

EVALUATING FACTORS IN SUSTAINABLE ROAD CONSTRUCTION AND MANAGEMENT – A LIFE CYCLE APPROACH

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Roads perform an important connecting function for the community. At the same time their design, construction and operation are not always easy from the point of view of sustainability. Achieving sustainability in this process requires the undertaking of initiatives such as sound environmental management, water sensitive urban design, use of advanced and recycled materials, and environmentally responsible project management and construction. The contribution of such factors to a particular road project can be different for alternative options for constructing and managing the road. This can be an issue in comparing these options. A methodology is proposed to address this issue through calculating a weighted score of the sustainability related economic, environmental and social factors for each option, using a life cycle management approach that considers stakeholder requirements. As the variables in this process tend to be measured in a range of units and may be either quantitative or qualitative, each variable in a given road construction option is both given a weight and also assigned a suitable comparative score obtained through calculation for quantitative variables, or using a utility approach for qualitative variables. The calculated total weighted scores for various road construction and management options may then be compared when assessing the most sustainable option. An example calculation that compares the weighted sustainability for two road construction options is provided. The approach described is flexible and may be used in conjunction with other methodologies, and is also capable of being developed into a suitable computer based modelling tool.

Keywords: sustainability, roads, development, construction, management.

INTRODUCTION

While roads are important transportation and communication links, there are some concerns about their sustainability aspects. In particular, while roads have both economic and social benefits, there is concern about their impact on the natural environment. The main environmental issues with roads tend to revolve around greenhouse gas emissions from the traffic they carry. They also have other potential

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environmental and social effects, such as their ability to impact on natural landscapes and on those who live near them.

However, it is possible to construct and manage roads in an environmentally and socially responsible manner. Another aspect of road sustainability is that roads, as a significant component of the transportation fabric of society, should be available for as much time as possible. In particular, major routes should wherever possible. If they are not, essential goods may not be able to be transported and there is significant impact on the economy. In the flood disasters in 2011 in Queensland, Australia, for example, some major transportation routes were unable to be used both during and for some time after being flooded, with consequent social and economic effect.

Roads are significant contributors to national wealth and are vital elements of the social fabric in many nations. They also represent a significant component of national infrastructure capital.

Given the tension between the environmental impact of roads and their importance in modern society, road authorities and governments have provided guidance on the planning, development and operation of roads in a sustainable manner. For example, the United Kingdom Stationery Office has provided a guide to sustainable highways for the use of local authorities (Department of Transport Office, 2008). This document provides advice for local authority engineers on the choice of sustainable materials and techniques for highway maintenance and construction.

Similarly, the European Union Road Federation has produced a discussion paper on sustainable roads (European Union Road Federation, 2007). This particular document discusses the importance of reliable road networks in developing countries in the connection of communities (and hence their prosperity), the trend towards cleaner road transport, environmentally sound road design, and the ethical balance between the societal advantages of road provision and environmental sustainability.

While it is recognised that many aspects of sustainable roads are developed during planning and design, this paper concentrates on the construction and operation phases of the road life cycle. It uses a life cycle approach to demonstrate, from the point of view of stakeholders, a methodology for the evaluation of environmental, economic and social aspects of road construction and management. This approach focuses on the road pavement and surfacing, and therefore excludes road transportation activities (which would have been considered in the planning and design phases of the road life cycle) and the development of drainage structures, road furniture and similar construction.

Following a discussion of the relationship between the road and its environment, this paper discusses some potential issues in the construction and management of sustainable roads, discusses the road life cycle and investigates options for evaluating these factors using a strategic approach based on this life cycle.

THE RELATIONSHIP BETWEEN THE ROAD AND ITS ENVIRONMENT

To better understand the issues in sustainable roads, it is firstly important to understand the concept of sustainability, and then to understand how roads interact with their environments and communities.

The concept of sustainability used in this paper is based on the well-known definition of sustainable development used by Brundtland (1987), which is “meeting the needs

of the present without compromising the ability of future generations to meet their own needs." Such sustainability, as commonly understood, has three components, all of which require to be kept in balance - economic sustainability, social sustainability and environmental sustainability. Thus, while from an economic viewpoint roads are required to be built and managed to a budget and provide economic benefit, it is also necessary to consider their impact on society and the physical environment.

