EVALUATION OF ISSUES AROUND ROAD MATERIALS FOR SUSTAINABLE TRANSPORT

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ABSTRACT

In addition to a number of other factors (social, economic, etc) sustainable transport requires the sustainable supply and use of construction materials. This includes the use of marginal materials, waste materials, novel/innovative materials and reuse of existing materials. It also includes the provision of long-lasting or perpetual infrastructure. This field, however, requires a careful evaluation of the impact of these materials on the broader road infrastructure environment.

The following contributory issues are addressed in this paper:

- Sustainable use of non-renewable natural resources
- Sustainability of other material supplies – specifically the use of marginal materials and waste materials
- Effect of continuous reuse/recycling on the engineering properties of existing materials (i.e. grading, plasticity, etc) and perpetual roads
- Cost and extraneous effects of innovative/novel materials
- Definitions of perpetual infrastructure and the economics thereof. Effects of perpetual infrastructure on material behaviour and condition and the use of specific marginal, waste, novel and recycled materials
- Modification of construction methods to minimise the use of natural resources

This paper highlights some of the issues that need to be considered and identifies possible solutions as well as other needs that require solution to ensure sustainable and economical use of the available non-renewable and renewable resources to ensure a sustainable transport infrastructure for future generations.

INTRODUCTION

The sustainable provision of roads is required to satisfy a number of social, economic, environmental, political, technical, institutional and financial factors (SADC, 2003). Although the provision of construction materials falls within the broader technical and environmental factors, little consideration is usually directed towards sustainability issues regarding these materials. There is no doubt that, apart from the environmental effects of developing quarries and borrow pits, these materials are non-renewable resources and certain suitable construction materials are likely to have finite reserves.

As the population of South Africa increases, the transport infrastructure will need to expand concomitantly. Irrespective of the form of transportation that the future brings, natural resources will be required for its development and expansion. It is thus essential that careful evaluation of the use of non-renewable resources be conducted during the design phase of transportation projects in order to maximise sustainability.

This paper highlights some of the issues that need to be considered in South Africa and identifies possible solutions as well as other needs that require solution.

SUSTAINABILITY

Sustainability is defined in a number of ways, the most pertinent one to this paper probably being "to keep going continuously" (Fowler and Fowler, 1963) or in the engineering sense "development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland Commission, 1987). One of the objectives of the transport infrastructure engineer is to ensure that his efforts do not affect the continuous provision and operation of the infrastructure and its environment.

"Sustainability Science" is a relatively new field of interest that has been developed mostly during this century. It involves the dynamics of human-environmental systems in attempting to minimize the future consequences of human impacts on nature and society. Closely allied with this is the need to ensure sustainable livelihoods (DFID, 2009), and essentially entails balancing the social, economic, physical and natural capitals during any development, such that none of these capitals is detrimentally affected or depleted such that it becomes unavailable or unsuitable for future generations. The discussion in this paper is, however, mainly restricted to issues around the primary components of the natural capital, i.e., the atmosphere, lithosphere and hydrosphere.

Construction materials obtained from quarries and borrow pits are non-renewable resources and their continued use results in depletion of a natural capital. These are currently consumed with no replacement cost, which should at least be factored into overall "life-cycle cost studies" to more closely indicate the actual cost of infrastructure development. The use of a "non-renewable material" cost could in many instances make the use of alternative materials considerably more attractive in terms of real cost.

Water used for construction can also be classified as a non-renewable material and this aspect is discussed in greater depth in section 8.

Construction of the infrastructure involves the extended use of fuel burning plant, which has severe negative implications on air quality and the atmosphere in general. Careful design of infrastructure, selection of materials and optimisation of construction processes can assist with reducing these impacts.

Sustainability also includes the cost of energy input to produce a certain product. This embodied energy of a product includes the amount of energy required to manufacture and transport a product, material or service (Green Home Guide, 2009). For road infrastructure, this would include all of the energy requirements to ultimately deliver a material on site, ready to be incorporated into the road infrastructure, as well as the subsequent energy requirements to combine this material with the other parts of the road to deliver a final product. In this regard it is important to evaluate the complete energy footprint of all materials, as materials that may have higher economic costs, may have lower global energy footprints (and costs) due to lower energy requirements either during production or during reworking on the site.

Of course, issues such as maintenance, rehabilitation/reconstruction, operation and de-construction of any road also have sustainability impacts, but these are not directly considered in this paper.

Muench et al (2008, 2009) have proposed a rating system ("*Greenroads*") that "awards credits for approved sustainable choices that can be used to certify roadway projects based on the total credits earned". This consists of 7 categories with between 2 and 11 requirements in each, which has up to a total of 62 credits that can be awarded. The Categories and total credits per category are shown in Table 1.

Table 1: *Greenroads* credit listing categories, typical components and available credits (Muench *et al*, 2008; 2009).

