EVALUATION OF BENEFITS ARISING FROM PAVEMENT ASSOCIATED TECHNOLOGY DEVELOPMENT WORK

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ABSTRACT

This paper outlines a general approach to the evaluation of the economic benefits arising from technology development work related to pavement design and construction technology. The basic concepts of benefit assessment are outlined, and impacts that are typically derived from pavement associated technology development work are defined and discussed. The paper uses an example to illustrate how economic benefits derived from technology development projects related to the road-building sector can be calculated. The example uses a typical life cycle cost comparison assuming scenarios with and without the benefit of technology development work. The example calculations are shown explicitly and assumptions are clearly stated so that variations on the examples can be easily considered. The example shows how the derived economic benefit is related to the size of the road network on which the technology development impacts are applicable. It is shown that, for the stated assumptions (which involve a typical two year technology development project), a benefit-cost ratio in excess of 1.0 is obtained for any network which involves in excess of 150 km of medium to heavy rehabilitation per year, if a single impact is considered in isolation. It is pointed out that this evaluation of economic benefits does not incorporate the more intangible benefits of technology development, such as contribution to technical progress and development of science and engineering technology (SET) human capital. Because of this, indicators of direct economic return (such as the benefit-cost ratios shown in this paper) always present a lower-bound estimate of the actual benefits related to technology development projects.

1. INTRODUCTION

Traditionally, the challenge of providing cost effective pavement design and construction practices has been well met in South Africa. A significant contributing factor in this regard is the relatively strong research and development resources (specifically human resources) that have traditionally been available in South Africa, and which is held in high regard across the world. 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 R 50 million in 1991 to less than R 20 million in 2003 (Myburgh, 2004).

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. Also, since the impacts of these activities are often of a highly technical nature, the link between applied funding and the associated benefits is not always clear. The lack of immediate, tangible benefits stemming from road-related research funding is a significant detriment when such funding 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, Gautrans 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 the Gautrans HVS Technology Development Programme. In this paper, some of the findings of this study are outlined and discussed. Specifically, the paper summarizes the key impacts that stem from road-related technology development work, and outlines methods for evaluating the economic benefits that can be derived from such impacts. Example calculations are provided to illustrate the concepts that are presented. Given the background to this study, the discussion and examples are related to HVS Technology Development work, but it should be noted that the concepts can be applied to road-related research and development activities in general.

2. CONCEPTS OF BENEFIT EVALUATION

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.

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 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:

2.1 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 those findings are implemented in practice are often more diffuse and general. This effect is illustrated in Figure 1, 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.

