Modified Material is More Durable

Discount Rate	4%		8%		12%	
Savings / Lane-Km	R 14,108		R 19,118		R 10,996	
Annual Km of 2 Lane Road Rehabilitated	Savings		Savings		Savings	
	Annual	Total Discounted Over 10 Years	Annual	Total Discounted Over 10 Years	Annual	Total Discounted Over 10 Years
100	R 846,484	R 7,140,375	R 1,147,077	R 8,312,736	R 659,782	R 4,175,268
150	R 1,269,726	R 10,710,563	R 1,720,615	R 12,469,104	R 989,674	R 6,262,902
200	R 1,692,968	R 14,280,750	R 2,294,153	R 16,625,472	R 1,319,565	R 8,350,535
250	R 2,116,211	R 17,850,938	R 2,867,692	R 20,781,840	R 1,649,456	R 10,438,169
300	R 2,539,453	R 21,421,125	R 3,441,230	R 24,938,208	R 1,979,347	R 12,525,803
350	R 2,962,695	R 24,991,313	R 4,014,768	R 29,094,576	R 2,309,238	R 14,613,437
400	R 3,385,937	R 28,561,500	R 4,588,307	R 33,250,944	R 2,639,130	R 16,701,071
450	R 3,809,179	R 32,131,688	R 5,161,845	R 37,407,312	R 2,969,021	R 18,788,705
500	R 4,232,421	R 35,701,875	R 5,735,383	R 41,563,680	R 3,298,912	R 20,876,339
550	R 4,655,663	R 39,272,063	R 6,308,922	R 45,720,048	R 3,628,803	R 22,963,972
600	R 5,078,905	R 42,842,250	R 6,882,460	R 49,876,417	R 3,958,694	R 25,051,606
650	R 5,502,147	R 46,412,438	R 7,455,998	R 54,032,785	R 4,288,585	R 27,139,240

Key Assumptions
Percentage projects on which new technology is applied = 30%
Period over which savings are added = 10 Years

Table 3: Network Wide Cost of Implementing a More Expensive Material that is NOT More Durable

Discount Rate	4%		8%		12%	
Cost / Lane-Km	-R 36,540		-R 36,540		-R 36,540	
Annual Km of 2 Lane Road Rehabilitated	Savings		Savings		Savings	
	Annual	Total Discounted Over 10 Years	Annual	Total Discounted Over 10 Years	Annual	Total Discounted Over 10 Years
100	R -2,192,400	R -18,493,621	R -2,192,400	R -15,888,077	R -2,192,400	R -13,874,055
150	R -3,288,600	R -27,740,432	R -3,288,600	R -23,832,116	R -3,288,600	R -20,811,082
200	R -4,384,800	R -36,987,242	R -4,384,800	R -31,776,154	R -4,384,800	R -27,748,110
250	R -5,481,000	R -46,234,053	R -5,481,000	R -39,720,193	R -5,481,000	R -34,685,137
300	R -6,577,200	R -55,480,863	R -6,577,200	R -47,664,231	R -6,577,200	R -41,622,165
350	R -7,673,400	R -64,727,674	R -7,673,400	R -55,608,270	R -7,673,400	R -48,559,192
400	R -8,769,600	R -73,974,484	R -8,769,600	R -63,552,308	R -8,769,600	R -55,496,219
450	R -9,865,800	R -83,221,295	R -9,865,800	R -71,496,347	R -9,865,800	R -62,433,247
500	R -10,962,000	R -92,468,105	R -10,962,000	R -79,440,385	R -10,962,000	R -69,370,274
550	R -12,058,200	R -101,714,916	R -12,058,200	R -87,384,424	R -12,058,200	R -76,307,302
600	R -13,154,400	R -110,961,726	R -13,154,400	R -95,328,462	R -13,154,400	R -83,244,329
650	R -14,250,600	R -120,208,537	R -14,250,600	R -103,272,501	R -14,250,600	R -90,181,356

Key Assumptions
Percentage projects on which new technology is applied = 30%
Period over which savings are added = 10 Years

Table 4: Payoff Table for Consideration to Use a More Expensive Modified Material

Situation	Prior Proba-bility	Cost of Decision To:		Expected Payoff for Implimentation
		Implement Modified Material on Network	NOT Implement Modified Material on Network	
More Expensive Modified Material is NOT More Durable	**0.4**	- R 63 million (see Table 3)	R 0 (no change in status quo)	**- R 25.2 million**
More Expensive Modified Material IS More Durable	**0.6**	R 33 million (see Table 2)	R 0 (no change in status quo)	**R 19.8 million**
Net Expected Payoff (NEP) for Implementation				**- R 5.4 million**

To simplify the calculations, a fixed discount rate of 8 per cent was selected, and costs and savings are those for a network that will require 400 km of rehabilitation per year. The costs and savings shown in Table 4 are thus those for an 8 per cent discount rate, and for the row highlighted in Tables 2 and 3.

A key element of the payoff table is the assignment of a “prior probability” to each consequence. This probability is a subjective estimate (usually made by a person experienced in the field of application) of the likelihood of each consequence transpiring. In this case, the indicator laboratory test data showed that the material is promising, and because of this, a prior probability of 60 per cent was assigned to the possibility that the material will indeed increase the durability of the asphalt surfacing by an average of 5 years.

The net expected payoff in Table 4 shows that, despite the initial indications that the modified material is more durable (and therefore more cost effective), the net payoff is negative, which indicates that, on average, the network wide use of the modified material is likely to be more expensive. Based on the costs and assigned probabilities in the payoff table, a client would typically prefer not to implement the new material on the network, but would rather implement a pilot study with long term monitoring. This approach will effectively nullify any potential savings whilst the pilot project monitoring is in progress, but it will also minimize the risk of unnecessary costs.

The Expected Value of Perfect Information (EVPI)

Consider now the situation where the client has the opportunity to perform full scale Accelerated Pavement Testing with additional laboratory testing of the new material. Consider further that such a technology development program will take one year to complete at a total cost of R4 million, which is the current (2004) budget allocated to the Gautrans HVS technology development programme. Given the situation and costs outlined in the preceding paragraphs, would it be cost effective for the client to undertake such a test programme? The concept of Expected Value of Perfect Information (EVPI) allows a rational evaluation of this question. To evaluate the EVPI, we re-evaluate the payoff table (Table 4) by taking into account the decisions that a client would make *if perfect information regarding the performance of the modified material was available*.

Table 5 shows the modified payoff table for the case that perfect information is available to assist in making the decision as to whether the modified material should be implemented on a network wide basis or not. Thus, if the technology development programme shows the material is not as durable as was initially claimed, the client, who would now have this information, will NOT implement the material on the network. If the tests confirm the durability of the material, the material will be implemented on appropriate projects across the network (assumed to be 30 per cent of rehabilitation work undertaken).

Table 5: Payoff Table with Perfect Information

Situation	Prior Proba-bility	Cost of Decision To:		Option That Will Be Selected With Perfect Information	Maximized Payoff
		Implement Modified Material on Network	NOT Implement Modified Material on Network		
More Expensive Modified Material is NOT More Durable	**0.4**	- R 63 million (see Table 4)	R 0 (no change in status quo)	**Do Not Implement Modified Material**	**R 0 million**
More Expensive Modified Material IS More Durable	**0.6**	R 33 million (see Table 4)	R 0 (no change in status quo)	**Implement Modified Material**	**R 19.8 million**
Net Expected Payoff With Perfect Information (NEPPI)					**R19.8 million**

The <u>Expected Value of Perfect Information (EVPI)</u> can now be calculated as follows (Lapin, 1983):

EVPI = NEPPI (Table 5) – NEP (Table 4) = [R 19.8 million] – [- R5.4 million]

= **R 25.2 million**

The EVPI is a valuable indicator of the average economic benefit of a test program such as that used in this example (i.e. one-year HVS technology development test program to evaluate the proposed modified material). This is because the EVPI shows, on average, what the economic benefit would be of having perfect information to drive the decision process.

Naturally no test program provides perfect information, but the EVPI sets the threshold against which the cost of an information gathering process can be evaluated (Lapin, 1983). Obviously, if the cost of gathering information (which is likely to be imperfect) is close to or more than the EVPI, then the proposal to perform the tests should be rejected. If, however, the cost of testing is significantly less than the EVPI, then the test programme can be regarded as highly cost effective.

In the case of the present example, the EVPI (i.e. R25.2 million) is roughly six times more than the cost of gathering the information (i.e. R 4 million). Thus for this example, gathering information regarding the durability of the modified asphalt can be expected to yield a high economic benefit. *It is very important to note that the principle of the EVPI evaluates this benefit regardless of the outcome of the test*.

As noted by Lapin (1983), the absolute level of the EVPI is in itself a valuable indicator. A relatively low EVPI suggests that gathering additional information to assist in the decision making process will not be of great benefit, and the decision process in such a case would be better driven by experience and currently available information. However, a relatively high EVPI suggests that it would definitely be cost effective to gather as much information as possible before the decision is made. A large EVPI thus indicates that a significant improvement can be expected if the decision is deferred until an exhaustive investigation is completed. In the case of the example considered here, the absolute value of the EVPI is regarded as being relatively high, which thus suggests that a one year technology development program at a cost of R4 million would definitely yield economic benefits over the medium term (10 years) considered.

4.8 SUMMARY AND CONCLUSIONS

SUMMARY

This section presented a general evaluation of the typical direct economic benefits that can be expected from a technology development project such as the Gautrans HVS programme. It was shown that the benefits that can be derived from technology development projects related to the roads industry generally fall into the following three impact categories:

1. Optimized materials and pavement design, which lead to reduced construction costs;

2. More reliable design and maintenance practices, which reduces the likelihood of costly early failures, and

3. More cost effective materials and pavement design, which optimizes the time between interventions and reduces pavement life cycle costs.

An economic evaluation was performed to assess the direct economic benefits that can be derived from each of the above three impacts. This evaluation was performed by means of two approaches. These were

1. A conventional life cycle cost comparison approach in which a benchmark case - without the benefit of technology development findings - was compared to an improved alternative which incorporated the impacts of a technology development project.

2. An approach which incorporated Bayesian statistics and is aimed at evaluating the value of information that can assist in making decisions which have economic impacts.

CONCLUSIONS: LIFE CYCLE COST COMPARISON APPROACH

Generalized examples of each impact type were presented and discussed. In all cases, the economic benefit of the impact was calculated over a period of 10 years. This benefit was then compared to the cost of a typical HVS technology development project lasting two years, and with a total cost of R 8 million. The examples considered in this section present a generalized approach for evaluating economic benefits from technology development projects like the Gautrans HVS programme.

For each example, an outline of the example situation was provided, and key assumptions were listed. The example calculations were then shown and discussed. It was noted that certain subjective assumptions had a significant impact on the calculated economic benefits. However, since all calculations were shown explicitly, the interested reader could easily re-construct the calculations using a spreadsheet, and then re-evaluate the benefits using different assumptions.

The examples that were evaluated for each of the three impacts showed very similar results. In all three examples, the findings were as follows:

- For the stated assumptions, any network on which more than 150 km of road is rehabilitated per annum will have a benefit cost ratio in excess of 1.0.
- For a network such as that operated by Gautrans, the calculations suggest that, for each of the three impacts, Gautrans will realize a benefit-cost ratio of 1.6 or more, with a total discounted saving over a 10 year period of between R12 million and R16 million per impact, depending on the discount rate.
- All three examples show that, if the impacts are considered in isolation, then a benefit-cost ratio of 2.0 or more will be realized for any road network that requires roughly 320 km of rehabilitation work per year. For larger networks that require in excess of 500 km of rehabilitation per year, the expected return on the technology investment will be roughly between R25 million and R33 million per impact, which – for the assumed development costs - equates to a return of three Rand for every one Rand invested in technology development.

In the three examples, the benefits of each impact were evaluated in isolation. This effectively implies that the impact considered in each example is the only significant finding of the assumed two year development project. However, HVS technology development projects have often resulted in findings that have related to more than one of the impacts listed above. The total expected benefits can therefore be expected to be much higher than those that are evaluated for an impact in isolation.

If two or more impacts are combined (i.e. if two impacts arise from the same technology development project), then there is a significant increase in the savings and benefit-cost ratios. For example, if a two year technology development project resulted in findings that lead to more cost effective materials as well as more reliable designs, then the combined savings for a network such as that operated by Gautrans would be between R 24 million and R36 million, depending on the discount rate assumed. For a technology development project with a cost of R8 million, these savings would result in a benefit-cost ratio of between 3.0 and 4.5. For a larger network that rehabilitates roughly 500 km of roads per year, the savings and benefit-cost ratios would be doubled (i.e. benefit cost ratios of 6.0 to 9.0 would apply).

CONCLUSIONS: VALUE OF INFORMATION APPROACH

The concept of the Expected Value of Perfect Information (EVPI) was presented. This concept stems from Bayesian statistics and can be used assess the relative value of information that is used to drive decisions that will have an economic impact (Lapin, 1983). An example was used to illustrate the expected value information that could assist a roads agency in the decision to either implement or disregard a network wide implementation of a new pavement technology.

The EVPI example used inputs and assumptions that are based on actual costs, and assume that information – relevant and significant to the decision making process – would be provided by a one-year HVS technology development project. The example clearly showed that, for the assumed decision making scenario, the EVPI was in excess of R25 million. When this relatively high EVPI is compared to the cost of gathering the information (estimated at roughly R 4 million), it is clear that a substantial economic benefit could be derived from the information that would be provided by the technology development project.

The concept of EVPI provides a rational way of evaluating the value of information that would typically stem from the Gautrans HVS programme. For the example considered, the EVPI indicates that significant economic benefit could be derived from technology development projects such as the Gautrans HVS programme. This benefit arises mainly from the relatively large scale on which benefits can be realized for a typical road network.

5 DIRECT ECONOMIC BENEFITS: SPECIFIC PROJECTS

5.1 INTRODUCTION

The preceding section presented an assessment of the direct economic benefits that derive from technology development projects in the road sector. This assessment used a generalized approach, together with illustrative examples, to show how economic benefits stemming from technology development work in the road section could be evaluated. By contrast to the generalized approach of the preceding section, this section presents an assessment of direct benefits stemming from two specific HVS projects. For the first project, which involved HVS testing on G1 base pavements, a detailed assessment of economic benefits was performed. Results of this assessment – which pertain to a well-established and mature technology - are summarized in Section 5.1. For the second HVS project, which involved Foamed Bitumen base pavements, only the key findings are presented and potential economic impacts are highlighted (Section 5.2).

5.2 BENEFITS FROM G1 DEVELOPMENT EFFORTS

A detailed evaluation of the economic benefits arising from the development work on the Crushed Stone material known as G1 material was performed. This evaluation is documented in detail in Jooste and Sampson (2004). Key elements of this evaluation are summarized in this section.