Figure 1 shows a simplified view of a road within its physical, environmental and social environments. The road consists of a sealed pavement, along which flows traffic. It is built on a subgrade and interacts environmentally with the biosphere (atmosphere, lithosphere and hydrosphere). It also interacts with the economic environment (for example, construction and maintenance cost, benefits and costs of transportation, bringing business to local communities) and the social environment. The social environment in this model consists of three overlapping communities - the road owner, the road user and the external community.

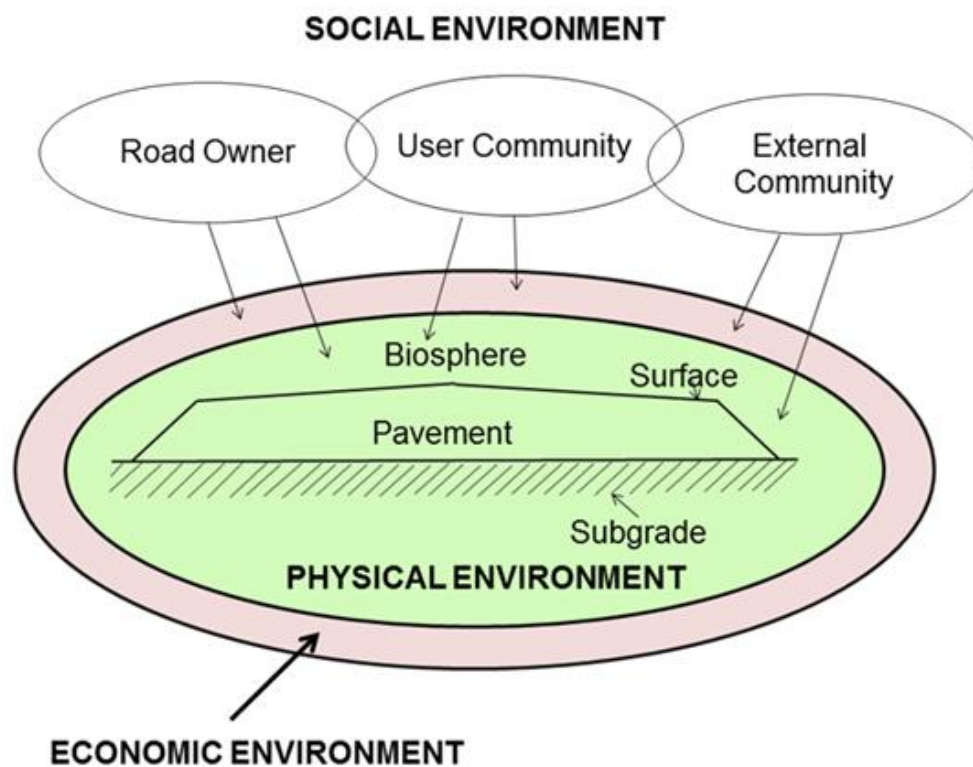


Figure 1: Relationship between road and its environments.

The owner of the road will expect the road to perform to a particular standard of service at minimum cost and provide maximum return on investment.

Road users expect the road to convey them as quickly, efficiently and smoothly as possible. They interact with the economic environment (for example, benefits and costs of transportation), and the social environment (for example, social benefits of using the road).

The external community consists of those people or organisations affected by the road. They may be property owners or tenants bordering or near the road, people who depend on the road for delivery of goods and produce, taxpayers who pay for the road, and other people are impacted by the road. The road may either deliver to this community benefits (for example, better access to transportation, improved property

values) or costs (for example, noise, pollution, resumed property, reduced access to local facilities). They are likely to be the group most directly impacted by the presence of the road, and have considerable influence within the local social environment.

These communities, or stakeholders in the road, therefore each have different requirements of the road. Sustainable road construction will require consideration of these requirements, and of stakeholder expectations within each of the physical, economic and social environments. It will also be required to meet legal environmental management requirements.

FACTORS IN THE CONSTRUCTION OF SUSTAINABLE ROADS

The construction and management of a sustainable road therefore requires consideration of a number of factors related to both legislative requirements and good sustainable management practices. Some of the factors in this process, as related to construction and management of the road, are described below.

Road Material Selection and Use

As with buildings (Sattary and Thorpe, 2011), it is important to minimise the embodied energy in road construction and maintenance materials. For example, consideration should be given to the selection, subject to their suitability, of locally occurring materials for aggregates, in order to reduce embodied energy of the transportation effort of importing material onto the construction site.