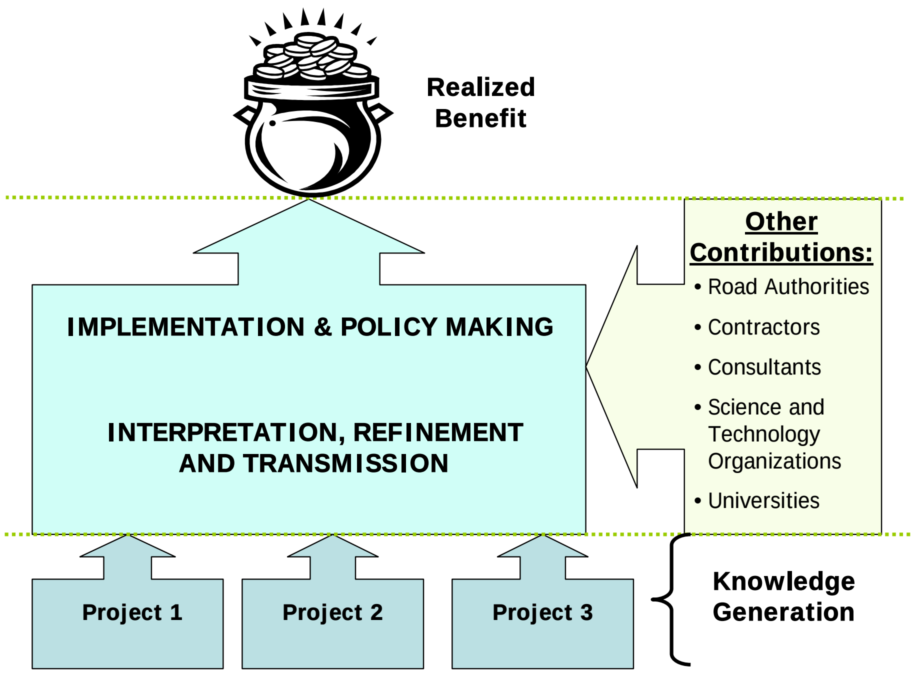


Figure 1: Pattern of Benefit Evolution from Knowledge Created by Technology Development Projects

2.2 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 1, 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 2. 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.

2.3 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) and Jooste and Sampson (2004) 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.

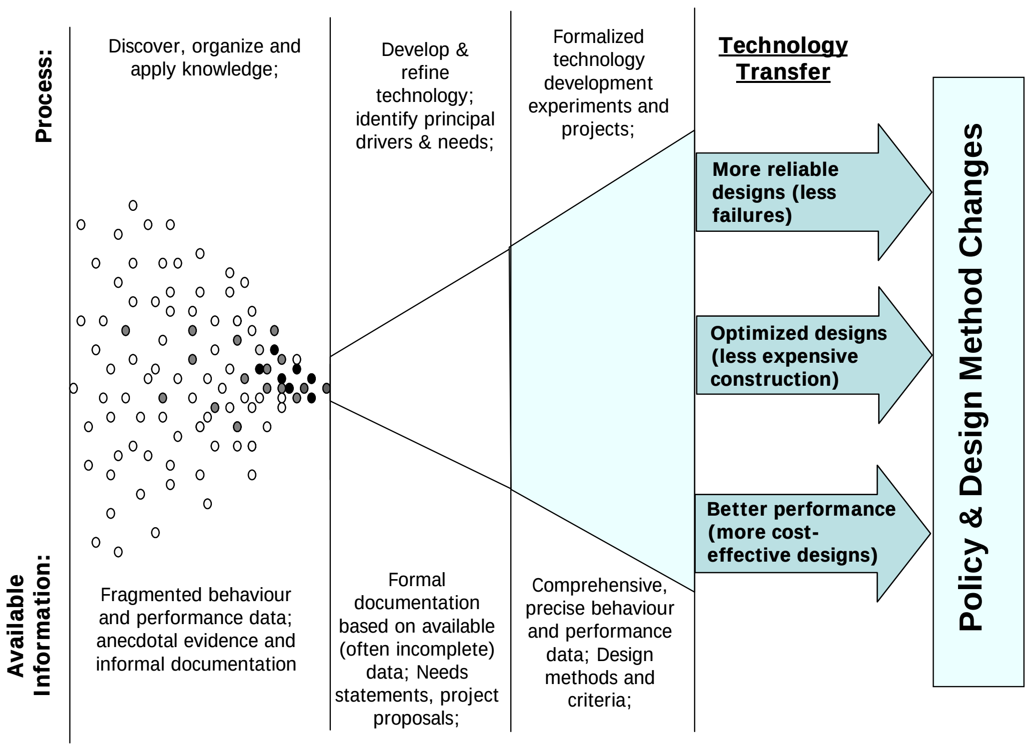


Figure 2: Technology Development to Policy Change (concept after Ounjian and Carne, 1987; and Horak et al., 1992)

3. METHODOLOGY FOR ASSESSMENT OF ECONOMIC BENEFITS

A survey of the technical impacts of road related technology development work, and specifically of those that involve accelerated pavement testing, showed that the technical impacts of such 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 can be evaluated in different ways (Jooste and Sampson, 2004). This paper focuses on an approach which compares the life cycle costs of scenarios with and without the benefit of the impacts that stem from technology development work. This approach comprises the following steps:

1. The life cycle cost for constructing and maintaining a typical road segment (e.g. 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 can now be 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 due to the impact of the technology development work.
5. The overall saving calculated in step 4 is the expected long term benefit owing 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 (e.g. 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.