HISTORICAL BACKGROUND

- The development of the technology for the design and construction of G1 base pavements was an extended process which was partly initiated by the former Transvaal Roads Department (TRD).
- Before the HVS investigations on G1 base pavements were conducted (between 1978 and 1982), there was considerable controversy over the structural capacity boundaries within which G1 base pavements could be expected to perform well. At the time there was doubt whether G1 base pavements could be used for the higher traffic loading applications (specifically, but not exclusively, the 12 to 50 Million Standard Axle (MISA) traffic category).
- The development of HVS technology was classified into two phases. These were: (i) a basic technology development phases from the early 1960's to roughly 1978, and (ii) a validation and refinement phase (1978 to 1985), in which the HVS played a pivotal role.
- There were several contributors to the successful implementation of G1 technology, as shown in Figure 16. The HVS development programme was one of these contributors, and played an important role in validating the earlier analytical work of Maree (1978) and others. It also provided an organized structure to the documenting and validation of the performance of G1 base pavements.

TECHNICAL IMPACTS

The key impacts of HVS investigations on G1 base pavements were identified as:

- The suitability for G1 base pavements for the 12 to 50 MESA design class was clearly proven;
- The feasibility of G1 base pavements in wet regions was proven (provided an impervious surfacing could be maintained);
- It was found that the damage exponent (or n-value) of pavements with a G1 base over a thick cemented subbase was close to 3, and not 4.2, as was commonly assumed;
- It was proven that a 150 mm thick G1 layer is optimal for G1 base layers;
- The difference between the high quality G1a, and lower quality G1b or G2 material was clearly shown;

CONTRIBUTION OF HVS INVESTIGATIONS

As shown in Figure 16, the assimilated finding of the HVS investigations was only one of the contributors to the successful implementation of G1 technology. Thus, in keeping with the best practice elements of benefit assessment presented in Section 3 (also presented in more detail in Jooste et al., 2004), any evaluation of economic benefits should take into account the relative contribution of other development phases and role players.

For each of the identified impacts, a relative contribution percentage was therefore assigned. This contribution ratio generally varied from approximately 30 per cent (for impacts in which the HVS investigations played a lesser role) to 80 per cent (for impacts in which HVS investigations played a decisive role).

Before the economic evaluation was performed, each of the impacts noted above, together with their assigned contribution ratios, were validated through interviews with acknowledged industry experts. Adjustments to the ranges of assigned contribution ratios were then made based on the findings of these interviews.

DIRECT ECONOMIC BENEFITS

After consideration of the identified impacts (and specifically of the data and assumptions needed to convert the impacts to economic benefits) it was decided to combine the identified impacts into the following three main benefits:

<u>Benefit 1:</u> Increased use of G1 Base Pavements for higher design classes and wet regions;

<u>Benefit 2:</u> Use of 150 mm thickness for G1 base layers, and

<u>Benefit 3:</u> Improved maintenance and construction practices.

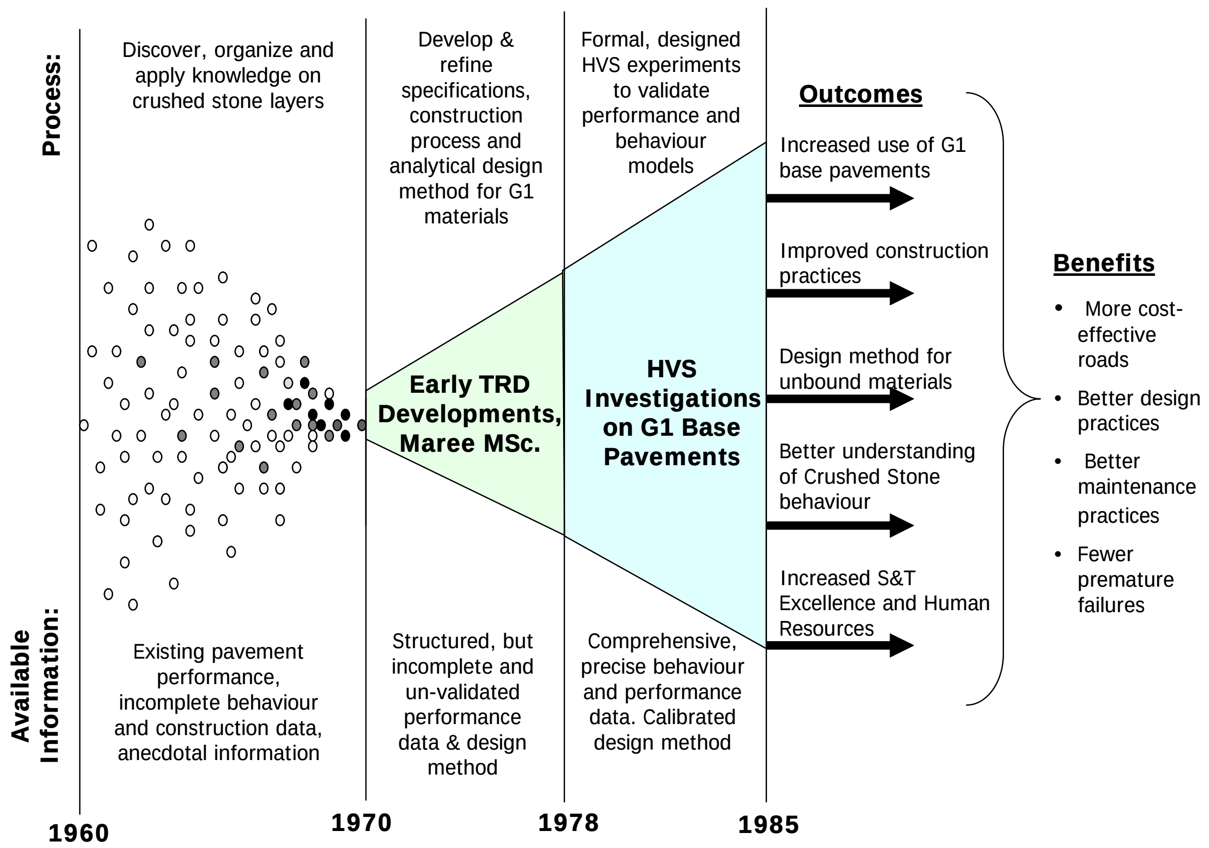


Figure 16: The contribution of HVS Investigations to the development of G1 technology (concept after Ounjian and Carne, 1987; and Horak et al, 1992)

The savings derived from these three benefits are summarized in Figure 17 to Figure 20. In essence, this assessment used a probabilistic approach to aggregate the likely unit savings that typically resulted from the above three benefits. Details of the assumptions and methodology can be found in Jooste and Sampson (2004). The overall savings were calculated for the Gautrans and SANRAL networks, by using the unit cost savings which were scaled to an absolute savings value. This scaling of benefits used the total lane-km of G1 base pavements constructed by Gautrans and SANRAL in the period between 1980 and 1990. The assessment of economic benefits showed the following:

- The overall benefit cost ratio (i.e. for Gautrans and SANRAL) varies from 2.4 to 6.1, depending on the contribution ratio and discount rate selected. For a nominal discount rate of 8 per cent, the overall benefit cost ratio varies between 2.9 and 5.1, depending on the contribution ratio selected. This range of estimated benefit cost ratios is similar to the range of 3.8 to 4.9 reported for accelerated pavement testing performed in Australia (ARRB, 1992).

Benefit Summary for Gautrans Investment in HVS Investigations on G1 Base Pavements

Benefit	Lower Contribition Ratio				Higher Contribution Ratio			
	Contribution Ratio	Discount Rate of 4%	Discount Rate of 8%	Discount Rate of 12%	Contribution Ratio	Discount Rate of 4%	Discount Rate of 8%	Discount Rate of 12%
Increased use of G1 Base Pavements	50%	R 535,117	R 410,881	R 318,534	80%	R 856,187	R 657,409	R 509,654
Increased use of 150 mm Thick G1 Layers	20%	R 55,267	R 42,436	R 32,898	30%	R 82,900	R 63,653	R 49,347
Improved Maintenance and Construction Practices	30%	R 183,504	R 140,900	R 109,233	60%	R 367,007	R 281,801	R 218,465
Total Benefit (in 1978 Rand):	**N/A**	**R 773,887**	**R 594,217**	**R 460,665**	**N/A**	**R 1,306,094**	**R 1,002,863**	**R 777,467**
Total Cost (in 1978 Rand):	**N/A**	**R 358,261**	**R 340,669**	**R 324,813**	**N/A**	**R 358,261**	**R 340,669**	**R 324,813**
Benefit: Cost Ratio	**N/A**	**2.2**	**1.7**	**1.4**	**N/A**	**3.6**	**2.9**	**2.4**
Total Benefit (in 2004 Rand):	**N/A**	**R 2,145,579**	**R 4,395,036**	**R 8,771,091**	**N/A**	**R 3,621,107**	**R 7,417,530**	**R 14,803,024**

Benefit Summary for SANRAL Investment in HVS Investigations on G1 Base Pavements

Benefit	Lower Contribition Ratio				Higher Contribution Ratio			
	Contribution Ratio	Discount Rate of 4%	Discount Rate of 8%	Discount Rate of 12%	Contribution Ratio	Discount Rate of 4%	Discount Rate of 8%	Discount Rate of 12%
Increased use of G1 Base Pavements	50%	R 488,451	R 375,049	R 290,756	80%	R 781,522	R 600,079	R 465,209
Increased use of 150 mm Thick G1 Layers	20%	R 85,307	R 65,501	R 50,780	30%	R 127,960	R 98,252	R 76,169
Improved Maintenance and Construction Practices	30%	R 656,590	R 504,152	R 390,842	60%	R 1,313,179	R 1,008,303	R 781,684
Total Benefit (in 1978 Rand):	**N/A**	**R 1,230,347**	**R 944,702**	**R 732,378**	**N/A**	**R 2,222,661**	**R 1,706,634**	**R 1,323,063**
Total Cost (in 1978 Rand):	**N/A**	**R 218,277**	**R 194,911**	**R 174,765**	**N/A**	**R 218,277**	**R 194,911**	**R 174,765**
Benefit: Cost Ratio	**N/A**	**5.6**	**4.8**	**4.2**	**N/A**	**10.2**	**8.8**	**7.6**
Total Benefit (in 2004 Rand):	**N/A**	**R 3,411,101**	**R 6,987,351**	**R 13,944,522**	**N/A**	**R 6,162,261**	**R 12,622,867**	**R 25,191,213**

Benefit Summary for Combined Gautrans and SANRAL Investment in HVS Investigations on G1 Base Pavements

Benefit	Lower Contribition Ratio				Higher Contribution Ratio			
	Contribution Ratio	Discount Rate of 4%	Discount Rate of 8%	Discount Rate of 12%	Contribution Ratio	Discount Rate of 4%	Discount Rate of 8%	Discount Rate of 12%
Increased use of G1 Base Pavements	50%	R 1,023,568	R 785,930	R 609,290	80%	R 1,637,709	R 1,257,488	R 974,864
Increased use of 150 mm Thick G1 Layers	20%	R 140,573	R 107,937	R 83,678	30%	R 210,860	R 161,905	R 125,517
Improved Maintenance and Construction Practices	30%	R 840,093	R 645,052	R 500,075	60%	R 1,680,187	R 1,290,104	R 1,000,149
Total Benefit (in 1978 Rand):	**N/A**	**R 2,004,235**	**R 1,538,919**	**R 1,193,042**	**N/A**	**R 3,528,755**	**R 2,709,497**	**R 2,100,530**
Total Cost (in 1978 Rand):	**N/A**	**R 576,538**	**R 535,580**	**R 499,578**	**N/A**	**R 576,538**	**R 535,580**	**R 499,578**
Benefit: Cost Ratio	**N/A**	**3.5**	**2.9**	**2.4**	**N/A**	**6.1**	**5.1**	**4.2**
Total Benefit (in 2004 Rand):	**N/A**	**R 5,556,680**	**R 11,382,386**	**R 22,715,611**	**N/A**	**R 9,783,368**	**R 20,040,396**	**R 39,994,235**

Note: Discount rate is applied in converting savings (which are in terms of 1985 Rand) to 1978 Rand and to 2004 Rand

Figure 17: Summary of Benefits Derived from HVS Investigations on G1 Base Pavements