Minimising embodied energy is enhanced by the use of recycled materials and the recycling of pavement and surface materials during road rehabilitation or replacement. The use of recycled aggregate is quite common and recycled glass has also been used for road or pathway pavements in Australia (Fisher, 2010). As with all materials, caution is required in using recycled materials. For example, it is important to take measures to reduce leaching of contaminants from residual Portland cement in recycled concrete aggregate (Petkovic and Engelsen, 2004). However, provided the materials for recycling are selected with care and knowledge about their advantages and disadvantages, judicious reuse of selected materials can lead to substantial embodied energy savings and decrease waste.

Another option for addressing embodied energy of material is in-situ stabilisation of existing materials, using materials like cement, lime, or powdered polymers. This process can be used to effectively utilise available materials without using non-renewable pavement material. It reduces the use of imported material (often to a small percentage of the host material), and it is claimed that the pavement life can be similar to that of a pavement using aggregate (Wilmot and Wilmot, 2003).

Road Construction Processes

As construction activities significantly impact on waste, energy use and greenhouse gas emissions (Wallace, 2005), sustainability has increasingly become important from a project delivery point of view. Consequently, there has been pressure for the construction industry to be more accountable for its social and environmental impacts. Road development organisations have also recognised the importance of sustainability, with organisations like the International Roads Federation supporting green public procurement, which aims to procure goods, services and works with a reduced environmental impact throughout their life cycle (Roads Australia, 2012).

The importance of sustainable practices in construction is being recognised by regulatory authorities. Thus, the United Kingdom has a strategy for sustainable

construction that considers both the means (procurement, design, innovation, people and regulation) and the ends (such as climate change mitigation and adaptation, water, biodiversity, waste and materials) for sustainable construction (Department for Business, Innovation and Skills, 2008).

Planning and Design

The planning and design process defines the parameters of the road development, and also specifies the construction parameters. Sustainable planning and design may lead to reduced energy use, sustainable management of resources and waste management (Sinclair Knight Merz, 2009). Design also impacts on items like material selection and pavement design. For example, water sensitive urban design, which can be managed by innovations like permeable concrete pavements, is likely to impact on both construction and material selection and placement (Thorpe and Zhuge, 2010).

An important consideration from the social aspect of sustainability is safety in design. In Queensland, Australia, for example, a designer has an obligation to minimise risks in the design of a structure so that the design does not adversely affect the workplace health and safety of persons either during or post construction (Queensland Government, 2007). This requirement has implications for the whole road life cycle.

Finally, one important consideration in both design and construction is ensuring quality of materials and construction processes. For example, control of variability (such as in the properties of materials) will contribute to improved and more predictable outcomes for the road over its life cycle (Thorpe, 1998, pp. 116-124).

Availability of Key Roads

In January 2011, there was significant flooding in Queensland, Australia. This flooding caused damage to infrastructure, including roads, and therefore impacted on society and the economy. One estimate is that the Queensland transport sector lost AUD 467 million in revenue during this month (IBISWorld, 2011). The temporary loss of main connecting roads at such a time underlines the requirement to construct and maintain key roads so that they remain open as much as possible.

THE FACTORS AS PART OF THE ROAD LIFE CYCLE

While it is necessary to comply with legislation and it is highly desirable for road development to achieve recognition for sustainability, stakeholders are also likely to expect optimum sustainability performance for a particular road. To achieve this goal, it is necessary to consider and assess the contribution of the factors in the construction and management of the road over its life cycle. As a first step in this analysis process, the factors in sustainable road construction may be classified by the phase of the road life cycle in which they occur, and the stakeholder group impacted by the factor.

The road life cycle can broadly be subdivided into planning, development and operational phases. Each of these phases can be further subdivided into sub-phases. For example, the development phase may be subdivided into analysis, design, and construction. The operational phase may be subdivided into operation and retirement (Thorpe, 1998, pp. 22-25). For the purposes of evaluating sustainable construction, the life cycle may be considered as starting at the design phase.

Table 1 illustrates some of the factors, based on those discussed above, in sustainable road construction, their relationship with the life cycle phase in which they occur and the potential stakeholder groups interested in or affected by them.

Table 1: Selected sustainable construction factors by life cycle phase and stakeholder group.

