A Cost-Benefit Analysis of Heavy Vehicle Simulator Testing and Related Technology Development

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ABSTRACT

The paper describes the outcomes of a study to estimate cost-benefit ratios of technology development projects focused around the Heavy Vehicle Simulator (HVS). Specifically, the study evaluated the benefits of using the HVS to augment and focus the development of crushed stone base technology in South Africa. This technology has been in use in South Africa for more than 25 years and is now considered mature. The technology is therefore well-suited to a cost/benefit analysis. The paper outlines critical aspects of the cost/benefit study, including a description of the approach, identified benefit streams and key outcomes. It is shown that for the projects that were evaluated, a benefit/cost ratio of between two and six is likely, depending on the discount rate and other factors.

INTRODUCTION

The South African developed Heavy Vehicle Simulator (HVS) is a mobile testing unit capable of evaluating the rate and manner in which roads deteriorate within a relatively short period of time. Under normal circumstances, roads deteriorate over a period of eight to twenty years. The HVS, however, can evaluate such deterioration within a period of three to six months. The Gauteng Department of Public Transport, Roads and Works (GDPTRW) has owned a HVS machine since 1978 and since 1994 has been the only road authority in South Africa to operate a HVS through its HVS Technology Development Programme.

Although the HVS technology development programme is to a large extent focussed around the HVS machine, a significant portion of the work is focused on data analysis and transmission of findings to the industry. The technical developments that have resulted from the GDPTRW HVS programme have played a pivotal role in furthering South African road design and construction technology and have led to international recognition of the excellence of this technology.

In recent years, available funding for transport related research and development activities has decreased significantly. It is estimated that the available annual funding for road related research has decreased from more than R50 million in 1991 to less than R20 million in 2003 (Myburgh, 2004) *(1)*. This decrease in funding has impacted significantly on the human resource component involved in research and development activities. With the steady erosion of human resources related to pavement research and development and as the demands of the operating environment start to outstrip the advances in pavement related knowledge, there can be no doubt that, over time, South Africa will find it more and more difficult to provide a cost effective and efficient road network.

A key element associated with the decrease in funding is the relatively high cost of research and development activities conducted in the road building sector. In addition, the impacts of these activities are often of a highly technical nature with the link between applied funding and the associated benefits not always obvious. The lack of immediate, tangible benefits stemming from road-related research funding is a significant detriment when the motivation for funds has to compete with other budget demands such as those related to health and education, which have more immediate and obvious benefits.

In an attempt to investigate and clarify the benefits associated with technology development work in the road sector, GDPTRW initiated a study to develop and execute an appropriate methodology for quantifying the benefits stemming from road-related research and development, with specific emphasis on their HVS Technology Development Programme. This paper outlines critical aspects of the cost/benefit study including a description of the approach, identified benefit streams and key outcomes. The paper also outlines a generic approach to cost benefit assessment which can be used to assess current and future technology development projects in the road engineering sector and provides an example of the direct benefits obtained by applying the methodology to the mature G1 Crushed Stone base technology investigated with the HVS in the 1980s.

KEY IMPACTS FROM TECHNOLOGY DEVELOPMENT PROGRAMMES

In general, the quantification of benefits centres around the assumption of new and freely available information that will impact positively on policies which, in turn, lead to measurable economic benefits. Approaches centred on such assumption have been implemented with success in the field of Accelerated Pavement Testing (APT) (ARRB, 1992) *(2)*. However, this “simple linear model” referred to by Scott et al. (2002) *(3)* 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 the quality of life of the population at large means that the benefits of publicly funded technology development are likely to be greatly underestimated.

In an effort to provide a more accurate assessment of the more diffuse benefits of technology development work, two main categories have been adopted in this study (Jooste and Sampson, 2004) *(4)*; direct (or “delivery”) benefits, and indirect (or “process”) benefits. The two categories are defined as follows:

- Direct 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.
- Indirect benefits arise because of the development process. These benefits largely concern human resource development and the development of a better understanding of the problems facing a particular development area. In a well-managed research and development programme, these benefits will start accruing during the project and submission of the final deliverables. Indirect benefits are not readily quantified into economic terms, and are best monitored and evaluated through indicators and trend analysis.