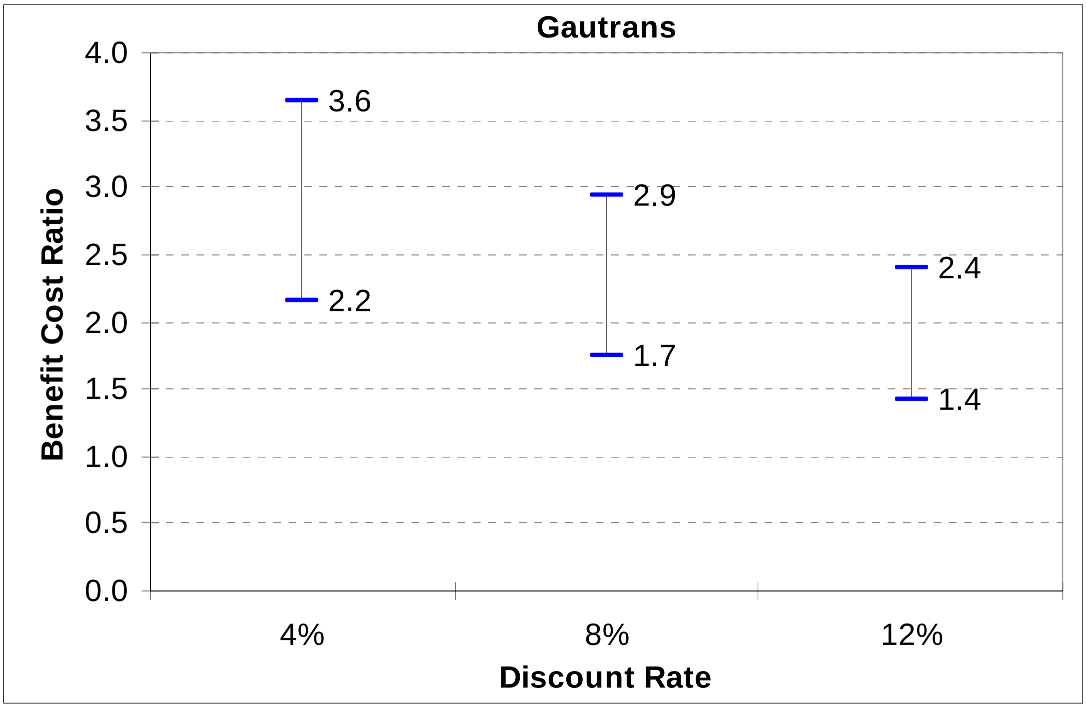


Figure 18: Summary of Likely Benefit Cost Ratio Ranges for Gautrans

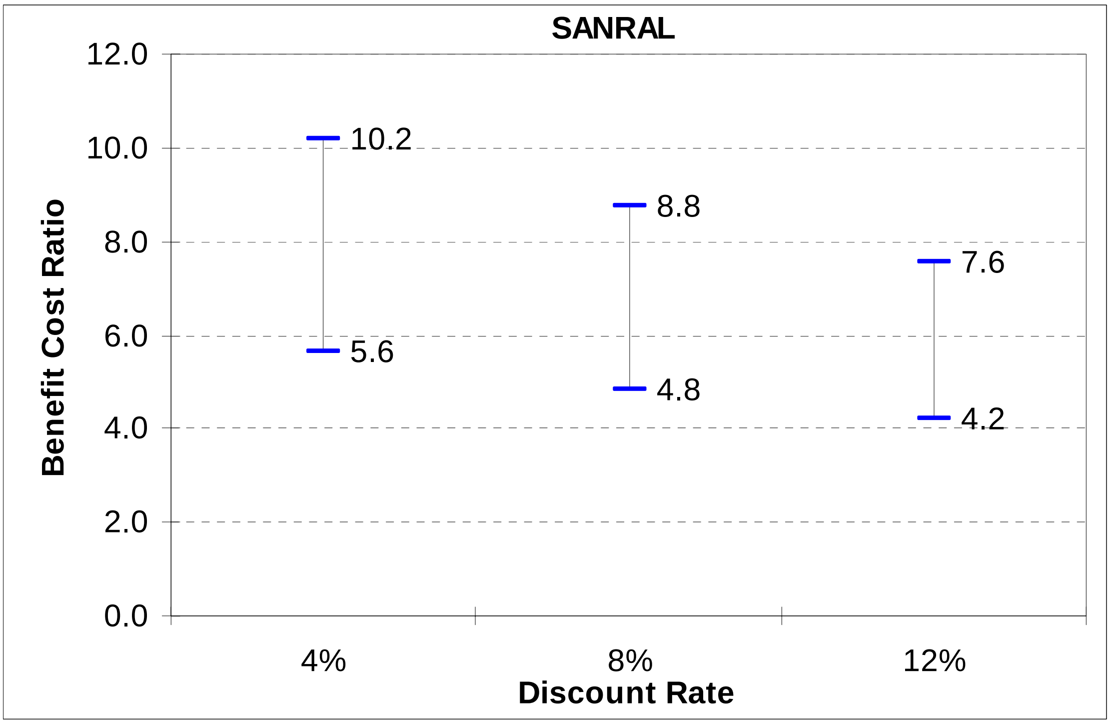


Figure 19: Summary of Likely Benefit Cost Ratio Ranges for SANRAL

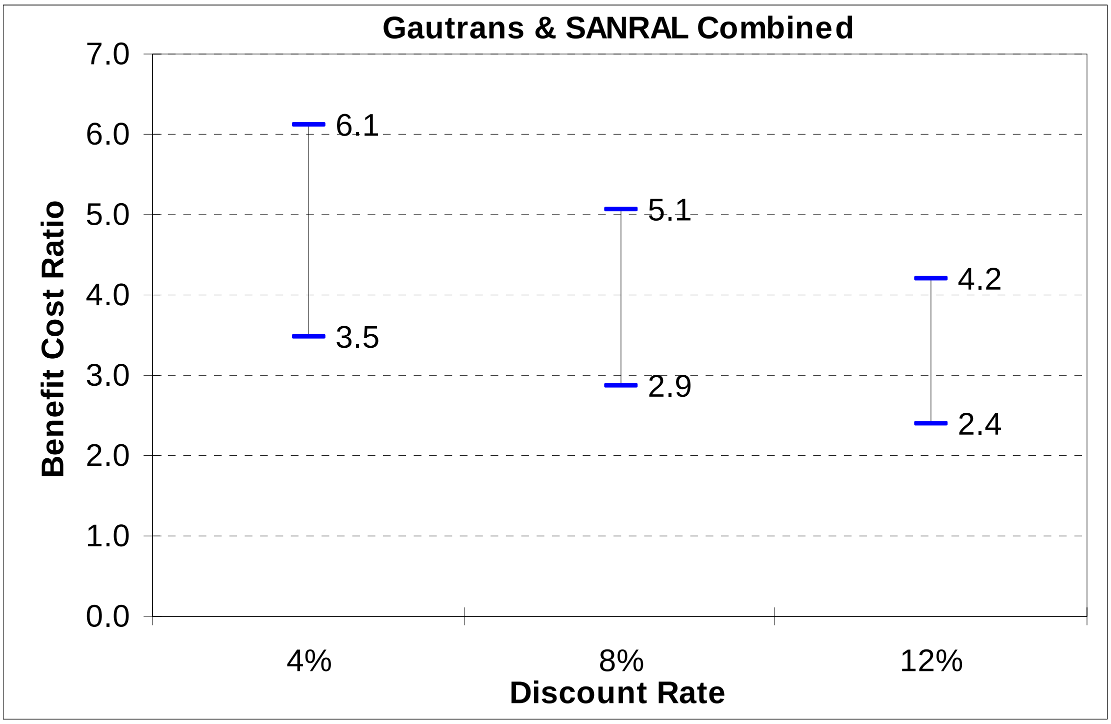


Figure 20: Summary of Likely Benefit Cost Ratio Ranges for Combined Gautrans and SANRAL Contributions

- For Gautrans, the estimated direct benefit derived between 1980 and 1990 from the HVS investigations on G1 base pavements is roughly between R 2.2 and R 14.8 million (in 2004 Rand terms). Taking into account the contribution made by Gautrans to the funding of HVS investigations on G1 pavements, this results in a benefit cost ratio of between 1.4 and 3.6, depending on the discount rate and contribution ratio selected.

- For SANRAL, the estimated direct benefit is roughly between R 3.4 and R 25.2 million (in 2004 Rand terms). This results in a benefit cost ratio of between 4.2 and 10.2. This benefit cost ratio is higher than that realized by Gautrans, mainly because of the greater scaling of benefits provided by the larger SANRAL pavement network.

It should be noted that the lower bound of these benefit cost ratios shown in Figure 18 to Figure 20 represent a total which consists of the sum of all the lowest estimated contribution ratios. Thus the lower limit of the calculated benefit cost ratios represents a highly conservative estimate.

It is also important to note that the benefits that were evaluated include only those aspects which could be converted to economic savings with reasonable confidence and assumptions. There are several other benefits resulting from the HVS investigations on G1 base pavements, which cannot easily be converted to economic savings, yet are sure to impact positively on the Gautrans and SANRAL budgets and networks over the long term. These benefits include aspects such as:

- Calibration of the South African mechanistic design method;
- Technology transfer to local and international practitioners which raised the technical competence of designers working for Gautrans and SANRAL;
- Improved understanding of the systems behaviour of granular base pavements, and particularly the interaction between the granular base and cemented subbase.
- Improved understanding of the behaviour of cemented subbase layers under loading. This led to further research into the behaviour and performance of cemented layers.

Since none of these impacts are included in the assessment of economic benefits, it will be appreciated that the above noted benefit-cost ratios represent a lower bound estimate of the benefits of HVS investigations on G1 base pavements. As suggested by Scott et al (2002), the simple linear benefit assessment process that was followed in this study fails to take into account the further downstream benefits and the impact of these benefits on the population at large. This means that the benefit assessment summarized in this section probably greatly underestimates the true benefit stemming from the HVS investigations on G1 base pavements.

5.3 BENEFITS FROM FOAMED BITUMEN DEVELOPMENT EFFORTS

BACKGROUND

The use of foamed bitumen to treat and improve the properties of existing pavement materials has increased significantly in South Africa during the past decade.♣ The process of creating foamed bitumen treated materials involves adding foamed bitumen to existing pavement layer materials as part of a cold recycling process (i.e. the aggregates are not heated during mixing process). The pavement layers used in foamed bitumen treatment typically includes the surfacing and base layers, but can also include part of the existing subbase.

The foamed bitumen is created by injecting water into hot bitumen. This temporarily creates a foam that can be readily mixed into the aggregate during the recycling process. The foamed bitumen typically adheres to the finer particles. The foamed bitumen, together with an active filler such as cement, increases the strength and reduces the moisture susceptibility of the recycled pavement materials.

In certain situations, the use of the foamed bitumen process offers significant advantages over conventional pavement rehabilitation approaches. A key advantage of the foamed bitumen process lies in the environmental advantages associated with the recycling of existing pavement materials, and with the relatively low pollution associated with the process. The recycling process also minimizes traffic disruption and road user costs.

♣ For a more detailed discussion of the Foamed Bitumen process, as well as advantages and disadvantages of Foamed Bitumen Treated Materials, please refer to the TG2 Guidelines which deals with the Design and Use of Foamed Bitumen Treated Materials (Asphalt Academy, 2002).

HVS TESTING ON FOAMED BITUMEN TREATED MATERIALS

Owing to the obvious advantages of the foamed bitumen recycling process, practitioners showed interest in this process in South Africa and the process has been used with success on various minor roads for several years. However, before the start of the HVS project, it was felt that the design method used for foamed bitumen treated projects simply adopted the approach and specifications for bitumen-emulsion or lightly-cemented materials. Thus a need was identified to develop guidelines, together with a mix and pavement design methodology, specific to foamed bitumen treated materials. To this end, Gautrans initiated an HVS test programme, together with an extensive laboratory testing project. These tests were conducted between 2000 and 2004 (some laboratory tests are still in progress at the time of writing [November, 2004]).

The key objectives of the HVS and laboratory test programme were:

- To determine the deterioration and distress pattern for pavements with foamed bitumen treated layers;
- To evaluate the structural capacity of foamed bitumen treated materials;
- To develop transfer functions for foamed bitumen treated materials, to be used in the mechanistic-empirical design method;
- To quantify the effects of load, different binder and filler contents as well as different aspects of material behaviour;
- To develop models to evaluate permanent deformation behaviour as well as shear and flexural strength properties of foamed bitumen treated materials.

KEY TECHNICAL FINDINGS OF THE TEST PROGRAMME

To date, the key findings and deliverables that emerged from the test programme on foamed bitumen treated materials were:

- It was confirmed that recycling with foamed bitumen treatment reduces the sensitivity of the material to moisture and density;
- Permanent deformation accumulated at a low rate on well-designed foamed bitumen treated materials - especially when in a dry state.
- Despite the decreased sensitivity to moisture and density of foamed bitumen treated materials, the test programme showed that the material can fail prematurely at low density and high moisture saturation levels.
- It was found that traditional material strength indicators such as Unconfined Compressive Strength (UCS) and Indirect Tensile Strength (ITS) were not always appropriate to evaluate the benefits of foamed bitumen treatment. The real benefit of foamed bitumen treatment seems to inhere in the increase in long term durability which is not always properly evaluated with conventional strength indicators;

- A balance between the bitumen and cement content is essential to ensure both flexibility and resistance to permanent deformation. Too much bitumen or cement effectively nullifies the benefit of the other, leading to wasted costs. It was specifically found that too much cement renders the bitumen ineffective.

- It was found - owing to the short time available before the foamed bitumen collapses to a normal bitumen state - that traditional laboratory mixers are too slow to effectively simulate the field mixing process. Because of this finding, a high speed laboratory mixer was specifically developed for the laboratory design of foamed bitumen treated materials;

- The HVS and laboratory tests yielded typical material stiffness and strength parameters that can be used as inputs for the mechanistic-empirical design method;

- Structural capacity evaluation models (i.e. Transfer Functions) were developed to evaluate the structural capacity of pavement layers treated with foamed bitumen;

- Classes of foamed bitumen treated material were identified and defined. These classes provide practitioners with an easy way to group foamed bitumen treated materials into classes from which similar behaviour and performance can be expected;

- A design catalogue and design approach was developed for pavements that incorporate foamed bitumen treated materials. This catalogue and methodology has since been published in the TG2 guidelines (Asphalt Academy, 2002).

KEY IMPACTS OF THE TEST PROGRAMME

Based on interviews with the principal investigators on the foamed bitumen test programme, it was established that the findings of the programme and the information dissemination process had the following impacts on the southern African road building industry:

- Better understanding of the relative contributions or roles of bitumen and cement. In particular, the development work showed that too much cement nullifies the effect of bitumen. This has lead to improved project specifications. The emphasis on obtaining a balance between the cement and binder contents prevents materials waste.

- The development of a materials classification approach, together with the understanding of differences in behaviour and performance of different materials classes, ensure that materials are appropriately designed for specific situations. This leads to more cost effective and reliable designs;

- An improved laboratory mix design procedures (including the development of a new high speed mixer) which ensures a better agreement between materials prepared in the laboratory and the field. This leads to optimized mixes and minimizes the risk of premature failure owing to inappropriate materials design;

- The development of structural design models for use in the mechanistic-empirical design method, combined with a design catalogue (as part of the TG2 Guidelines), ensure optimized and reliable designs using Foamed Bitumen materials.

BENEFITS OF THE TEST PROGRAMME ON FOAMED BITUMEN TREATED MATERIALS

The HVS programme and associated laboratory tests have significantly accelerated understanding of the behaviour and performance of Foamed Bitumen Treated Materials. Without this accelerated knowledge gain, practitioners would have had to learn from failures. The technology would have progressed at a much reduced pace and in a fragmented fashion. As a result of the technology development programme on foamed bitumen treated materials, assimilation of knowledge in the industry was considerably enhanced and accelerated. This factor, together with the technical impacts noted above, translates to the following three benefits:

Benefit 1: More cost-effective design of foamed bitumen treated *materials*;

Benefit 2: More cost-effective design of *pavements* incorporating foamed bitumen treated materials;

Benefit 3: More *reliable* design of pavements incorporating foamed bitumen treated materials;

Conceptual frameworks for evaluating economic returns from these benefits are shown in Figure 21 to Figure 23. In these figures, the term DISR (deep in situ recycling) is used to represent the foamed bitumen treatment process.