Factor	Life Cycle Phase	Economic Environment	Physical Environment	Social Environment
Energy usage over life cycle	Construction Operation	Owner	Owner External	External
Use of locally occurring materials	Design Construction	Owner	Owner External	External
In-situ stabilisation	Design Construction Operation	Owner	Owner External	External
Use of recyclable materials	Design Construction Operation	Owner	Owner	External
Sustainable procurement practices	Construction Operation	Owner	Owner	External
Management of waste	Construction Operation	Owner External	Owner External	External
Innovative sustainable construction	Construction Operation	Owner External	Owner External User	Owner External User
Water sensitive design and construction	Design Construction Operation	Owner External User	Owner External User	External User
Safety in design	Design Construction Operation	Owner External User	Owner External User	Owner External User
Quality of materials and processes	Design Construction Operation	Owner External User	Owner External User	Owner External User
Ability to use road at all times	Design Construction Operation	Owner External User	Owner External User	Owner External User

Most of these factors listed above are measured in different units. However, they require consideration in any evaluation of sustainability on an equivalent basis. In addition, several are qualitative in nature. They may also be stochastic in nature and have some interdependency. In order to simplify and make practical the analysis process, a methodology, using three stages, that assumes in the first instance that variables are deterministic and independent, is proposed below. This process is based on, but considerably simplifies, that of Thorpe (1998), and may be applied at either the individual stakeholder level or from an overall viewpoint. The stages in it are:

- Adopt a scoring system that enables factors expressed in different units of measurement to be included in the evaluation on an equivalent basis.
- Weight the factors with respect to each other.

- Calculate a weighted total score combining the weights and the scores of individual factor values.

Adopting a scoring system that to allow the factors to be considered on an equivalent basis

In order to provide an approach that permits a mix of quantitative and qualitative variables to be combined in the same analysis on an equivalent basis, it is proposed that each variable in the evaluation be assigned a score on the same rating scale (for example, ranging from zero for the lowest value to five for the highest value). For quantitative variables, the score would be assigned on the basis of calculation based on a formula that relates the scores to actual variable values. For some factors (for example, energy use), the lowest value of the variable may correspond to a high score and vice versa, and in such cases an inverse formula would be used. Thus for energy use, for example, low energy use might have a score of (say) 4.5, and high energy use might have a score of (say) 0.5.

Assessment of qualitative variables (for example, use of good water management practices) tends to be more subjective. While such variables can be ranked on an ordinal scale, one approach to assigning a score to them is by assigning to them a utility value derived from a risk profile based on the indifference point between various combinations of worst and best expected outcomes, given the probabilities of receiving each (Hamburg, 1970, pp. 631-644). For example, the benefit of a particular road could be traded off against the risk of poor drainage practices resulting from the construction process. In this case, a score of five, for example, might be allocated to best practice sustainable water management and a score of zero to poor practice such as blocking natural water flow. Other scores would be between these extremes, the exact profile of scores being determined by the risk profile of affected stakeholders.

A disadvantage of this process is that it is not easy to accurately assign utility values without an understanding of stakeholder views and what they might accept as a trade-off between risk and return. Therefore, it may be necessary to convene public meetings, undertake surveys, or undertake other stakeholder consultation activities.

Weighting the factors

There are a number of options for weighting each of the factors on a comparative basis. One approach is to use a relative importance index (for example, Lim *et al.* 1995). Another approach is to use a compared comparison approach to rank the variables, in which variables may be assigned weights by judgment, or by sophisticated tools such as the Analytic Hierarchy Process (Saaty, 1990). This last approach is particularly useful where there are a range of sub-factors involved.

Another approach is based on the rational management process discussed by Kepner and Tregoe (1981). This approach formulates a goal statement (for example, maximise life cycle construction sustainability for a particular road), and considers the objectives supporting this goal by dividing them into musts (which are not negotiable) and wants. The wants are then grouped into related variables, and the groups are ranked using pair wise comparison or other techniques (Thorpe, 1998, pp. 182-184).

In any of these approaches, which tend to be designed around qualitative variables, benefit and cost may be considered separately from the analysis, or else assigned a score and included in the analysis.

Calculating a weighted score

The final step is to calculate a total weighted score by summing the individual weighted scores, as follows:

$$T = \sum_{i=1}^n W_i S_i$$

Where:

T = Total Weighted Score

W_i = Weight for factor i

S_i = Score for factor i

ILLUSTRATIVE EXAMPLE

As an example, consider a two-lane sealed road, of 9 metres width and 5 kilometres long. There are two options for its construction, which are shown in Table 2. Option A is a bitumen sealed pavement constructed from recycled aggregate. Option B is constructed of permeable concrete with the aim of good storm water management. Both options have the same expected service life of 20 years.