Although indirect benefits such as the number of employment opportunities created and technical progress are important, it can be argued that at the strategic level a favourable economic indicator such as a benefit/cost ratio provides the most powerful motivation for continued technology development funding. However, quantified estimates of the direct economic benefits arising from technology development work are 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:

- Conceptual and time-related separation between project findings and benefit realization

Whilst the findings of technology development projects may be quite specific, the manner in which the findings are implemented in practice are often more diffuse and general in that several stages of information transfer, along with a period of implementation, are required before benefits are realised. This process is illustrated in Figure 1 and dictates that the link between the technology development project and the benefits thereof are less obvious.

- Benefits often result from several contributing projects and processes

The situation rarely occurs where a single technology development project is solely responsible for a realized benefit. Under normal circumstances, other role players and processes are needed to transform technical findings into policy changes that will result in economic benefits. This is particularly relevant to technology development projects that involve accelerated pavement testing where projects are often identified based on results of earlier work. As such, technology development projects often refine and complete a technology that was instigated and/or supplemented by earlier (often informal or anecdotal) inputs (see Figure 2). Therefore, it is essential to ensure that all contributions to technology development projects (including those leading up to the project and those required to refine and implement policy changes) are taken into account in the benefit assessment process.

- Benefit assessment involves a significant subjective component

Because of the difficulties noted in the two preceding bullets, 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 personnel directly involved in the technology development project. 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) *(5)*, also implemented in ARRB (1992) *(2)* and used by Jooste and Sampson (2004) *(4)* 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.

METHODOLOGY FOR ASSESSMENT OF ECONOMIC BENEFITS

A survey of the technical impacts of road related technology development work, and specifically of those involving accelerated pavement testing, showed that the technical impacts of such work can be generalized into the following three categories (ARRB, 1992 *(2)*; Jooste and Sampson, 2004 *(4)*, Gillen et al. 2002 *(6)*):

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

Direct economic benefits that are typically derived from these impacts can be evaluated in different ways (Jooste and Sampson, 2004) *(4)*. The approach described here compares the life cycle costs of viable scenarios with and without the benefit of the impacts that stem from technology development work. The approach comprises the following steps:

1. The life cycle cost for constructing and maintaining a typical road segment (eg 1 lane km or road) is calculated for scenarios with and without the benefits of technology development work.
2. A probability of occurrence is assigned to each scenario. This probability provides an indication of the average long-term, network-wide likelihood of occurrence for each scenario.
3. The two life cycle costs calculated in step 1 are multiplied by the probabilities assigned in step 2 and the difference between the two products is calculated. This is then the net benefit per road segment.
4. The net benefit per road segment is now multiplied by the size of the network on which the technology development will have an impact. This product provides an indication of the overall network-wide savings that is associated with the impact of the technology development work.
5. The overall saving calculated in step 4 is the expected long term benefit assigned to a specific impact stemming from technology development work. To calculate the benefit stemming from a single contributing development project, a contribution ratio (or a range of ratios) is assigned (eg 30 to 60 per cent) and multiplied by the overall network savings. This yields an estimate of the savings that stem from a specific technology development project. A key aspect of the process used by Jooste and Sampson (2004) *(4)* is that it relies on detailed, documented interviews with key individuals involved in the implementation and use of the technology. These interviews form the basis for the critical subjective assumptions and lend consistency and credibility to the approach.

EXAMPLE OF BENEFITS DERIVED FROM HVS TESTS ON G1 MATERIAL

G1 material can be generally defined as a high quality Graded Crushed Stone which is constructed in a specific manner to obtain a high density, cohesion and friction strength. The technology for manufacturing the materials and constructing pavements with G1 base layers evolved in the late 1950's to early 1960's in South Africa and a construction process was developed in which the fines (minus 0,075 mm material) could be utilised as a lubricant during the final wet compaction process. In the process, excess fines are extracted and discarded, in order to achieve a densely packed stone matrix. This compaction process is known as "slushing" and although it achieves an increase in density of only 3 to 4 per cent over that reached during the normal compaction phase, the overall result is a material with significantly higher shear strength. To achieve this state, a cemented subbase is required to provide a strong, water resistant support on which the final compaction phase is executed.