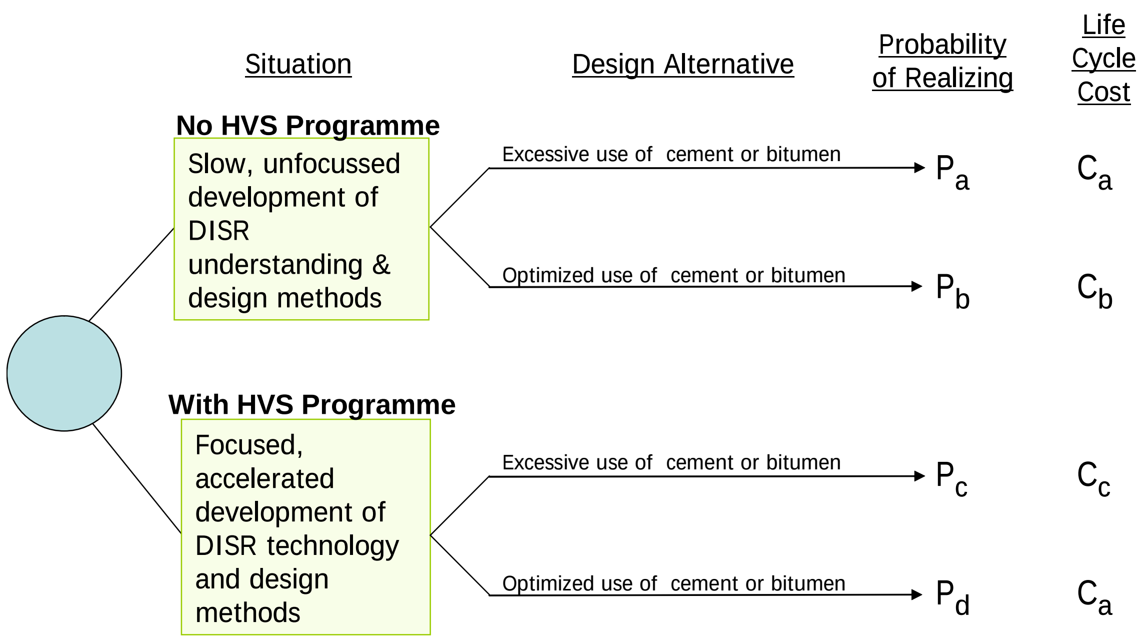


Figure 21: Framework for Assessing Benefits Arising From More Cost-Effective Design of Foamed Bitumen Treated Materials.

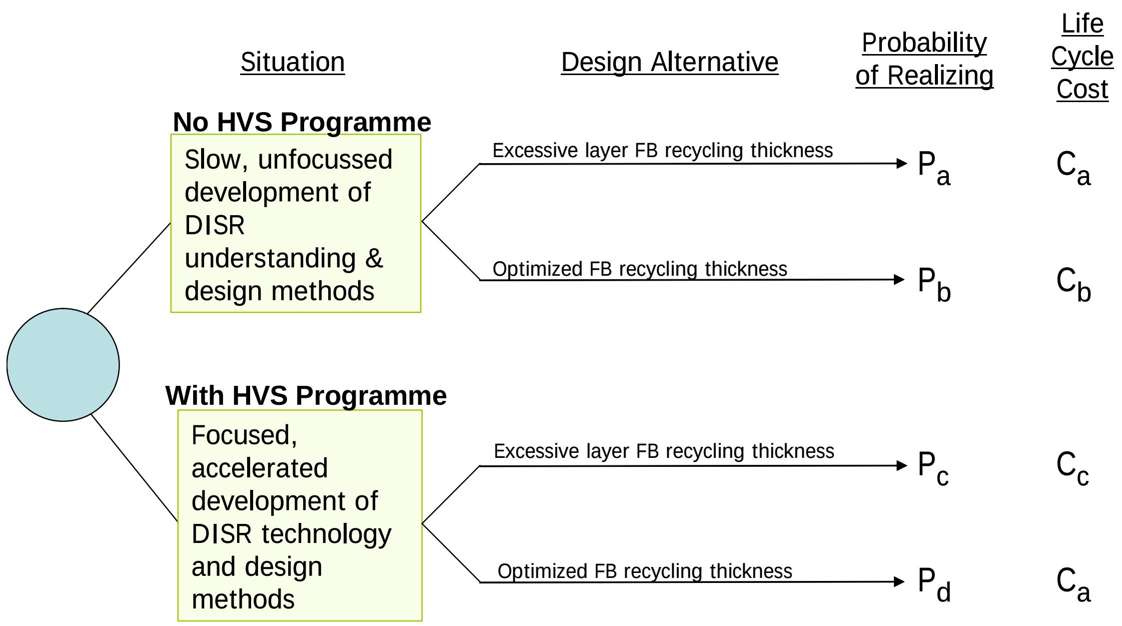


Figure 22: Framework for Assessing Benefits Arising From More Cost-Effective Design of Pavements Incorporating Foamed Bitumen Treated Materials.

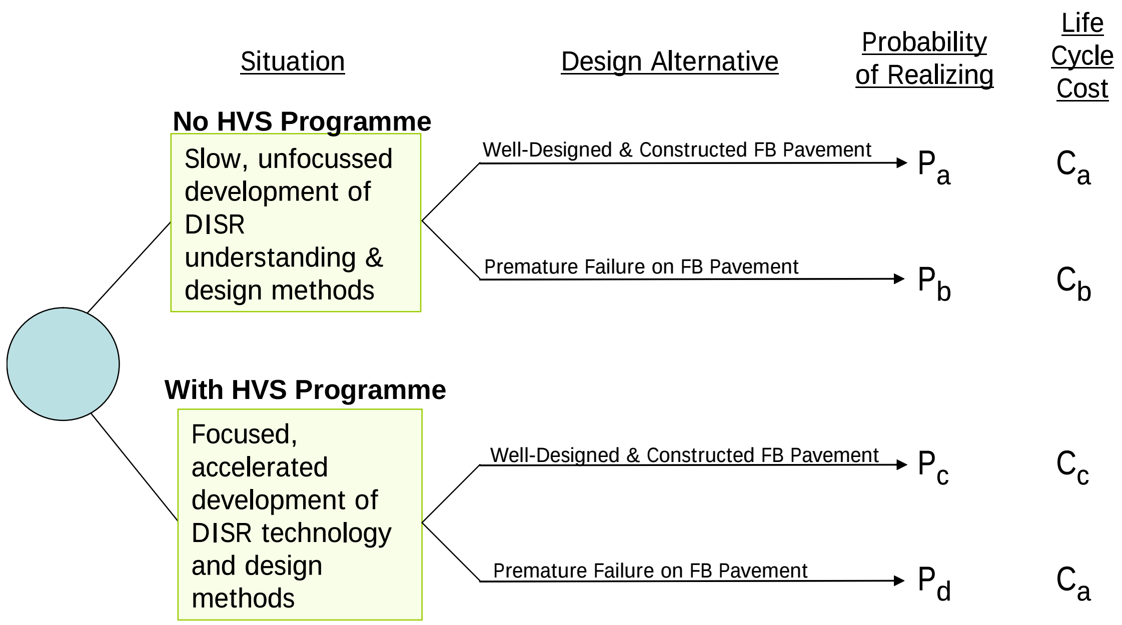


Figure 23: Framework for Assessing Benefits Arising From Increased Reliability in the Design of Pavements Incorporating Foamed Bitumen Treated Materials.

Compared to the G1 material technology described in Section 5.2, the technology associated with foamed bitumen is still new, and foamed bitumen can thus be described as an emerging technology. At present, there seems to be considerable debate in the South African road building industry with regards to the advantages and disadvantages of foamed bitumen treatment. Whilst some practitioners seem to be strong proponents of the technology, others seem to feel that foamed bitumen is only practical in exceptional cases (specifically where material quality and layer thicknesses are relatively uniform).

Because of the emerging nature of the technology associated with foamed bitumen treatment (and in fact with deep in-situ recycling technology in general), and specifically since the results of the tests on foamed bitumen treated materials have not been finalized, it was felt that an evaluation of the economic benefits arising from the test programme on foamed bitumen treated materials would be premature. It was therefore decided to postpone the benefit calculation until such time that the scaling of the benefits can be approached with more clarity and confidence.

As in all technology development efforts, it is vital to recognize that the economic benefits arising from such efforts do not reside only in the aspects that stem from the technical findings and which can be readily evaluated in economic terms. In the case of the foamed bitumen technology development programme, the development process has allowed technology development workers as well as practitioners to gain significant understanding with regards to the *in situ* recycling process.

As noted earlier, DISR technologies such as foamed bitumen treatment offer significant advantages from an environmental and road user cost perspective. Although difficult to quantify at present, these advantages will become more clear and significant in the near future, as natural resources become depleted and as traffic volumes increase. These two factors may in future render conventional rehabilitation (which typically require new pavement materials to be excavated and transported to the site using processes which greatly reduces the flow of traffic) impossible to consider owing to environmental as well as economic limitations.

The Gautrans technology development programme on foamed bitumen treated materials represents one of the first structured, multi-year technology development programmes aimed at developing practical knowledge that can be applied to all aspects of DISR (this includes materials design, pavement design and technology transfer aspects). Although perhaps difficult to appreciate at the moment, this applied knowledge lays the foundation for future DISR developments which, in a decade or two, is likely to become the mainstay of pavement rehabilitation processes worldwide.

6 INDIRECT BENEFITS

6.1 INTRODUCTION

In the Sections 4 and 5 it was shown that the direct benefits from the HVS Technology Development programme are significant, and, when the overall contributions and benefits are considered, provides at least a doubling of each Rand invested. Owing mainly to the tremendous scaling offered by the huge quantities of materials that are involved in road building, even the smallest improvement or innovation can lead to significant returns on investment. Road owning agencies such as Gautrans are direct beneficiaries of these savings, which result in a more cost effective use of available funding, which in turn optimizes the safe and affordable movement of people, goods and services.

In essence, the economic benefits stemming from the HVS Technology development programme relate to better business performance. In the context of transportation infrastructure development, this means better use of available resources through improved design, construction and planning activities. Improved business performance is, however, only one element in the total spectrum of benefits that is offered by this programme (this aspect is outlined in more detail in Section 2).

Over many years, HVS investigations and its associated development of human resources, new technologies and international alliances has impacted significantly on the people of South Africa, and in particular on the science and engineering community involved in road design and construction. There is little doubt that this contribution of the HVS programme to technical progress and human capital development has huge economic benefits over the long term. Apart from economic benefits arising from these processes, they also serve the higher ideals of quality of life and wealth creation, as shown in Figure 24.

The benefits stemming from technical progress and human capital development are difficult to assess in direct economic terms. Following the approach adopted in the National Research and Development Strategy document (RSA, 2002), an attempt was made to assess these benefits not through an economic evaluation, but rather by means of key indicators.

In this section then, an assessment is given of the indirect benefits arising from the HVS Technology Development programme. These benefits are divided into two main classes, which are (i) contribution to technical progress, and (ii) contribution to Science and Technology (SET) human capital.

6.2 HVS PROGRAMME CONTRIBUTION TO TECHNICAL PROGRESS

According the South African Research and Development Strategy (RSA, 2002), technical progress essentially entails innovation and improvement of technical processes and resources. As noted in the R&D Strategy (RSA, 2002):

"Improvement and innovation directly impact quality of life (for instance in the health sector) and business performance (e.g. through new products and processes). In

developed countries more than 50% of economic growth is attributable to technical progress." (RSA, 2002)

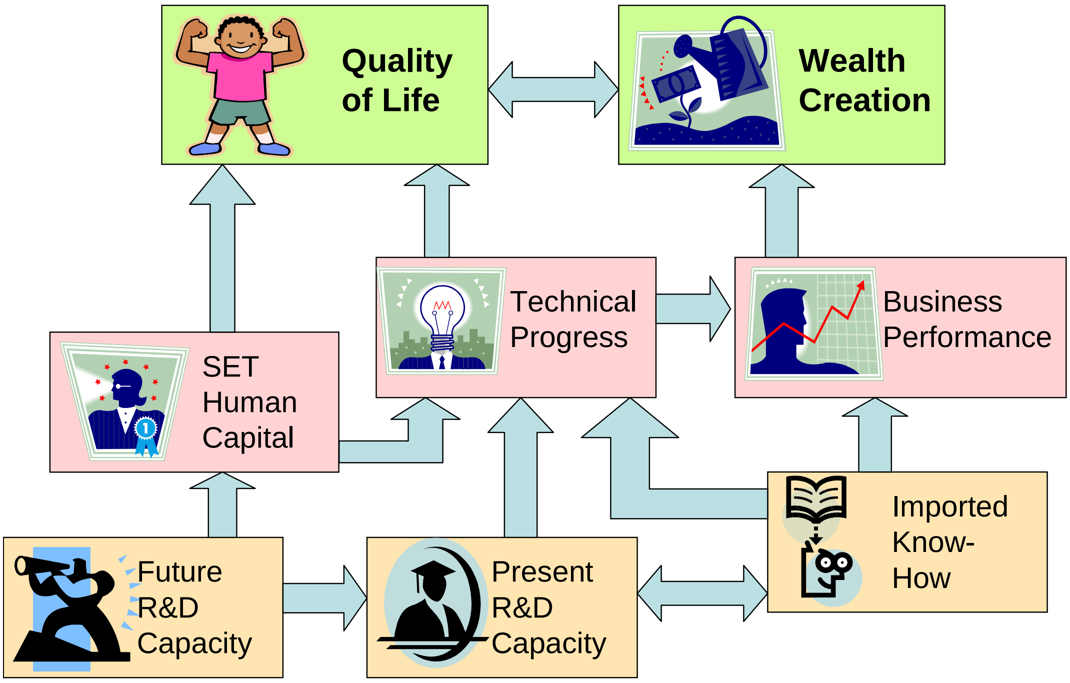


Figure 24: How Research and Development Impacts on Economic Growth and Quality of Life [adapted from (RSA, 2004)]

Excerpts from the National Research and Development Strategy (RSA, 2002):

"From a financing perspective, governments can target their investments in three focus areas to achieve the desired outcomes:

- The creation of a critical mass of SET human capital and a corps of researchers and future researchers;
- The stimulation and enhancement of innovation and improvement (technical progress) based on new technology and innovation missions and imported know-how; and
- The stimulation of enhanced entrepreneurship and enterprise development through targeted creation of venture capital and provision of fiscal incentives for private sector R&D."

As depicted in Figure 24, technical progress is central to the processes needed for the creation of wealth and quality of life. Direct indicators of a success in this arena include aspects such as (RSA, 2002):

- Patents registered;
- Business investment in innovation;
- Key technology missions.

Since technical progress is directly impacted by the current R&D capacity and imported know-how (see Figure 24), indirect indicators of the capacity for technical progress may also include (RSA, 2002; Jooste et al, 2004):

- Technical publications (local and international);
- International Alliances formed and interest attracted;
- High-tech developments and imports;

In terms of these indicators, the HVS Technology Development programme has sustained an excellent record for technical progress over more than three decades. This achievement is outlined in the following paragraphs.

TECHNICAL PUBLICATIONS

An immense volume of technical publications and reports have resulted either directly or indirectly from HVS investigations. Many of these publications have been published in international journals and were presented at prestigious international forums and conferences, and were influential in shaping directions taken by the international pavement design and construction industry.

Some of the more important publications, guidelines and reports that were impacted on by HVS investigations are summarized in Appendix B. This list includes more than 20 publications in international journals or conference proceedings, at least three important design guidelines and more than 30 influential research and development reports or dissertations.

INTERNATIONAL ALLIANCES FORMED

Since 1978, the Gautrans HVS Technology Development programme has contributed significantly to the refinement and expansion of the HVS machine and associated technologies. For several years now, the HVS machine and its associated technologies has been one of South Africa’s key technology exports.