4. EXAMPLE: LIFE CYCLE COST APPROACH

An important impact of technology development projects relates to the reliability of design practices. For example, 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.

4.1 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 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. Key assumptions relating to this example are defined below. More detailed assumptions relating to treatment costs and network sizes are provided in Jooste and Sampson (2004).

4.2 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 reduces the incidence of premature failures. 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.

Examples of More Reliable Design and Construction Practices Resulting From Technology Development Projects

- 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 identified 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 when 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.

4.3 Results and 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 3. The scaled total savings and benefit-cost ratios are summarized in Figure 4 for road networks of various sizes. The highlighted line in Figure 4 represents an annual pavement rehabilitation length that is roughly appropriate for the Gautrans network.

Evaluation of the Cost of Premature Failure

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 Premature Failure

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	**3**	
Action: Correct Premature Failure	**R / m²**	**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 / 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 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**

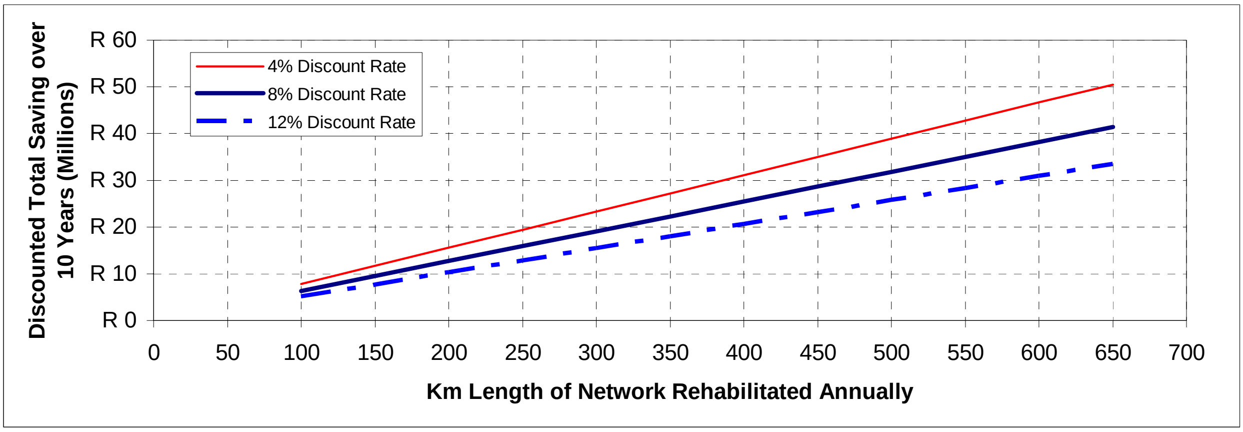
Note: A lane width of 3.7 m is assumed, plus an effective shoulder width of 0.5 m. Thus the effective lane width is 4.2 metres.

Figure 3: 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			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 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