Application of the then newly developed crusher run specification to heavier pavement designs showed a remarkable ability to handle the heaviest traffic loads, was quite impervious to water ingress and performed relatively well if it became wet. Although the G1 technology seemed promising, the technology as a whole was at the time not well established and there was uncertainty regarding several aspects of the new technology. Of these, perhaps the most important was the lack of confidence in the structural capacity of G1 base pavements. Researchers and engineers struggled to define the boundaries within which a G1 base pavement could be expected to perform well. Specifically, there was uncertainty

regarding the ability of G1 base pavements to handle traffic in the very high traffic category (classified as 12 to 50 million standard axles, or MISA, at the time).

The general attitude of researchers and pavement designers towards the use of high quality Crushed Stone materials for these types of traffic demand is best summarized in a document prepared in 1980 by the Committee on Pavement Type Selection for the National Transport Commission (Freeme et al., 1980) *(7)*. The document entitled "The Economics of Pavement Type Selection", compared the cost effectiveness of various pavement types, including bitumen, tar, crushed rock and concrete base pavements. The following statement, quoted from the introduction, well expresses the attitude towards the use of crushed rock base pavements at that time:

"Only pavements of approximately equal traffic carrying capacity are economically compared in this document. Therefore, in the high traffic range (12 to 50 million standard axles over 20 years), only bitumen base pavements are compared with concrete pavements, even though indications are that other pavement types (such a crushed-rock base pavements) may be potentially capable of carrying these high repetitions of axle loads in certain areas of South Africa. It is considered that insufficient reliable performance data are currently available to make this comparison."

To address the uncertainty with regards to the structural capacity, and also to validate some of the behavioural elements of G1 base pavements, several HVS investigations on G1 base pavements were undertaken between 1978 and 1982. A summary of the main findings with further references can be found in Jooste and Sampson (2004) *(4)*. These HVS tests and associated investigations allowed researchers to calibrate and refine the technology related to G1 base pavements. Some of the main findings from the HVS tests were:

- Pavements with high quality Crushed Stone bases (ie materials that can be classified as G1) are capable of accommodating traffic demands of up to 50 million standard axles;
- The optimum thickness for a G1 base layer on a cemented subbase is 150 mm;
- If a pavement with a Crushed Stone base is maintained with resurfacings at appropriate intervals, the pavement can provide service for an indefinite time;
- For pavements with a G1 base on a cemented subbase, it was found that the damage, or equivalency exponent "n" has a value of approximately 3, and not 4.2 as was commonly accepted at the time;
- The moisture content of the G1 base is a determining factor in the bearing capacity of G1 base pavements. The quality of the Crushed Stone base becomes even more apparent when moisture enters the layer;
- The high quality, high density Crushed Stone (G1), placed on a thick cemented subbase (200 mm or more), showed the least permanent deformation under loading and was also the least sensitive to moisture;
- A more open graded and less dense Crushed Stone was less stable under loading and also acted as a water carrier to distribute water to the rest of the pavement structure (this observation refuted the perception prevalent at that time that more open graded Crushed Stone layers were less sensitive to water as they do not retain water for long periods).
- There was a reasonable correlation between the calculated and observed structural capacities for Crushed Stone layers. This confirmed the appropriateness of the mechanistic design method to analyze these types of structures.

To facilitate the assessment of economic benefits derived from the HVS tests on G1 material several key impacts were identified and are discussed in detail in Jooste and Sampson (2004) *(4)*. After consideration of the data and assumptions needed to convert the impacts to benefits in economic terms, it was decided to combine the identified impacts into the following main benefits:

Benefit 1: Increased use of G1 Base Pavements for higher design classes and wet regions
Benefit 2: Use of a 150 mm maximum thickness for G1 base layers
Benefit 3: Improved maintenance and construction practices

A key element of this benefit assessment is the recognition that needs to be made to other role players that contributed to the realization of the above benefits. As such, the evaluation of economic benefits derived from HVS tests should recognize the process of technology development, as illustrated schematically in Figure 3.

As indicated earlier, an economic benefit can only be calculated if the outcome of a technology development effort can be compared to a scenario that would have existed had the development not been undertaken. Such an assessment includes a large element of uncertainty and subjective judgement. For example, no-one can state with certainty what direction the road-building industry would have taken in the absence of the HVS investigations on G1 base pavements. This is especially relevant in the case of a mature technology such as that of G1 material and its associated knowledge elements that have been assimilated for several decades. Simply put: it is difficult for most South African pavement engineers to imagine a life without G1 material and the knowledge associated with it.