The sale and export of HVS technology has not only contributed to more than R100 million of foreign income into South Africa (and Gauteng in particular), but has also been the departure point of several alliances with international research and development organizations. The HVS units sold to overseas agencies to date are summarized in Figure 25.

A key aspect of the export of HVS technology to overseas agencies is the forming of alliances with the aim to cooperate on research and development projects. Such alliances are key indicators of technical progress. Gautrans has played a lead role in establishing and maintaining such an alliance.

During a workshop held in South Africa on 7 and 8 October 2002, the international HVS user group represented by Finland/Sweden, the United States (the U.S. Army Engineer Research and Development Centre, the Florida DOT and California Pavement Research Centre) and South Africa, agreed to establish an Alliance to facilitate collaboration among all HVS users worldwide for a three-year trial period.

During this alliance meeting, it was agreed that the first lead agency would be the Gauteng Department of Public Transport, Roads and Works (Gautrans).

The alliance thus formed (the HVS International Alliance, or HVSIA) meets at least once a year, and the format of the meetings consist of presentations and discussions on activities/topics of common interest to the members, supplemented by site visits and/or demonstrations where appropriate.

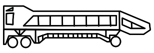
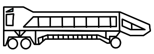
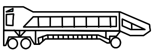
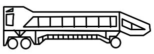
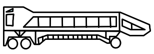
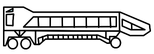
Units Used	Alliance Agency
 	California Department of Transportation Berkeley, California, USA
	US Army Corps of Engineers Cold Regions Research & Engineering Lab. New Hampshire, USA
	US Army Corps of Engineers Waterways Experimental Station, Missisippi, USA
	Technical Research Centres: Finland & Sweden Finland and Sweden
	Florida Department of Transportation Gainesville, Florida, USA

Figure 25: Summary of HVS Units Sold and Alliances Formed

Key objectives of the HVSIA are to:

- Promote and share knowledge related to HVS technology;
- Establish a structure for ongoing interactions on topics related to pavement engineering with a specific focus on the HVS technology;
- Establish mechanisms for funding, monitoring and completing studies of common issues through the optimum participation of members;

- Provide expertise so that studies of interest can be expeditiously defined, managed and results reviewed;
- Optimize the use of resources through the coordination of HVS related research;

The benefits toward the promotion of technical progress that is offered by the HVSIA are obvious from the above objectives. Gautrans is a key beneficiary of this progress. Further, the HVSIA also provides a formal platform for importing know-how (see Figure 24). The approximate constitution of HVSIA meeting delegates is shown in Figure 26. As can be seen from this figure, the international interest generated by this alliance is significant.

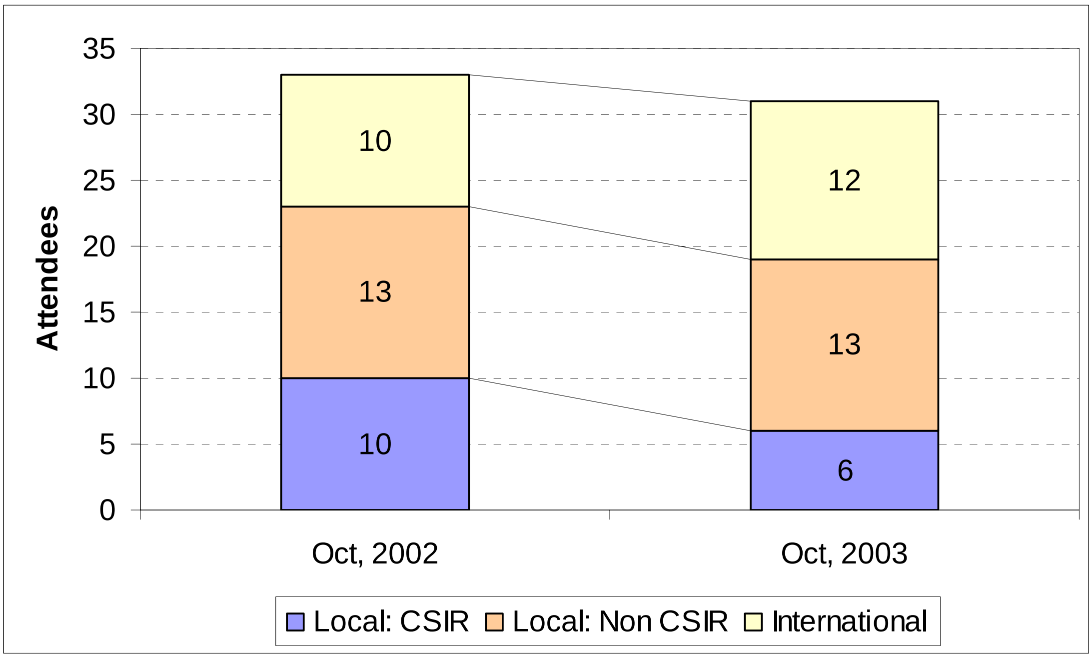


Figure 26: Summary of Attendance of the HVS International Alliance Meetings Held to Date

The Gautrans initiative which led to the execution of the technology development programme on foamed bitumen treated materials has allowed South African technology workers to become involved in similar investigations on foamed bitumen treated materials worldwide. This involvement includes the Accelerated Pavement Testing programme on foamed bitumen treated materials that is currently in progress in California, and in which South African engineers and technologists are actively involved. This involvement not only results in inflow of funds into South Africa, but serves to ensure continued improvement of South African practitioners and technologists.

INTERNATIONAL EXPOSURE

Over more than three decades, the HVS program has been a constant source of interest for overseas agencies involved in pavement technology development. Such interest generally takes the form of visits to Gautrans HVS sites and CSIR Transportek, or invited presentations at international forums. Key achievements in this respect include:

- A special session dealing with accelerated testing of pavements was held as part of the South African Annual Transportation Convention (ATC) in 1985. This session provided a showcase for South African technology in accelerated pavement testing and attracted prominent researchers and engineers from the United States, Australia and the United Kingdom.

- A South African delegation was invited to present a special session at the 1999 Annual Transportation Research Board conference held in Washington, D.C.. This session was devoted entirely to South African Flexible Pavement Design Technology, and consisted of eight presentations by South African engineers, including technologists from Gautrans, SANRAL, CSIR and South African Consultants. A significant proportion of the information presented at this session was related to, or impacted on by, the Gautrans HVS programme.

- Visits by a number of high level international delegations. This includes more than 17 visitors from China alone over the past three years (including visits by the Sichaan Provincial delegation in June 2001 and May 2003, and visits during the 4th forum on SA-China Engineering & Technological Science Co-operation).

- Visits from international delegates interested in HVS associated technology (this includes visitors from Iran, Kingdom of Saudi Arabia, Italy and the United States).

- The establishment of the Transport Engineering Research Centre (TERC) in Taiwan during the early 1990's was a direct result of Taiwan's need for an accelerated pavement testing facility as part of their road research establishment. Owing to the experience gained during the development and implementation of the HVS concept, CSIR Transportek could play a key contributor to the establishment of the TERC.

- In 2000, a delegation of South African pavement technologists presented a course on HVS pavement technologies to the California Department of Transport (CALTRANS) as part of the CALTRANS APT research programme.

HIGH-TECH DEVELOPMENTS AND IMPORTS

The number of high-tech patents and technologies developed is another indicator of technical progress. In this regard, the HVS has acted as a focal point around which eight offspring technologies have either been improved upon or have been developed specifically as an HVS associated technology. These offspring technologies include the following:

- The HVS Data Acquisition System (DAS) which captures, stores and displays key indicators measured under the HVS;

- The Road Surface Deflectometer (RSD), which measures pavement surface deflection profiles under the action of a dual wheel load (HVS or other);
- The Multi-Depth Deflectometer (MDD), which measures in-depth pavement deformation data under loading;
- The Joint Deflection Measuring Device (JDMD), which measures edge and corner deflections as well as curling and warping deformations of concrete slabs;
- The Laser Profilometer, which measures a continuous localized surface profile of a road;
- The Crack Activity Meter (CAM), which is capable of simultaneously measuring vertical and horizontal crack activity under loading;
- The Stress-In-Motion (SIM) system, which measures three dimensional surface contact stresses under loaded tyres.
- Thermo-couples which automatically record and store air and surface temperature data required during experiments;

6.3 CONTRIBUTION TO SET HUMAN CAPITAL

The contribution of the HVS Technology Development programme to the South African SET human capital is significant. The HVS programme has accomplished this by serving as a focal point and a catalyst for the continued improvement of technology for the South African pavement design and construction industry. This contribution to SET human capital, and also to Science and Technology in general, is achieved through the following processes:

EDUCATIONAL VALUE

Once of the key indicators for performance of a Science and Technology (S&T) system is the number of post-graduate degrees in S&T areas. The Gautrans Technology Development programme has contributed directly to this indicator through the following processes:

- By facilitating the experiments, data gathering and analysis needed for advanced post graduate work.
- By contributing to the development of the HVS concept and related technologies, which in turn opened up opportunities for more post graduate research work in other provinces and countries.

Since the start of the Gautrans HVS Technology Development programme in 1978, the programme has contributed directly or indirectly to more than 25 Masters and more than 15 Doctoral qualifications. There can be no doubt that the recipients of these post graduate degrees have made – and continue to make - a significant impact on S&T

Excellence in Gauteng and South Africa, specifically in areas related to pavement design and construction.

Figure 27 shows the types of contributions made by recipients of post graduate degrees that were impacted on by HVS investigations. The figure shows that the majority of these S&T workers have contributed by offering consulting services, or have contributed through further research and development activities.

In this regard, the HVS Technology Development programme provides benefits to Gauteng not only by improving the quality of design and construction practice that is applied to the Gautrans road network, but also by contributing significantly to a critical mass of SET Human Capital.

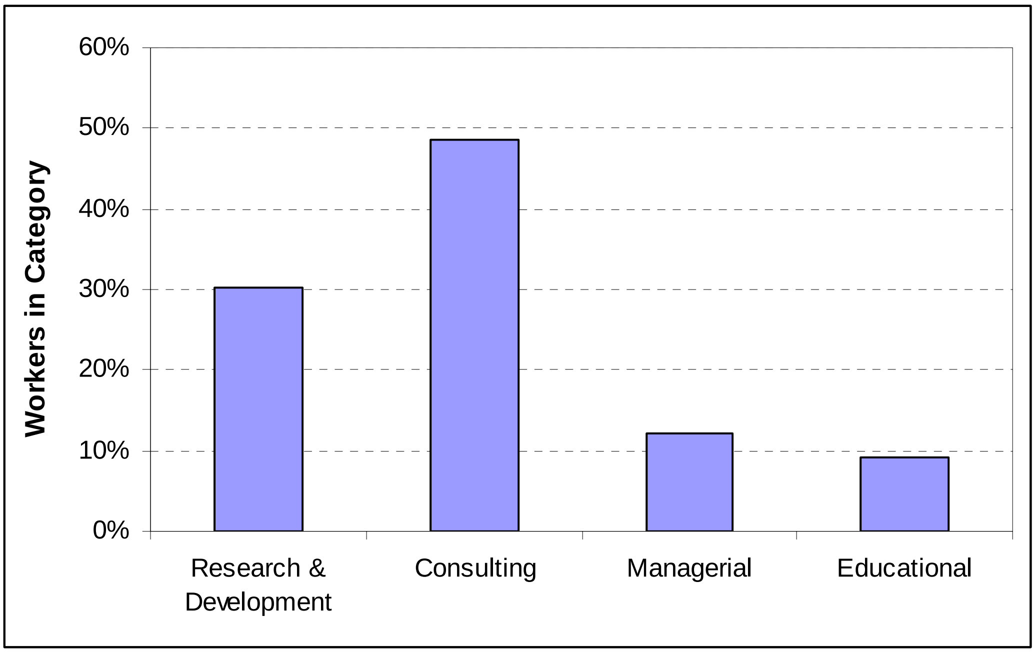


Figure 27: Principal Type of Contribution Made By S&T Workers Who Have Obtained Post-Graduate Degrees Related To HVS Investigations

IMPROVEMENT IN S&T EXCELLENCE

The findings of the HVS technology development programme have been instrumental in the formulation of guidelines and specifications that are used on a daily basis in South Africa and elsewhere. More specifically, the findings of HVS experiments have impacted significantly on the following:

The South African Mechanistic Design Method (SAMDM) (Theyse et al, 1996):

HVS experiments have played, and continue to play a significant role in the refinement and calibration of the South African Mechanistic Design Method. Without the accelerated performance data provided by HVS experiments, the method will in effect cease to be a component of pavement design in South Africa. Once developed and calibrated, the SAMDM allowed engineers and researchers to extrapolate and widen the impact of HVS experiment findings to other areas and design situations. Significant in this respect is the extension of the design methodology to incorporate Labour Intensive Construction projects.

TRH4 1985 to 1996 (TRH4, 1996):

This document deals with the Structural Design of Interurban and Rural Roads, and forms part of the Technical Recommendations for Highways series. The document is an essential guide for any pavement designer in Southern Africa. Knowledge gained through HVS experiments, and specifically the experiments on granular and cemented base pavements during the 1980's have played a significant role in the development of (i) Conversion Factors for determination of equivalent single axles required for design (ii) Structural Design principles; (iii) Pavement type selection principles and (iv) the Design Catalogue. It is expected that the findings of the latest HVS tests will contribute significantly toward the much needed revision of the current TRH4 document.

Guidelines for the Large Aggregate Mixes for Bases (LAMBS) (SABITA, 1993)

HVS experiments were instrumental in determining the performance characteristics of these materials. The data gathered from HVS tests and associated analysis also formed a critical element in the calibration of design functions for thick asphalt bases in South Africa.

TG2 Guidelines for the Design of Foamed Bitumen Treated Materials (Asphalt Academy, 2002)

HVS tests and the associated laboratory tests were instrumental in shaping the TG2 Guidelines for the Design and Use of Foamed Bitumen Treated materials. Specifically, prior to the HVS tests on foamed bitumen pavements, mechanistic-empirical design methods for foamed bitumen pavements was based only on laboratory test data. The HVS tests and associated analyses of data on trial sections built with foamed bitumen allowed calibration of the design method using full scale accelerated test data. The methodology that resulted from this work is perhaps the only calibrated systematic design approach in existence for Foamed Bitumen Treated materials.

Apart from being a driving force in the development and publication of essential guidelines, the HVS programme also contributed to Science and Technology excellence by acting as a catalyst and focal point for the development of new and improved pavement design and construction practices in South Africa. According to some of the practitioners interviewed as part of this study, a "hub of interest" is created amongst pavement practitioners wherever HVS experiments are being conducted. Experience showed that forward looking practitioners in the area of HVS operations immediately took interest in the HVS experiments and its findings which are frequently made available through conferences and technical forums.

For example, approximately 700 practitioners in South Africa and elsewhere have obtained and are using the TG2 guidelines on the design and use of foamed bitumen treated materials. Furthermore, as part of the process of introducing the TG2 guidelines to practitioners, a series of workshops were held across South Africa. These workshops involved more than 300 practitioners who were exposed to the developed foamed bitumen technology. Related workshops were also designed and presented specifically to Gautrans personnel involved in materials design and construction.