Possible construction sustainability factors for these roads are compared in Table 2.

Table 2: Evaluation of total weighted scores for two road construction options.

Factor	Weight	Option A	Unit Score	Total Score	Option B	Unit Score	Total score
Energy use over life cycle	0.20	Low – embodied energy 0.1 MJ/kg	4.00	0.80	High – embodied energy 1.9 MJ/Kg	1.00	0.20
Sustainable material use	0.20	Use recyclable materials	4.00	0.80	Permeable concrete	1.50	0.30
Waste management	0.15	Very good waste management potential	4.00	0.60	Good waste management potential	3.00	0.45
Innovation in construction	0.15	Potential for some innovation	2.00	0.30	Significant scope for innovation	4.00	0.60
Water management	0.20	Standard water management practices	2.00	0.40	Water sensitive - permeable pavement	4.50	0.90
Availability at all times	0.10	Road unavailable for average of one day per year	1.00	0.10	Road is drivable quickly after storm as undamaged	4.00	0.40
TOTALS	1.00			3.00			2.85

This table omits factors (such as service life) that are common to both options, and also omits factors, also common to both options, that are related to sound sustainable management, such as meeting and managing stakeholder requirements, sustainable procurement practices, and managing quality and safety.

In this table, the weights (assessed by judgment) of each of the listed sustainability factors are shown in the column to the right of the factor. For each option, there is a brief description of the extent to which the factor is met, plus an estimated score

allocated through considering its utility to the owner, and an overall weighted score for the factor (named "total score" in the table). The weighted scores are aggregated.

Option A is estimated to cost AUD 5 million to construct and AUD 120,000 per year to maintain. Over the 20 year life of the road, using an inflation free discount rate of 6% per annum, the present value to the owner of this option is approximately AUD 6.376 million. Its overall sustainability score is 3.0 out of a possible 5.0.

Option B is estimated to cost AUD 5.5 million to construct and AUD 60,000 per year to maintain, leading to a present value of cost to the owner over 20 years at 6% per annum of AUD 6.188 million. Its overall sustainability score is 2.85 out of 5.0.

Thus while Option A is slightly more expensive on a whole of life basis to develop than Option B, it has a slightly better life cycle sustainability score. As neither option is clearly, on an overall basis, better than the other, further investigation should be undertaken, including a sustainability analysis of the views of the user and external stakeholder groups. The allowable construction budget also requires consideration. If, for example, there were only AUD 5 million available for construction, Option A would probably be selected given the closeness of the other evaluation results.

CONCLUSION

The methodology discussed in this paper evaluates, using a life cycle concept, options for constructing and managing roads in as sustainable manner as possible. As illustrated in the example, this methodology is conceptually simple and uses a scoring system based on principles similar to those of rational management. While it may be argued that the proposed evaluation methodology is similar to that of green rating tools, it is more flexible than such tools; considers all of economic, environmental and social aspects of sustainability; takes account of the views of all stakeholders; and focuses on the construction and operation phases of the road. Its flexibility also allows it to be used in conjunction with other methodologies. The worked example, for instance, uses a two stage evaluation, which calculates the present value of life cycle cost and separately evaluates, using a proposed weighted scoring system based on utility, life cycle environmental and social sustainability. It could alternatively have considered combining economic and non-economic factors in a single figure if it was considered that doing so resulted in a better evaluation.

There are disadvantages with this approach. The main disadvantage is the subjectivity and difficulty in assigning utility scores unless extensive consultation is undertaken. The methodology also assumes independence of variables. This may affect its accuracy. However, steps can be taken, such as careful checking of dependencies with respect to the likely impact on the final result and the use of techniques such as conditional independence of the variables with respect to factors common to all options. Finally, the methodology as presented also does not consider the stochastic nature of many variables. This weakness can be addressed through techniques like sensitivity analysis.

In conclusion, the proposed methodology uses a relatively simple approach to the evaluation of the sustainability aspects of road construction. While it may have some disadvantages, it is capable of enhancement through approaches like the Analytic Hierarchy Process to better weight variables and extend the detail of analysis, and it can be extended to improve its rigour through other considerations such as stochastic variables. It can also be developed into a suitable computer based modelling tool.

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