The methodology adopted for the evaluation of economic benefits takes this uncertainty into account, and is based on the framework established by other investigators concerned with assessment of the benefits of technology development work (ARRB, 1992 *(2)*; Swoveland and Cawdery, 1989 *(8)*). Key elements of the methodology shown in Figure 4 are:

- The situation with and without the benefit of HVS investigation findings are assessed;
- The uncertainty of each situation being realized is acknowledged and accommodated by assigning a probability to each outcome;
- The cost of each outcome is determined and multiplied with the probability to obtain the effective cost for a given outcome.

Once the different outcomes and their associated costs are determined, the benefit of the development work is calculated by subtracting (i) the total effective cost of all options without the benefit of HVS investigations from (ii) the total effective cost of all options with the benefit of HVS investigations. The calculated benefit can then be used with the cost of the development to determine an economic indicator such as a benefit/cost ratio or a rate of return.

As noted earlier, each of the identified impacts and benefits were validated through formal interviews with acknowledged experts and key role players in the South African pavement design and construction industry who were involved during the period when the results of the HVS investigations on G1 materials were being incorporated into the industry. Details of these interviews are presented in Jooste and Sampson (2004) *(4)*. In each interview, respondents were asked to comment on each of the identified impacts. Respondents were also asked to comment on the assigned contribution ratio (i.e. the approximate percentage contribution of HVS investigations, specifically, to each impact).

BENEFIT CALCULATION

To illustrate the manner in which economic benefit assessment can be performed, an example is provided of the assessment of the benefits derived from improved maintenance and construction practices. This benefit is related to the impact that the HVS investigations had on improved construction practices, better material specifications and the recognition of the importance of timely maintenance on pavements with Crushed Stone base layers. The background to these aspects is discussed in detail in Jooste and Sampson (2004) *(4)*. To evaluate the economic benefits for these aspects, a life cycle cost calculation was performed for three different performance scenarios. The scenarios are:

- <u>Scenario 1: Typical G1 Base Pavement Performance</u>

This scenario is considered to be the reference case scenario, and is based on the typical G1 base pavement performance as documented in Jooste and Sampson (2004).

- <u>Scenario 2: Delayed Maintenance Causing Earlier Rehabilitation</u>

This scenario represents a case where the maintenance of an impervious surfacing is delayed, with the result that the unbound base rapidly deteriorates when water enters into the layer. The result is earlier structural rehabilitation.

- Scenario 3: Poor Compaction and Material Specifications during Construction

This scenario represents a case where the material used during construction is not of the quality required for G1 materials. More importantly, it assumes a case where the base is not properly compacted. The assumed consequence is early structural rehabilitation caused by deformation in the base and disintegration of the surfacing.

The calculation of the life cycle cost for the three scenarios is presented in Jooste and Sampson (2004) *(4)*. The benefit calculation presumes that, partly as a result of HVS investigations and dissemination of findings to the industry, the incidence of Scenarios 2 and 3 decreased somewhat and the incidence of Scenario 1 increased somewhat. The calculation of the economic benefit is presented in Table 2. The savings realized through this benefit are summarized in Table 1. Key assumptions and supporting notes are:

- The assumed probabilities of each scenario reflect a general improvement in the life cycle design approach for Crushed Stone base pavements. In particular, it assumes that the incidence of delayed maintenance and of poor construction (mainly attributed to poor compaction and inappropriate specifications) decreased from 1980 to 1990. It is further assumed that the HVS investigations and the dissemination of findings significantly contributed towards the decreased incidence of delayed maintenance and poor construction.
- The life cycle cost shown in Table 2 is per square metre and is based on a nominal discount rate of 8 per cent over the 25 year design period considered for the three scenarios.
- The lane-km of road used to scale the cost per square metre to an overall saving is based on the approximate lane-km of road owned by GDPTRW and the National Road Agency (SANRAL) with G1 base layers and traffic loading greater than 3 MISA over a 25 year design period. Details of the calculation of the total lane-km are presented in Jooste and Sampson (2004) *(4)*. The lane-km of road used to scale the cost per square metre to an overall saving takes into account only those G1 base pavements constructed between 1980 and 1990. Thus, the calculation shown in Table 3 essentially considers the benefit to be relevant only for a period of 10 years.