Employment and Career Growth Opportunities

HVS experiments and their requirements for collection, analysis, documentation and dissemination of information provide not only direct employment opportunities, but also a constant and effective training ground for SET human resources. In the past, when three HVS machines were operational, the HVS programme contributed to the employment of approximately 20 S&T workers (this included three high level engineers, one data analyst, three instrumentation specialists, and one HVS operator and three to six assistant operators per HVS).

Figure 28 shows the S&T human resource component associated with current HVS investigations, and also provides an indication of the workforce demographics. At present, with only one HVS machine operational, the machine still contributes to the employment of at least 10 S&T workers (this includes four engineers, one HVS operator, three assistant operators and two personnel dealing with instrumentation and data collection).

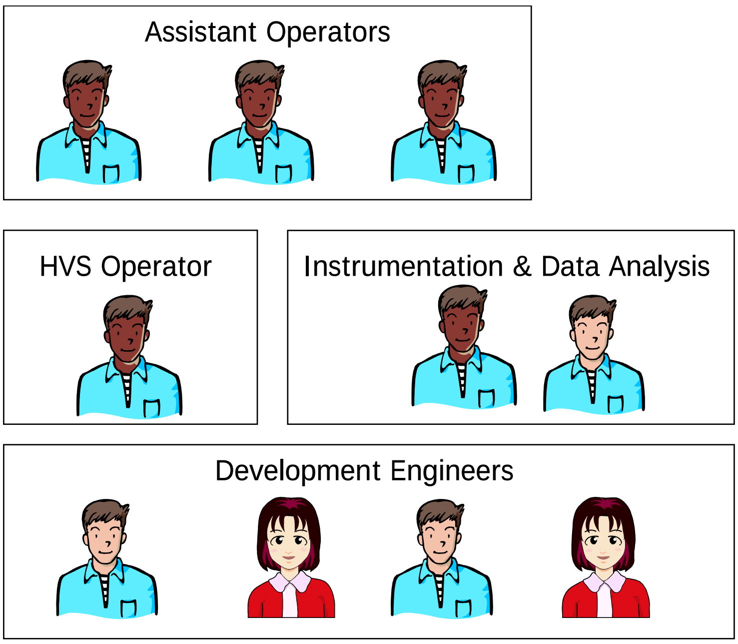


Figure 28: Current Human Resource Component for the Gautrans HVS Development Programme

The international alliances that resulted from early HVS developments, have contributed significantly to expose the HVS workforce to international experiences. Specifically, four assistant operators from previously disadvantaged communities were trained in specific areas of operation and maintenance of HVS equipment, and were also provided with a general understanding of the performance of roads under evaluation. This training has enabled five assistant HVS operators to travel abroad and play a major role in the transfer of the technology to an accelerated pavement testing (APT) programme in California.

Through a technology transfer agreement signed with the California Department of Transport, opportunities are also created for two individuals to partake in the CALTRANS accelerated pavement testing programme and to enrol for post graduate studies at the University of California. This contribution toward SET Human Capital is again a direct result of sustained development of the HVS concept and associated technologies.

7 FRAMEWORK FOR BENEFIT ASSESSMENT

7.1 INTRODUCTION

In Section 3, a best practice approach for evaluating the direct economic benefits of technology development projects in the road sector was presented. In Section 4, this approach was implemented in a generalized *manner* to calculate typical benefits that can be derived from impacts of technology development projects like the Gautrans HVS programme. Section 5 then summarized the direct economic benefits stemming from *specific HVS projects* conducted in the past.

In this section, the approach presented in Section 3 will be refined and re-stated in the form of a framework that could be used for future assessments of the economic benefits stemming from HVS technology development work. This framework is based not only on the best practice approach summarized in Section 3, but also takes into account the experience gained through the implementation of this approach on specific Gautrans HVS projects. The framework focuses primarily on the assessment of direct economic benefits, but also provides for the gathering of information to facilitate the longer term ideal of quantifying indirect benefits through indicators and trend analysis.

7.2 FRAMEWORK DETAILS

The framework for evaluating the direct economic benefits stemming from technology development projects in the road building sector is summarized in Figure 29. This framework or methodology is defined in a manner which enables cost-effective benefit assessment for specific projects. The methodology is easy to execute and essentially consists of four steps which are discussed below. The methodology should ideally be executed by an independent investigator (i.e. an entity not involved in the funding or technical investigation process).

STEP 1: SUMMARIZE THE TECHNICAL FINDINGS AND KEY IMPACTS

In this task, the project principal investigators (i.e. key technical personnel involved in the execution of the selected project) are tasked to assess the selected projects main findings and the impact thereof on the road building industry. The assessment and clarification of impacts are vital to the successful evaluation of economic benefits, since this information will form the basis for further tasks.

To ensure that impacts can be clearly identified and isolated, the information provided by the principal investigators need to be as specific and comprehensive as possible. The information provided by principal investigators will be used to formulate questionnaires to users of the developed technology (i.e. practitioners and client body representatives). Since these users often to not realize how their activities are impacted by technology development findings, they will need to be made aware of the specific impacts that resulted from the execution of the selected project.

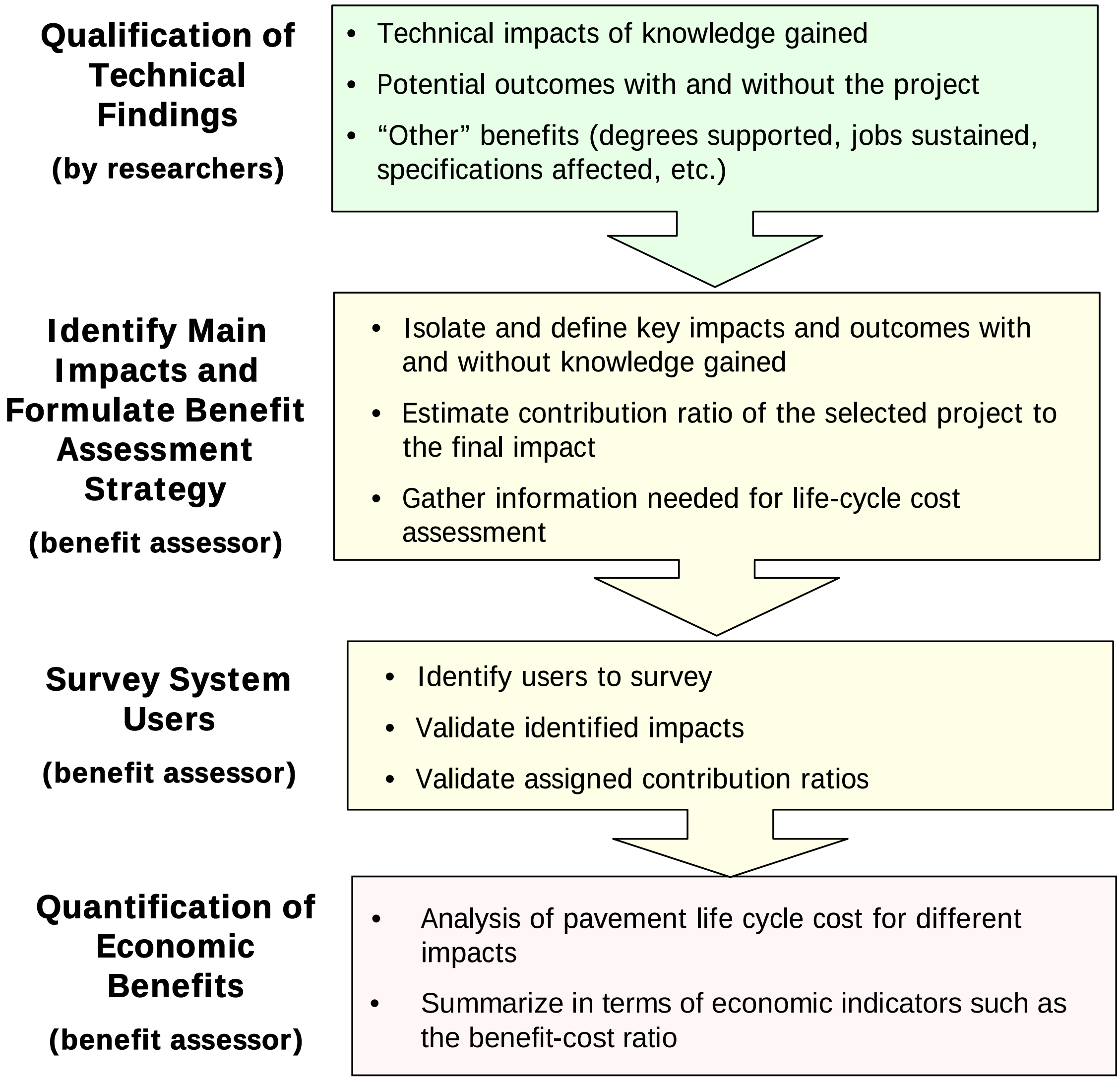


Figure 29: Framework for Economic Benefit Assessment

The information provided by the principal investigators should – as far as possible – address the following aspects:

<u>Technical:</u>
- Brief description of the project outcomes;
- Summary of all project costs;
- Description of the technical impact of the project outcomes;
- Description of how the findings will impact design and/or construction activities;
- Description of alternatives, or status quo, that would be implemented in the absence of the new knowledge;
- List any specifications affected by the project outcomes;
- List any relevant information on the implementation of findings (projects where implemented, contact persons, anecdotal information, etc.)

Human Resources:

- List people involved in the project, including demographic information;
- Number of qualifications affected by the project, with relevant details;
- Describe any outcomes that have led to job creation, safety or environmental improvements;
- Man-hours international exposure owing to presentation of findings, liaison etc. that took place within the framework of this project;
- List any training courses or workshops affected by the findings of this project, including a rough estimate of percentage contribution.

Technological Excellence:

- Describe any direct income created partly as a result of the project (e.g. equipment sales, software sales etc.);
- List any manuals or guidelines affected by the findings of this project. Specifically note any guidelines with international recognition or impact.
- Describe any new products developed or refined as a result of this project, with estimates of percentage contribution by this project;
- List any patents registered as a result of this project, with estimates of percentage contribution by this project;
- Describe any international cooperation efforts that have developed or were affected as a result of this project;
- Describe the number of papers or articles published as a result of this project, or which were influenced by the findings of this project;
- If any new businesses were formed partly as a result of the findings of this project, then list these with an estimated percentage contribution from this project;

Key Impacts:

- List specific findings or outcomes of the project which contributed to *optimization of pavement layer thicknesses or materials cost*; Also describe the scope of this impact (e.g. does it apply to pavements or materials of a certain type or traffic class);
- List specific findings or outcomes of the project which contributed to *more cost-effective pavements or materials*; Also describe the scope of this impact;
- List specific findings or outcomes of the project which contributed to *more reliable pavements or materials design*; Also describe the scope of this impact;

STEP 2: IDENTIFY MAIN IMPACTS AND FORMULATE BENEFIT ASSESSMENT STRATEGY

Once the main findings and impacts of the selected project have been identified, the benefit assessment strategy should be developed. This step essentially comprises the formulation of (a) a benefit assessment diagram (an example of such a diagram is shown in Figure 21), (b) a calculation template; and (c) the gathering of data to accomplish scaling of benefits.

The benefit assessment diagram should explicitly show the scenarios likely to transpire with and without the benefit of the impacts arising from the selected project. The benefit assessor should also assign typical probabilities to the different outcomes, as well as a contribution ratio to the impact (at this stage, these factors can be based on experience or advice from the project principal investigators).

Once the benefit assessment diagram is formulated, a calculation template should be constructed. This calculation template will typically allow a concise evaluation of the unit savings that are achieved by the impact under consideration. Figure 8 shows an example of a calculation template.

The calculation template will explicitly show the types of information needed to perform the benefit calculation. This will typically involve key assumptions with regards to the life-cycle cost calculation (where appropriate), as well as typical unit rates required to calculate the unit saving.

The benefit assessor can now gather the information needed to perform the calculation of unit saving, and to scale this saving for the impacted network or networks. The scaling calculation will typically require knowledge of the total lane-km affected by the impact under consideration.

STEP 3: VALIDATION BY SYSTEM USERS

The benefit assessment diagram and calculation template ensures that the impact and method of calculation is adequately clarified. Identified users of the developed technology (typically knowledgeable practitioners and client body representatives) can now be surveyed to validate (a) the identified impacts and (b) the assumptions required for the calculation template and benefit scaling.

For the survey, a structured, project specific questionnaire should be formulated. This questionnaire should be designed to achieve the following:

- Validate that the identified impacts are real and effective;
- Validate that the selected project was at least partly responsible to realize the identified impacts;
- Obtain a range of contribution ratios for the selected project for each impact (i.e. determine the percentage contribution made by the selected project to realize each impact);
- Discuss the benefit calculation template with the user and identify any contentious issues or assumptions;
- Discuss the scaling of benefits with the user and identify any contentious issues or assumptions;

STEP 4: REFINEMENT OF ASSUMPTIONS AND BENEFIT CALCULATION

The information obtained through the interviews with system users should be used to refine and adjust the calculation template and the assumptions associated with the scaling of benefits. The opinions of the technology users should be used to establish a range of appropriate contribution ratios for each benefit, and these should be used for the final benefit calculation. The refined and validated assumptions can now be used in conjunction with the benefit calculation template to assess and document the benefits.

7.3 IDENTIFYING BENEFICIAL TECHNOLOGY DEVELOPMENT PROJECTS

The framework for benefit assessment provided in the Section 7.2 outlined a procedure to evaluate the benefits from a technology development project after the findings are implemented. However, the findings and experience gained from the present study can also be used in the future to assist in (a) identifying technology development projects with a high potential for realizing benefits; and (b) to formulate and conduct technology development projects in a manner that facilitates easier identification and quantification of benefits. Detailed comments on the design of benefit centred HVS experiments were summarized in the inception report for this study (Jooste at al., 2004). The key elements of this summary are provided here for completeness, together with some additional comments.

Based on the experience gained during the execution of this study, the following elements should be considered in the formulation and selection of benefit centred technology development projects:

- **An overarching, policy-oriented strategic plan is needed**
  As a first step towards the selection and design of policy and benefit oriented technology development projects, an overarching strategic plan is needed. Such a plan ensures that the long-term objectives of the technology development programme serve the mission and core objectives of the funding agency. Naturally, such a plan requires adequate understanding of the short and long term needs of the funding agency (e.g. Gautrans).

  Excerpts from strategic plans and test programme objectives for various APT centred technology development programs were presented in the inception report for the present study (Jooste et al., 2004). Since the publication of the inception report, a strategic plan has been published for the Gautrans Accelerated Pavement Testing programme (Gautrans, 2004). Excerpts from this strategic plan are shown in the highlight box below.