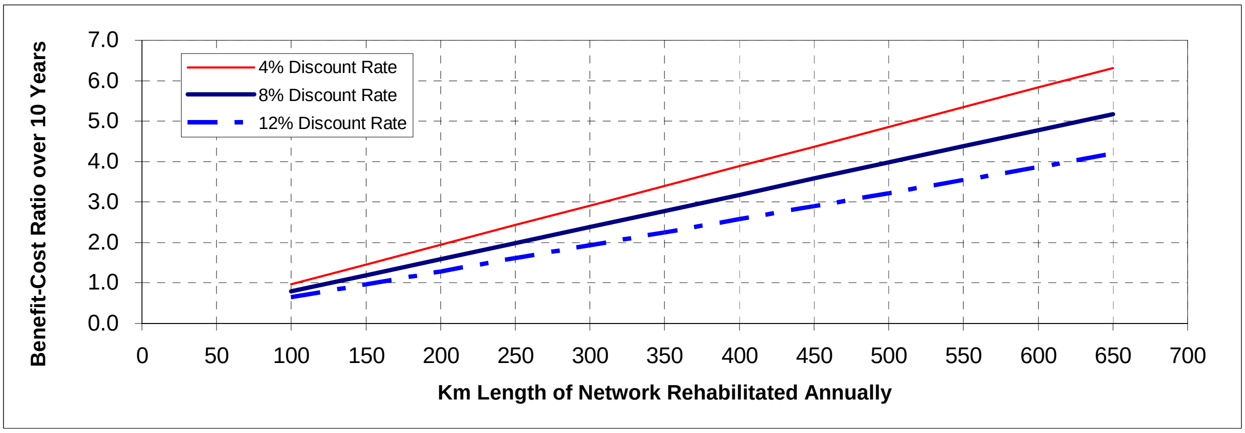


Figure 4: Scaling of Savings Resulting from More Reliable Design and Construction Processes

Figure 4 shows the following:

- The benefit derived from more reliable design and construction aspects is directly dependent on the size of the network.
- For this example, and for the stated assumptions, a benefit-cost ratio of 1.0 or greater is derived on any network that performs medium to heavy rehabilitation on more than 150 km of lane-km per year
- For a network that performs roughly 250 lane km of medium and heavy rehabilitation per year, and for the stated assumptions, the benefit derived from more reliable design and construction practices is roughly between R 12 million and R 20 million, which implies a benefit cost ratio of 1.6 to 2.4.
- For a network that rehabilitates 500 km of road per year, the estimated benefit is roughly between R28 million and R39 million, which implies a benefit-cost ratio of 3.2 to 4.9.

It should be noted that in this example, the benefit assessment is focused on only one of the three general impacts that can be derived from technology development projects. In many instances, technology development work can result in more than one impact (e.g. more reliable and more cost effective design and construction practices). For such projects, this example would naturally provide a lower-bound estimate of the actual long term benefits.

5. SUMMARY AND CONCLUSIONS

This paper discusses and evaluates the benefits that can be derived from road-related research and technology development projects. The basic concepts of benefit assessment are presented, and the impacts that typically derive from road related research and development projects are defined. An example is presented to illustrate how economic benefits derived from technology development projects can be calculated.

Based on the results of the example considered in this paper, and on the more thorough documentation presented in Jooste and Sampson (2004), it is clear that significant benefits can be derived from technology development projects in the road-building sector. This fact stems largely from the size of most road networks, which introduces a multiplication factor that greatly amplifies even small benefits resulting from technology development projects.

For the example presented here, a benefit cost-ratio of 1.0 or greater is derived on any network that performs medium to heavy rehabilitation on more than 150 km of lane-km per year. For a network that performs roughly 250 lane km of medium and heavy rehabilitation per year, and for the stated assumptions, the benefit derived from more reliable design and construction practices is roughly between R 12 million and R 20 million, which implies a benefit cost ratio of 1.6 to 2.4. For a network that rehabilitates 500 km of road per year, the estimated benefit is roughly between R28 million and R39 million, which implies a benefit-cost ratio of 3.2 to 4.9.

It is important to note that the impacts defined and discussed in this paper, and specifically the calculation example, does not include any of the indirect benefits associated with technology development projects (such as educational benefits). It will thus be appreciated that the benefit assessment presented in this paper represents a lower bound estimate of the potential benefits of road-related technology development work. As suggested by Scott et al (2002), the simple linear benefit assessment process that was followed in this paper 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 road-related technology development work.

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