The savings summarized in Table 1 represent the total saving to the GDPTRW and SANRAL attributed to improved maintenance, construction practices and material specifications for G1 base pavements. However, as shown in Figure 3, the HVS was only one contributor towards the realization of these savings. Based on interviews conducted with acknowledged experts in the road building industry, it is estimated that the contribution of the HVS to effecting this shift toward improved maintenance and construction practices is between 30 and 60 per cent (interview details can be found in Jooste and Sampson, 2004). Thus, for a nominal 8 per cent discount rate, the estimated contribution of HVS tests on G1 base pavements to this benefit is approximately between R5 million and R9 million (in terms of 2004 Rand).

OVERALL BENEFIT ASSESSMENT

The overall estimated economic benefit stemming from the HVS tests on G1 base pavements is summarized in Table 3. The data is based on economic assessments of the three main benefits noted earlier. For each of these benefits, the assessment process that was illustrated in the previous section was followed. Details of the assumptions and calculations can be found in Jooste and Sampson (2004) *(4)*. Key observations stemming from Table 3 are:

- The overall benefit/cost ratio for the combined networks of GDPTRW 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) *(2)*.

- For the GDPTRW network, 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 GDPTRW 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 the SANRAL network, the estimated direct benefit is 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 GDPTRW, mainly because of the greater scaling of benefits provided by the larger SANRAL pavement network.
- It should be noted that the totals shown in columns 3, 4 and 5 of the tables in Table 3 represent a total which consists of the sum of all the lowest estimated contribution ratios. Thus, the benefit/cost ratios shown in these columns represent a highly conservative benefit estimate.

SUMMARY AND CONCLUSIONS

The paper outlines critical generic aspects to be considered when undertaking a cost/benefit study including a description of the approach, identified benefit streams and key outcomes. An example of how to apply the methodology to assess the direct economic benefits of HVS testing in the development of a mature technology related to G1 Crushed Stone base is also provided. The approach used in the example has now been adopted by GDPTRW to assess and prioritise current and future projects in their HVS Technology Development programme based on the likely benefits to accrue from the specific projects. Key aspects of the benefit assessment methodology described in the paper are:

- The method focuses on the quantification of direct benefits. Indirect benefits (such as those relating to education) are qualitatively expressed through trend analysis and statistical indicators.
- A first step in the method is the identification of the primary benefits stemming from research. Scenarios with and without these benefits can then be constructed and form the basis for a cost/benefit evaluation.
- The method acknowledges upfront that benefit estimation related to research cannot be realistically performed without making subjective assumptions. A key assumption is the “contribution ratio” which estimates how much of the development benefits can be attributed to the development project and how much to earlier developments and other contributors.
- Documented interviews with key individuals involved in the implementation and use of the research form the basis for substantiating the subjective assumptions.

The example presented in the paper shows that for the selected HVS development project, the overall benefit/cost ratio varies from 2.4 to 6.1, depending on the contribution ratio and discount rate selected. It is important to note that the benefit assessment presented here only includes those aspects which could be converted to economic savings with reasonable confidence. There are several other benefits resulting from the HVS investigations on G1 base pavements which cannot easily be converted to economic savings but are sure to impact positively on road agency budgets and networks over the long term. These Indirect Benefits include aspects such as:

- Calibration of the South African mechanistic-empirical design method;
- Technology transfer to local and international practitioners which raised the technical competence of designers working for road agencies;
- 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 the above impacts are included in this assessment of purely economic benefits, the benefits presented in this paper clearly represent a lower bound estimate of the benefits of HVS investigations on G1 base pavements. As suggested by Scott et al (2002) *(3)*, any simple linear benefit assessment process 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 documented here probably greatly underestimates the true benefit stemming from the HVS investigations on G1 base pavements. It does, however, present one approach to the rational, if conservative, estimation of purely economic benefits.