- **Evaluate Candidate Projects Against the Strategic Plan**
  The strategic plan, and specifically the objectives of the plan, provides "values" to guide the selection and formulation of technology development projects. A proposed technology development project can be evaluated against the objectives of the APT strategic plan. It is, however, essential that the project proposal or execution plan should show – in a highly specific manner – how the project will contribute toward the objectives of the strategic plan. In essence this means that the project plan should provide clear and specific answers to the question: how will the project contribute toward the strategic plan and its objectives?

- **Clarify Potential Benefits At the Project Design Stage**
  The project objectives may easily be worded in a way that it appears to be aligned with the strategy objectives. However, the project proposal or execution plan should also provide a clear indication of the likely impacts, and how these will ensure that the objectives are met. Often, a key element is the definition of a hypothesis that will be tested or verified during the project. Formulating such a hypothesis will assist in identifying alternatives or counter-facts against which the benefits of the project can be measured. Thus, in addition to stipulating the likely

overall outcome of the project, the design of the technology development project should also clearly determine what would happen if the project was not executed. This approach will ensure a focused, benefit-oriented approach, as opposed to the mere gathering of information and publishing of technical reports.

Excerpts from the Gautrans Accelerated Pavement Testing Programme (Gautrans, 2004)

Vision:
To provide cost-effective pavements through the application of appropriate technology and resources to assist in achieving a better quality of life for all in Southern Africa.

Mission:
To effectively and efficiently use APT to develop and assess technologies for the provision of cost-effective pavements in support of the overall drive to improve accessibility, mobility and safety of road transport users.

Goals:
APT will contribute to:

- Minimizing premature pavement distress;
- Improving design procedures and models;
- Optimizing material type, use and performance;
- Evaluating appropriate construction technologies;
- Quantifying pavement performance;
- Integrating APT, LTPP, laboratory testing and existing pavement knowledge; and
- Optimizing use of resources;

- **Technology Transfer Should Form Part of the Project Design**
  An element highlighted by this benefit assessment study is the fact that benefits stemming from technology development work are not only realized through the generation of technical information. Rather, benefits are realized when such information is actively transferred to practitioners and implemented through manuals, policy changes and specifications. A technology development project which does not contribute to the implementation of findings cannot reasonably claim a high contribution of the realized benefits. Thus, a technology development project should incorporate plans for the transfer of findings to practice. This will ensure a larger contribution ratio and will also greatly speed up the realization of benefits.

The four elements outlined above form the basis of an approach that will ensure that projects are planned and executed in a manner that will not only maximize benefits, but will also facilitate more effective assessment of benefits once the findings of a project have been assimilated by practitioners. It is recommended that these elements be expanded and refined so that it could serve as guidelines for the formulation of benefit-oriented work proposals.

7.4 SUMMARY

In this Section, a framework for evaluating the benefits arising from technology development projects was presented. The framework was developed based on the best practice elements outlined in Section 3 as well as the experience gained during the execution of this benefit assessment project. It was shown that the benefit assessment framework consists of the following four steps:

Step 1: Summarize the Key Technical Findings and Impacts
In this step, the primary investigators on the selected project are asked to provide a detailed assessment of the findings of the project. Guidelines are provided according to which data can be collected with respect to the following aspects: (a) technical findings; (b) human resources; (c) contributions to technical excellence; and (d) key impacts arising from the project.

Step 2: Identify Main Impacts and Develop a Benefit Assessment Strategy
This step involves the identification and definition of the main impacts. This information is used to develop a benefit assessment strategy, which involves three key tasks. These are: (a) the design of a benefit assessment diagram showing alternatives with and without the identified impacts; (b) design of a benefit calculation template, which includes a preliminary assignment of probabilities and contribution ratios needed to perform the calculation; and (c) obtaining the information needed to calculate unit benefits and to scale these benefits for the network under consideration.

Step 3: Refine Assumptions and Calculate Benefits
This step involves the validation of the identified impacts, assigned probabilities and contribution ratios as well as other assumptions that form part of the benefit assessment process. The validation is achieved through interviews with independent users of the developed technology. These users are typically knowledgeable practitioners and client body representatives.

Step 4: Validate Impacts and Assumptions through Interviews
Once the identified impacts, contribution ratios and other assumptions involved in the calculation template have been validated, the benefit calculation is performed using the refined impacts and contribution ratios.

Guidelines were provided for the identification and design of benefit-centred technology development projects. Key elements highlighted in these guidelines are:

- An overarching, policy-oriented strategic plan is needed to guide the selection and design of candidate projects. The strategic plan should be aligned to the needs of the funding agency.

- The objectives of candidate projects should be evaluated against those of the strategic plan. Proposals or execution plans for candidate projects should show - in a specific manner - how the project findings will impact on and contribute towards the objectives of the strategic plan.

- Potential benefits that are expected to be derived from a candidate project should be clarified at the project design stage. A counter-factual or alternative situation that will develop without the benefit of the project findings should be stated.

- A plan to facilitate technology transfer should form part of the project execution plan. A technology development project which does not contribute to the implementation of findings cannot reasonably claim a high contribution of the realized benefits. Thus, a technology development project should incorporate plans for the transfer of findings to practice. This will ensure a larger contribution ratio and will also greatly speed up the realization of benefits.

The four elements outlined above form the basis of an approach that will ensure that projects are planned and executed in a manner that will not only maximize benefits, but will also facilitate more effective assessment of benefits once the findings of a project have been assimilated by practitioners. It is recommended that these elements be expanded and refined so that it could serve as guidelines for the formulation of benefit-oriented work proposals.

8 SUMMARY AND CONCLUSIONS

8.1 GENERAL CONCEPTS

Some of the basic concepts related to assessment of benefits arising from technology development programmes were described, and a general approach to identify and assess benefits arising from the HVS technology development programme was provided. Key elements presented were:

- To ensure a benefit assessment is relevant, the needs and objectives of the funding agency first need to be understood. In the context of the HVS technology development programme, the overarching objectives of Gautrans and of the South African Research and Development strategy (SA R&D strategy) were deemed to be most relevant;

- The overarching objectives of Gautrans and of the South African Research and Development strategy were evaluated. For the purpose of this study, three main benefit streams, resulting from the HVS technology development programme, and relevant to Gautrans and to the SA R&D strategy, were identified. These are:

    4. Contribution to <u>better business performance</u>;

    5. Contribution to <u>technical progress</u>;

    6. Contribution to the development of <u>SET human capital</u>.

- Not all of the benefits arising from technology development work are quantifiable in economic terms. Because of this, quantified estimates of the returns on investment of technology development programmes provide a lower bound estimate of the real long term benefits arising from such programmes. In other words, quantified economic benefits typically underestimate the true long term benefits of technology development work, since such estimates only take into account those benefits that can be isolated and quantified in economic terms.

- There is a need to distinguish between direct (or “delivery”) benefits, and indirect (or “process”) benefits arising from technology development programmes.

- <u>Delivery benefits</u> are those benefits that rely primarily on the technical outcome(s) of technology development projects. In the context of road technology development projects, these benefits arise because of improved technology which leads to more effective design and construction processes, which in turn reduces agency and road user costs. These benefits can to some extent be quantified in economic terms by means of indicators such as benefit-cost ratios.

- <u>Process benefits</u> arise because of the development *process*. These benefits largely concern human resource development and the development of better understanding of the problems facing a particular development area. In a well-managed research and development program, these benefits should arise even when the project deliverables have only been partially achieved. Process benefits are not readily quantified into economic terms, and are best monitored and evaluated through indicators and trend analysis.

8.2 GENERAL ASPECTS RELATED TO DIRECT BENEFIT ASSESSMENTS

General aspects relating to the assessment of direct economic benefits arising from technology development work were discussed. Specifically, difficulties associated with the assessment process were highlighted, and a best practice approach for addressing these difficulties was outlined. It was noted that the assessment of direct economic benefits involves, amongst other issues, the following three difficulties:

4. There is a conceptual and time-related separation between project findings and benefit realization. This diffusion of project findings greatly complicates the identification and isolation of the links between project deliverables and the benefits that arise as a result. Considerable experience of the field of application is needed to identify and isolate the links between realized benefits and the technical findings of technology development projects.

5. Benefits often result from several contributing projects and processes. It is thus essential to ensure that contributions that precede technology development projects, as well as contributions required to refine and implement policy changes, are taken into account in the benefit assessment process.

6. In order to arrive at the assumptions needed to complete an economic assessment of benefits, a significant amount of subjective input is needed. The subjective element of the assessment process impacts negatively on the credibility of the assessment.

A survey was conducted of previous investigations that involved assessments of direct economic benefits arising from research and technology development projects. From this survey, and also from evaluations conducted as part of the present study, a best practice approach was constructed to guide the assessment of direct economic benefits resulting from technology development projects. This approach involves the following guidelines:

- <u>Select the Best Performing Projects for Benefit Quantification</u>
  Earlier investigations found that it may be more effective to identify and then focus on the best performing projects within a research program, as opposed to trying to evaluate the entire research programme over a long term.

- <u>Identify Impacts and Benefits Through Interviews with Technology Development Workers</u>
  This approach quickly identifies the impacts resulting from technology development work, and helps to identify links between purely technical outcomes and downstream benefits.

- <u>Collect Evidence from The Users Of The System</u>
  Whilst technology development workers are interviewed to identify impacts and potential benefits, estimates of the actual benefits are obtained through interviews with the more impartial users system (e.g. client body representatives and practitioners). This ensures transparency and credibility.

- <u>Acknowledge Other Contributions</u>
  A technology typically has to develop through several stages before its benefits are realized through changes in policy, design method or specifications. To realize such benefits, contributions from other role players are needed. The benefit assessment process should acknowledge such contributions, and a contribution ratio should be assigned to technology development projects when calculating benefits.

- <u>Use Confidence Intervals To Assess Benefits</u>
  The expected benefits of a research programme can seldom be known with any certainty and are typically obtained through subjective estimates that are highly uncertain. The credibility of benefit assessment can be increased if the analysis provides some measurement of the randomness of the estimated benefit. It may therefore be more useful to use a range or interval rather than a point estimate of economic benefits.

8.3 DIRECT ECONOMIC BENEFITS: A GENERAL ASSESSMENT

Examples were presented to illustrate the direct economic benefits that can typically be expected from a technology development project such as the Gautrans HVS programme. It was shown that the benefits that can be derived from technology development projects related to the roads industry generally yield information that fall into the following three impact categories:

4. Optimized materials and pavement design, which lead to reduced construction costs;

5. More reliable design and maintenance practices, which reduces the likelihood of costly early failures, and

6. More cost effective materials and pavement design, which optimizes the time between interventions and reduces pavement life cycle costs.

An economic evaluation was performed to assess the direct economic benefits that can be derived from each of the above three impacts. This evaluation was performed by means of two approaches. These were:

3. A conventional life cycle cost comparison approach in which a benchmark case - without the benefit of technology development findings - was compared to an improved alternative which incorporated the impacts of a technology development project.

4. An approach which incorporated Bayesian statistics and is aimed at evaluating the value of information that can assist in making decisions which have economic impacts.

Conclusions: Life Cycle Cost Comparison Approach

Generalized examples of each impact type were presented and discussed. In all cases, the economic benefit of the impact was calculated over a period of 10 years. This benefit was then compared to the cost of a typical HVS technology development project lasting two years, and with a total cost of R8 million. For each example, an outline of the example situation was provided, and key assumptions were listed. The example calculations were then shown and discussed. It was noted that certain subjective assumptions had a significant impact on the calculated economic benefits. However, since all calculations were shown explicitly, the interested reader could easily re-construct the calculations using a spreadsheet, and then re-evaluate the benefits using different assumptions. The examples evaluated for each of the three impacts showed similar results. For all three examples, the findings were as follows:

- For the stated assumptions, any network on which more than 150 km of road is rehabilitated per annum will have a benefit cost ratio in excess of 1.0.

- For a network such as that operated by Gautrans, the calculations suggest that, for each of the three impacts, Gautrans will realize a benefit-cost ratio of 1.6 or more, with a total discounted saving over a 10 year period of between R12 million and R16 million per impact (in 2004 Rand terms), depending on the discount rate.

- All three examples show that, if the impacts are considered in isolation, then a benefit-cost ratio of 2.0 or more will be realized for any road network that requires roughly 320 km of rehabilitation work per year. For larger networks that require in excess of 500 km of rehabilitation per year, the expected return on the technology investment will be roughly between R25 million and R33 million per impact (in 2004 Rand terms), which – for the assumed development costs - equates to a return of three Rand for every one Rand invested in technology development.

In the examples, the benefits of each impact were evaluated in isolation. This effectively implies that the impact considered in each example is the only significant finding of the assumed two year development project. However, HVS technology development projects have often resulted in findings that have related to more than one of the impacts listed above. If two or more impacts are combined (i.e. if two impacts arise from the same technology development project), there is a significant increase in the savings and benefit-cost ratios.

For the examples considered, and for a network such as that operated by Gautrans, a combination of impacts for a single project could lead to combined savings of between R24 million and R36 million (in 2004 Rand terms), depending on the discount rate assumed. For a technology development project with a cost of R8 million, these savings would result in a benefit-cost ratio of between 3.0 and 4.5. For a larger network that rehabilitates roughly 500 km of roads per year, the savings and benefit-cost ratios would be doubled (i.e. benefit cost ratios of 6.0 to 9.0 would apply).

Conclusions: Value of Information Approach

The concept of the Expected Value of Perfect Information (EVPI) stems from Bayesian statistics and can be used to assess the relative value of information that is used to drive decisions that will have an economic impact. An example was used to illustrate the expected value information that could assist a roads agency in the decision to either implement or disregard a network wide implementation of a new pavement technology.

The EVPI example used inputs and assumptions that are based on actual costs, and assumes that information – relevant and significant to the decision making process – would be provided by a one-year HVS technology development project. The example clearly showed that, for the assumed decision making scenario, the EVPI was in excess of R25 million. When this relatively high EVPI is compared to the cost of gathering the information (estimated at roughly R4 million), it is clear that a substantial economic benefit could be derived from the information that would be provided by the technology development project.

The concept of EVPI provides a rational way of evaluating the value of information that would typically stem from the Gautrans HVS programme. For the typical example considered, the EVPI indicates that significant economic benefit could be derived from technology development projects such as the Gautrans HVS programme. This benefit arises mainly from the relatively large scale on which benefits can be realized for a typical road network.

8.4 DIRECT ECONOMIC BENEFITS: SPECIFIC PROJECTS

Benefits arising from HVS technology development projects were evaluated for two specific projects. These were: (a) development of the high quality Crushed Stone called G1; and (b) development of foamed bitumen materials technology. In the case of the G1 development project, a full assessment of technical impacts and direct economic benefits was made. In the case of the foamed bitumen project, only the major findings and impacts on the industry were evaluated.