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LIST OF TABLES

TABLE 1 Savings Realized Due to Improved Maintenance and Construction Practices
TABLE 2 Benefit Calculation for Improved Maintenance and Construction Practices
TABLE 3 Summary of Benefits Derived from HVS Investigations on G1 Base Pavements

LIST OF FIGURES

FIGURE 1 Pattern of Benefit Evolution from Knowledge Created by Technology Development Projects
FIGURE 2 Technology Development to Policy Change (concept after Ounjian and Carne, 1987; and Horak et al., 1992).
FIGURE 3 The Contribution of HVS Investigations to the Development of G1 Technology (concept after Ounjian and Carne, 1987; and Horak et al, 1992).
FIGURE 4 Methodology for Evaluating the Economic Impact of G1 Development Work (based on ARRB, 1992).

TABLE 1 Savings Realized Due to Improved Maintenance and Construction Practices

Benefit To	In Terms Of	At a Discount Rate Of:		
		4%	8%	12%
Gautrans	1978 Rand	R 611,679	R 469,668	R 364,108
	1985 Rand	*R 804,928*	*R 804,928*	*R 804,928*
	2004 Rand	R 1,695,861	R 3,473,828	R 6,932,651
SANRAL	1978 Rand	R 2,188,632	R 1,680,505	R 1,302,807
	1985 Rand	*R 2,880,090*	*R 2,880,090*	*R 2,880,090*
	2004 Rand	R 6,067,916	R 12,429,609	R 24,805,531
Total	**1978 Rand**	**R 2,800,311**	**R 2,150,173**	**R 1,666,915**
	1985 Rand	***R 3,685,018***	***R 3,685,018***	***R 3,685,018***
	2004 Rand	**R 7,763,777**	**R 15,903,436**	**R 31,738,182**

Note: Savings were calculated in terms of 1985 Rand, and thus the discount rate does not affect the savings in 1985 terms.

TABLE 2 Benefit Calculation for Improved Maintenance and Construction Practices

Roads with > 3 MISA Design Traffic					
Situation	**Performance Alternatives**	**Probability of Realizing**	**Life Cycle Cost**	**Adjusted Cost**	**Total Adjusted Cost**
Without HVS Test Programme	**Typical**	0.6	R 18.97	R 11.38	**R 20.34**
	Delayed Maintenance	0.3	R 20.91	R 6.27	
	Poor Construction	0.1	R 26.88	R 2.69	
With HVS Test Programme	**Typical**	0.8	R 18.97	R 15.18	**R 19.66**
	Delayed Maintenance	0.15	R 20.91	R 3.14	
	Poor Construction	0.05	R 26.88	R 1.34	
Savings	R 0.68	per square metre			
	R 2.65	per metre of 3.9 m wide lane			
	R 2,652.00	per Km of 3.9 m wide lane			
Cost Scaling:	**Owner**	**Km**	**Saving**		
	GAUTRANS	301	R 798,252		
	SANRAL	1077	R 2,856,204		
Total Aggregated Saving Estimate			**R 3,654,456**		

TABLE 3 Summary of Benefits Derived from HVS Investigations on G1 Base Pavements

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

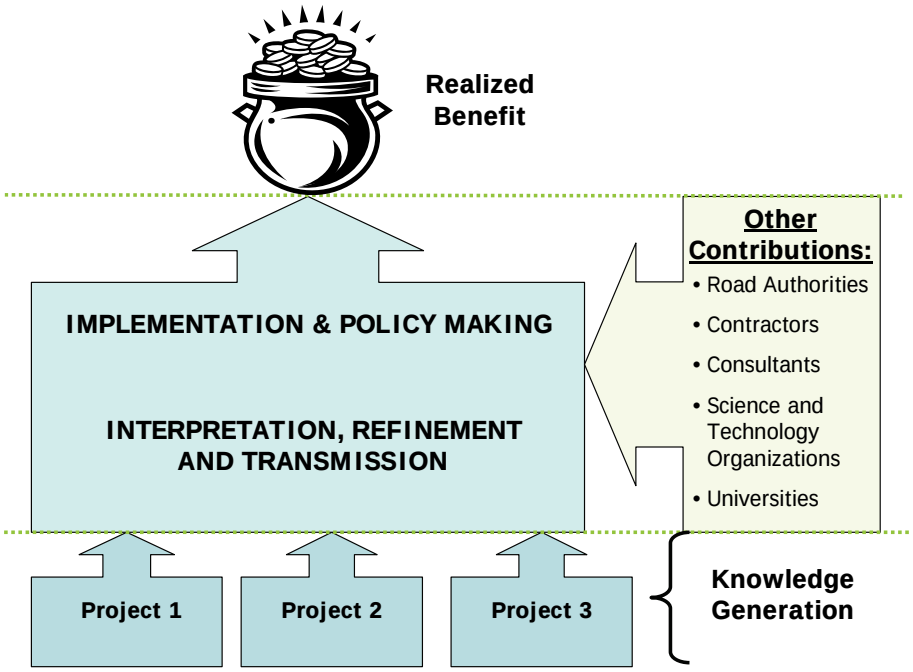

FIGURE 1 Pattern of Benefit Evolution from Knowledge Created by Technology Development Projects.

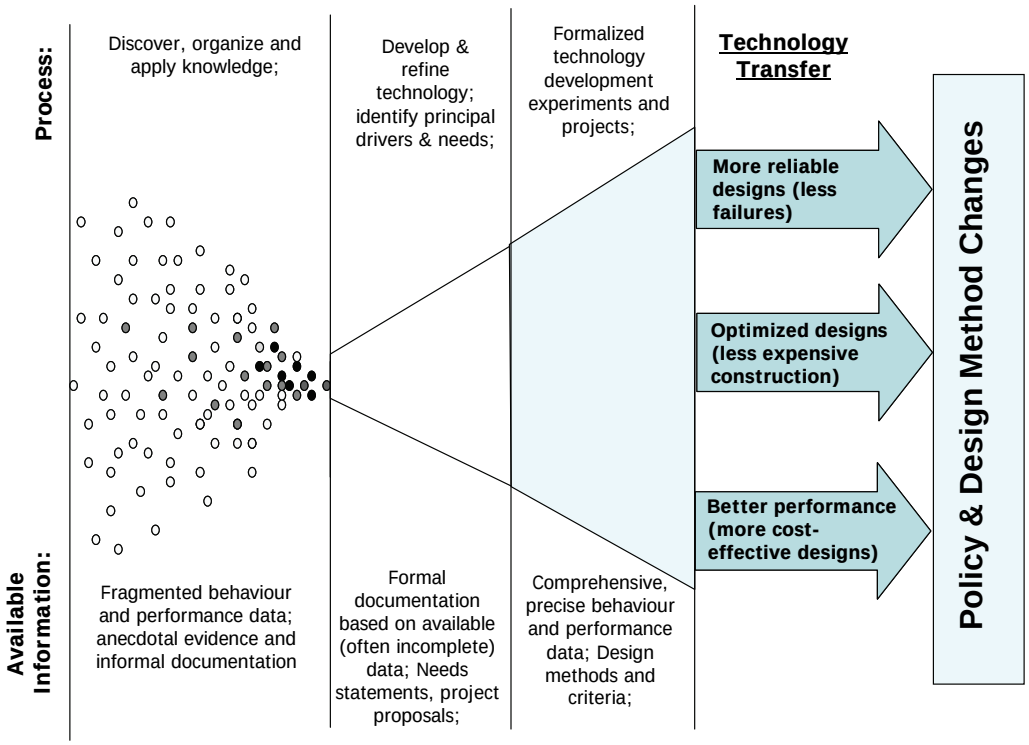

FIGURE 2 Technology Development to Policy Change (concept after Ounjian and Carne, 1987 *(9)*; and Horak et al., 1992 *(10)*).