G1 TECHNOLOGY DEVELOPMENT BENEFITS

The key impacts of HVS investigations on G1 base pavements were identified as:

- The suitability for G1 base pavements for the 12 to 50 MESA design class was clearly proven;
- The feasibility of G1 base pavements in wet regions was proven (provided an impervious surfacing could be maintained);
- It was found that the damage exponent (or n-value) of pavements with a G1 base over a thick cemented subbase was close to 3, and not 4.2, as was commonly assumed;
- It was proven that a 150 mm thick G1 layer is optimal for G1 base layers;

- The difference between the high quality G1a, and lower quality G1b or G2 material was clearly shown;

After consideration of the identified impacts (and specifically of the data and assumptions needed to convert the impacts to economic benefits) it was decided to combine the identified impacts into the following three main benefits:

<u>Benefit 1:</u> Increased use of G1 Base Pavements for higher design classes and wet regions;

<u>Benefit 2:</u> Use of 150 mm thickness for G1 base layers, and

<u>Benefit 3:</u> Improved maintenance and construction practices.

The savings derived from these three benefits were evaluated using a probabilistic approach to aggregate the likely unit savings that typically resulted from the above three benefits. The overall savings were calculated for the Gautrans and SANRAL networks, by using the unit cost savings which were scaled to an absolute savings value. This scaling of benefits used the total lane-km of G1 base pavements constructed by Gautrans and SANRAL in the period between 1980 and 1990. The assessment of economic benefits showed the following:

- The overall benefit cost ratio (i.e. for Gautrans and SANRAL) varies from 2.4 to 6.1, depending on the contribution ratio and discount rate selected. For a nominal discount rate of 8 per cent, the overall benefit cost ratio varies between 2.9 and 5.1, depending on the contribution ratio selected. This range of estimated benefit cost ratios is similar to the range of 3.8 to 4.9 reported for accelerated pavement testing performed in Australia (ARRB, 1992).

- For Gautrans, the estimated direct benefit derived between 1980 and 1990 from the HVS investigations on G1 base pavements is roughly between R2.2 and R14.8 million (in 2004 Rand terms). Taking into account the contribution made by Gautrans to the funding of HVS investigations on G1 pavements, this results in a benefit cost ratio of between 1.4 and 3.6, depending on the discount rate and contribution ratio selected.

- For SANRAL, the estimated direct benefit is roughly between R3.4 and R25.2 million (in 2004 Rand terms). This results in a benefit cost ratio of between 4.2 and 10.2. This benefit cost ratio is higher than that realized by Gautrans, mainly because of the greater scaling of benefits provided by the larger SANRAL pavement network.

It is important to note that these economic benefits include only those aspects which can be converted to economic savings with reasonable confidence and assumptions. There are several other benefits resulting from the HVS investigations on G1 base pavements, which cannot easily be converted to economic savings, yet are sure to impact positively on the Gautrans and SANRAL budgets and networks over the long term. Because of this, the above noted benefit-cost ratios represent a lower bound estimate of the benefits of HVS investigations on G1 base pavements.

FOAMED BITUMEN TECHNOLOGY DEVELOPMENT BENEFITS

To date, the key findings and deliverables that emerged from the test programme on foamed bitumen treated materials were:

- It was confirmed that recycling with foamed bitumen treatment reduces the sensitivity of the material to moisture and density;
- Permanent deformation accumulated at a low rate on well-designed foamed bitumen treated materials - especially when in a dry state.
- Despite the decreased sensitivity to moisture and density of foamed bitumen treated materials, the test programme showed that the material can fail prematurely at low density and high moisture saturation levels.
- It was found that traditional material strength indicators such as Unconfined Compressive Strength (UCS) and Indirect Tensile Strength (ITS) were not always appropriate to evaluate the benefits of foamed bitumen treatment. The real benefit of foamed bitumen treatment seems to lie in the increase in long term durability which is not always properly evaluated with conventional strength indicators;
- A balance between the bitumen and cement content is essential to ensure both flexibility and resistance to permanent deformation. Too much bitumen or cement effectively nullifies the benefit of the other, leading to wasted costs. It was specifically found that too much cement renders the bitumen ineffective.
- It was found - owing to the short time available before the foamed bitumen collapses to a normal bitumen state - that traditional laboratory mixers are too slow to effectively simulate the field mixing process. Because of this finding, a high speed laboratory mixer was specifically developed for the laboratory design of foamed bitumen treated materials;
- The HVS and laboratory tests yielded typical material stiffness and strength parameters that can be used as inputs for the mechanistic-empirical design method;
- Structural capacity evaluation models (i.e. Transfer Functions) were developed to evaluate the structural capacity of pavement layers treated with foamed bitumen;
- Classes of foamed bitumen treated material were identified and defined. These classes provide practitioners with an easy way to group foamed bitumen treated materials into classes from which similar behaviour and performance can be expected;
- A design catalogue and design approach was developed for pavements that incorporate foamed bitumen treated materials. This catalogue and methodology has since been published in the TG2 guidelines (Asphalt Academy, 2002).

Based on interviews with the principal investigators on the foamed bitumen test programme, it was established that the findings of the programme and the information dissemination process had the following impacts on the southern African road building industry:

- Better understanding of the relative contributions or roles of bitumen and cement. In particular, the development work showed that too much cement nullifies the effect of bitumen. This has lead to improved project specifications. The emphasis on obtaining a balance between the cement and binder contents prevents materials wastage.

- The development of a materials classification approach, together with the understanding of differences in behaviour and performance of different materials classes, ensure that materials are appropriately designed for specific situations. This leads to more cost effective and reliable designs;

- An improved laboratory mix design procedures (including the development of a new high speed mixer) which ensures a better agreement between materials prepared in the laboratory and the field. This leads to optimized mixes and minimizes the risk of premature failure owing to inappropriate materials design;

- The development of structural design models for use in the mechanistic-empirical design method, combined with a design catalogue (as part of the TG2 Guidelines), ensure optimized and reliable designs using Foamed Bitumen materials.

The HVS programme and associated laboratory tests have significantly accelerated understanding of the behaviour and performance of Foamed Bitumen Treated Materials. This factor, together with the technical impacts noted above, translates to the following three benefits:

Benefit 1: More cost-effective design of foamed bitumen treated *materials*;

Benefit 2: More cost-effective design of *pavements* incorporating foamed bitumen treated materials;

Benefit 3: More *reliable* design of pavements incorporating foamed bitumen treated materials;

Conceptual frameworks for evaluating economic returns from these benefits were defined and presented. However, the economic benefits were not quantified as part of this study, mainly because the development work on foamed bitumen materials is not yet complete. Also, at present there seems to be considerable debate in the South African road building industry with regards to the advantages and disadvantages of foamed bitumen treatment. Whilst some practitioners seem to be strong proponents of the technology, others seem to feel that foamed bitumen is only practical in exceptional cases (specifically where material quality and layer thicknesses are relatively uniform).

Because of the emerging nature of the technology associated with foamed bitumen treatment (and in fact with deep in-situ recycling technology in general), and specifically since the results of the tests on foamed bitumen treated materials have not been finalized, it was felt that an evaluation of the economic benefits arising from the test programme on foamed bitumen treated materials would be premature. It was therefore decided to postpone the benefit calculation until such time that the scaling of the benefits can be approached with more clarity and confidence.

8.5 INDIRECT BENEFITS

The indirect benefits associated with the HVS technology development programme were outlined and discussed. It was shown that these benefits contribute to (a) Technical Progress; and (b) development of a critical mass of Science and Engineering Technology (SET) human capital. These elements form two of the three key processes that serve the South African Research and Development Strategy goals (RSA, 2000).

The contribution of the HVS technology development programme to Technical Progress was discussed. It was shown how the HVS programme contributed through the following aspects:

- Technical publications (local and international);
- International alliances formed and international interest attracted, and
- High-Tech developments and imports;

The contribution of the HVS technology development programme to SET human capital was discussed. It was shown how the HVS programme contributed to the development of South Africa's SET human capital through the following aspects:

- Educational opportunities created;
- Improvement in Science and Technology Excellence by advancing critical technical aspects of South African pavement technology;
- Creation of employment and career growth opportunities;

8.6 FRAMEWORK FOR BENEFIT ASSESSMENT

A framework for evaluating the benefits arising from technology development projects was presented, with specific emphasis on HVS centred projects. The framework was developed based on the best practice elements outlined in earlier sections as well as the experience gained during the execution of this benefit assessment project. It was shown that the benefit assessment framework consists of the following four steps:

1. **Summarize the Key Technical Findings and Impacts**
   In this step, the primary investigators on the selected project are asked to provide a detailed assessment of the findings of the project. Guidelines are provided according to which data can be collected with respect to the following aspects: (a) technical findings; (b) human resource aspects; (c) contributions to technical excellence; and (d) key impacts arising from the project.

2. **Identify Main Impacts and Develop a Benefit Assessment Strategy**
   This step involves the identification and definition of the main impacts. This information is used to develop a benefit assessment strategy, which involves the three key tasks. These are: (a) the design of a benefit assessment diagram showing alternatives with and without the identified impacts; (b) design of a benefit calculation template, which includes a preliminary assignment of probabilities and contribution ratios needed to perform the calculation; and (c)

obtaining the information needed to calculate unit benefits and to scale these benefits for the network under consideration.

3. **Refine Assumptions and Calculate Benefits**
This step involves the validation of the identified impacts, assigned probabilities and contribution ratios as well as other assumptions that form part of the benefit assessment process. The validation is achieved through interviews with independent users of the developed technology. These users are typically knowledgeable practitioners and client body representatives.

4. **Validate Impacts and Assumptions through Interviews**
Once the identified impacts, contribution ratios and other assumptions involved in the calculation template have been validated, the benefit calculation is performed using the refined impacts and contribution ratios.

Guidelines were provided for the identification and design of benefit-centred technology development process. Key elements highlighted in these guidelines are:

- An overarching, policy-oriented strategic plan is needed to guide the selection and design of candidate projects. The strategic plan should be aligned to the needs of the funding agency.

- The objectives of candidate projects should be evaluated against those of the strategic plan. Proposals or execution plans for candidate projects should show - in a specific manner - how the project findings will impact on and contribute towards the objectives of the strategic plan.

- Potential benefits that are expected to be derived from a candidate project should be clarified at the project design stage. A counter-factual or alternative situation that will develop without the benefit of the project findings should be stated.

- A plan to facilitate technology transfer should form part of the project execution plan. A technology development project which does not contribute to the implementation of findings cannot reasonably claim a high contribution of the realized benefits. Thus, a technology development project should incorporate plans for the transfer of findings to practice. This will ensure a larger contribution ratio and will also greatly speed up the realization of benefits.

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APPENDIX A

Evaluation of Direct Economic Benefits: Supporting Documentation

COST OF TREATMENTS

In order to perform an assessment of the life cycle cost of different situations and alternatives, the costs of different treatment types need to be determined. To obtain these costs, a detailed approach was first attempted in which the various cost items involved in different types of rehabilitation were summarized. The costs of the various work items were obtained from the Committee of Land Transport Officials (COLTO) database of tendered rates (www.coltodatabase.co.za), and were used to construct a typical bill of quantities.

However, a comparison of the unit cost (i.e. Rand per m^2) obtained in this manner for a typical rehabilitation, and the unit costs of actual, typical light and heavy rehabilitations showed that this detailed approach tended to underestimate the overall cost of rehabilitation. It is believed that this is due to the many ancillary works and contingencies that are involved in actual rehabilitation work, but which were not included in the approach that was followed (since it included only the main layer work items).

It was therefore decided to adopt a generalized cost for various rehabilitation types. Such costs are also listed on the COLTO database of tendered rates, under the Management Information link and listed for the Gauteng province. Using the information provided in the COLTO database, the generalized unit costs shown in Table A1 were obtained. It should be noted that these costs do not include ancillary works such as cleaning of drains, etc. The rates which were finally adopted for the life cycle cost analyses is summarized in Table A2.

Table A1: Generalized Unit Costs for Different Rehabilitation Types

Rehabilitation Type	Cost (R/m^2)Per Square Metre, for a Discount Rate of:			
	N/A	**4%**	**8%**	**12%**
	1999	**2004**	**2004**	**2004**
Heavy Rehabilitation	**R 100.00**	R 121.67	R 146.93	R 176.23
Light Rehabilitation	**R 50.00**	R 60.83	R 73.47	R 88.12
Reseal	**R 18.00**	R 21.90	R 26.45	R 31.72

Note: Rates on COLTO database were in 1999 Rand, and thus no discount rate applies to the 1999 column

Table A2: Rates Adopted for Life Cycle Cost Analyses

Adopted Rates for 2004	Cost (R/m^2)
Heavy Rehabilitation	R 145.00
Medium Rehabilitation	R 100.00
Light Rehabilitation	R 70.00
Reseal	R 25.00

SCALING OF EFFECTS FOR THE GAUTRANS NETWORK

The analyses presented in Section 4 show that the overall benefit that is realized owing to the impact of technology development work is directly related to the size of the network. These analyses show that, the larger the size of the network, the larger the benefit and hence also the larger the benefit-cost ratio. For the approach adopted in Section 4, it is specifically the magnitude (in terms of road km) of light and heavy rehabilitation undertaken each year that is of importance.

For the Gautrans network, the quantity of light and heavy rehabilitation that will be undertaken in the ten years between 2005 and 2014 was obtained from the Gautrans budget optimization analysis performed using the dTIMS Asset Management Software♣. Table A3 shows a summary of the recommended maintenance intervention for the Gautrans budget.

Table A3: Predicted Maintenance Interventions for Gautrans, 2005 to 2014.

Planned Maintenance (Road Km) for Optimized Budget					
Year	**Diluted Emulsions (DE)**	**Reseals**	**Light Rehabilitation**	**Heavy Rehabilitation**	**Total Light and Heavy Rehabilitations**
2005	4	75	68	94	**162**
2006	4	152	60	108	**168**
2007	4	104	100	144	**244**
2008	4	91	113	143	**257**
2009	4	67	70	211	**281**
2010	4	24	125	198	**323**
2011	4	71	65	211	**276**
2012	4	79	73	196	**269**
2013	4	78	97	172	**269**
2014	4	103	185	60	**245**
10 Yr Average	**4**	**85**	**96**	**154**	**249**

Table A3 shows that, on average, Gautrans will aim to perform roughly 250 km of light and heavy rehabilitation per year. This value was then adopted as an indicator for the benefit scaling for Gautrans.

♣ This analysis was performed by Africon as part of the Gautrans' annual budget optimization and maintenance needs analysis. Mrs. Ileen Wolmarans of Africon, and Mr. Derek Roux of Gautrans are thanked for their contributions in this regard.

APPENDIX B

Supporting Documentation: Indirect Benefits

Important Technical Publications Impacted by HVS Investigations

PUBLICATIONS AT/IN CONFERENCES AND JOURNALS

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APPENDIX C

Original Work Proposal