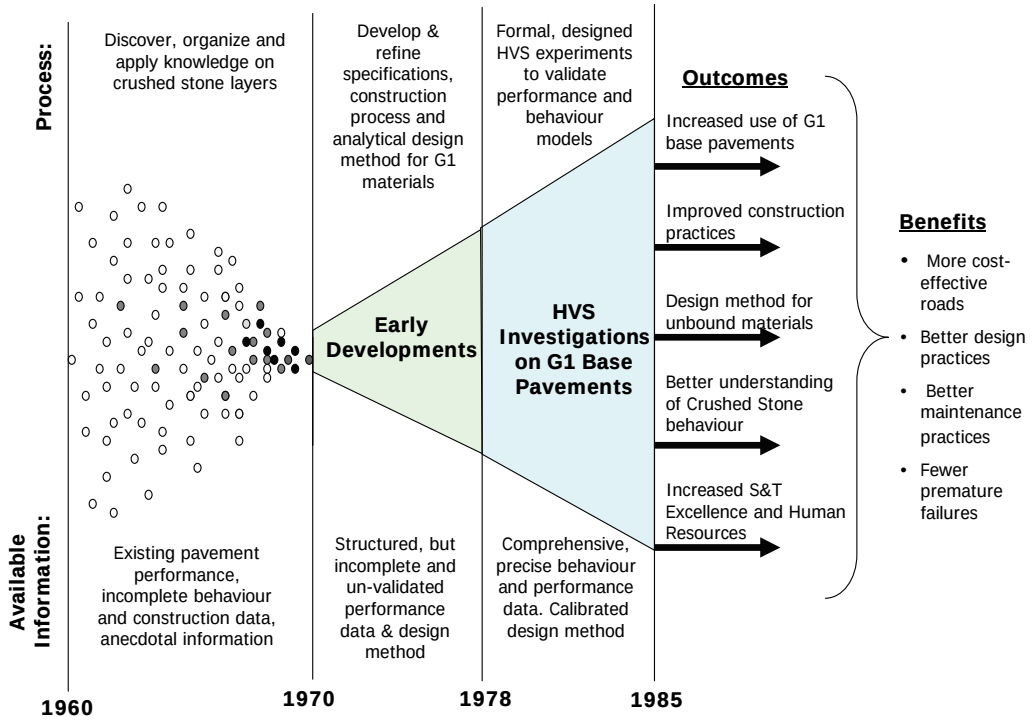

FIGURE 3 The Contribution of HVS Investigations to the Development of G1 Technology (concept after Ounjian and Carne, 1987 *(9)*; and Horak et al, 1992 *(10)*).

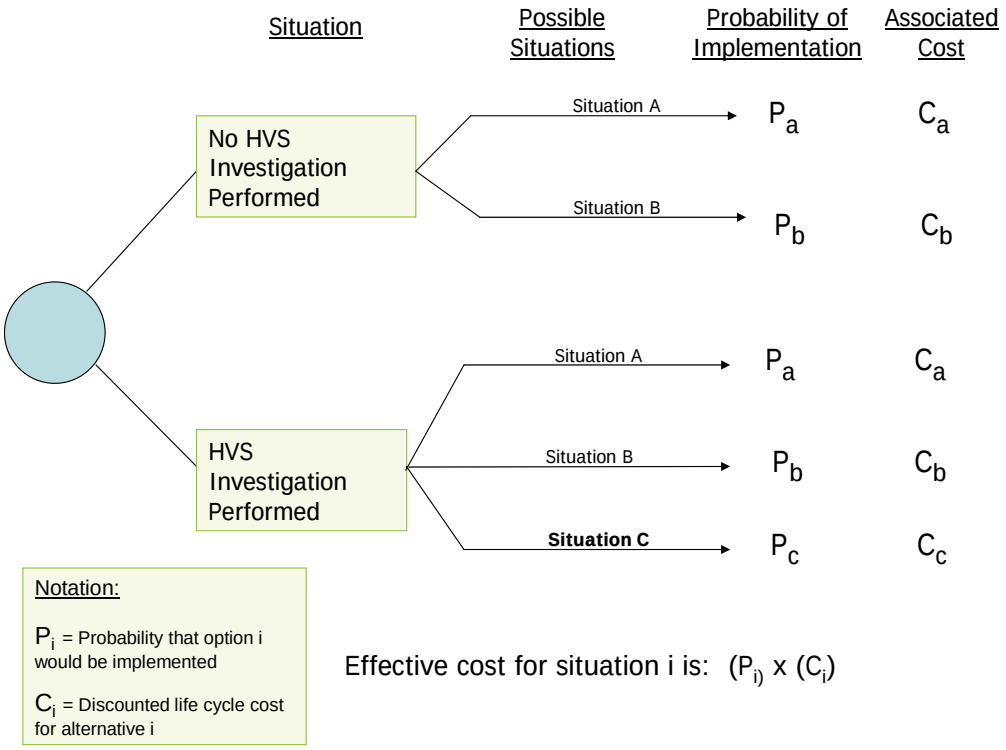

FIGURE 4 Methodology for Evaluating the Economic Impact of G1 Development Work (based on ARRB, 1992 *(2)*).