Category (typical components)	Available credits
Sustainable design (including alignment, traffic flow, and long-life design)	10
Materials and resources (including reuse, recycling, life-cycle analysis and local material)	11
Stormwater management	8
Energy and environmental control (including cool, quite and light pavements)	10
Construction activities (including reduction of fossil fuel requirements, noise and emission mitigation and construction quality)	9
Innovation	4

The Greenroads system has a wide range of input items which should be adapted or a simplified version should be developed for South African requirements. Current draft certification levels are:

- Certified. 19-25 credits.
- Silver: 26-31 credits.
- Gold: 32-37 credits.
- Evergreen: 38 credits or more.

NON-RENEWABLE MATERIAL RESOURCES

The construction and maintenance of roads and other transportation facilities consumes large quantities of material. This can be easily comprehended by noting that a typical 8 m wide pavement layer that is 150 mm thick requires 1 200 m^3 of material per kilometre whilst bearing in mind that most roads have a minimum of 3 layers. These materials are usually obtained from quarries or borrow (although they are never paid back) pits, which in themselves lead to environmental degradation, primarily in terms of aesthetics.

However, these construction materials are essentially non-renewable resources and once used cannot be replaced. This is especially true for gravel roads where the wearing course material is eroded by water, abraded by traffic or blown away by wind resulting in the loss of the entire 1 200 m^3 usually every 5 to 8 years (depending on the environment and traffic). Materials in sealed roads are not lost as such, but generally deteriorate with time (see later) and sealing of roads is essentially a more sustainable option, although usually more costly. Before deciding that an unsealed road is more cost-effective than a sealed road, the energy costs should also be considered. The energy involved in the repeated winning, delivery and processing of unsealed road materials every 5 to 8 years is considerably higher than that required for the construction and maintenance of a sealed road over the same period. Simplified methods for estimating the energy consumption (and carbon foot-print) during different construction operations should be developed to allow this factor to be taken into account during infrastructure design.

The Greenroads concept (Muench et al, 2008) will typically penalise a project in the categories of sustainable design, materials and resources and energy and environmental control. The inappropriate use of non-renewable resources (i.e. gravel roads) can typically provide a loss of up to 13 potential credits. This immediately renders an unsealed road an unsuitable applicant for certification as a Green Road.

Materials are currently consumed with no replacement cost, which should in fact be factored into overall “life-cycle cost studies” to more closely indicate the actual cost of infrastructure development. The use of a “non-renewable material” replacement cost could in many instances make the use of alternative materials considerably more attractive in terms of real cost. The charging of an aggregate tax on natural materials used for construction has been implemented in a number of European countries. This tax affects all virgin materials in an attempt to encourage the use of waste materials and recycling. In this way, it does force a value for the materials utilised to be taken into consideration during economic analyses of projects.

Large quantities of water are required for the compaction of pavement materials. In order to achieve optimum compaction, materials are usually compacted at or about optimum moisture content which for pavement layer materials will usually be between about 7 and 12 per cent of the mass of the material being compacted. In broad terms, this requires the use of between 150 and 200 thousand litres of water per layer per kilometre. Although much of the water used in construction ultimately evaporates from the road and is returned to the earth's surface as precipitation, this is a long process and local depletion can occur rapidly, particularly in areas becoming drier through progressive climate change. The injudicious use of water during construction thus also effectively results in the reduction of a natural capital.

Compaction water needs to be of near potable quality to avoid soluble salt and other problems (MoWTC, 2001). Therefore it is often difficult to justify the use of such large quantities of water in relatively arid areas, when the local population often struggles to obtain sufficient water for survival.

Apart from the social effect of using potable water for road construction, the energy cost of providing potable water in rural areas should also be considered. In this regard the potential of using nano-techniques to change the structure of materials to enable the effective use of non-potable water may become a major research area. If the embodied energy available in the salt crystallization process can be nurtured into development of bonds (similar to cement bonds) rather than a destructive force that causes deterioration of compacted layers, water use may have less of an environmental and sustainability impact than it does currently.

OTHER MATERIAL SUPPLIES

The use of waste materials in construction has positive consequences in terms of sustainability as the materials are a residue of their prime purpose and have undergone significant processing (often reducing their input requirements as construction materials) and energy input as part of their production - pulverised fuel ash (PFA) is an example of this where the embodied carbon dioxide for instance is about 90 per cent less than that of cement. These materials often cover valuable land, invariably lead to pollution (both air and water) and yet, given a better understanding of their properties, there should be no reason why they cannot be used in greater quantities in road construction.

In many countries, recycling of old building construction materials is almost ubiquitous (Schimmoller et al, 2000). Although their use is increasing in South Africa, there is still considerable scepticism regarding their use, particularly with respect to crushed building rubble and primarily in terms of the durability of their range of components. More efficient methods of separating out the lighter components (paper, wood, plastic, etc) need to be developed to ensure their increased use.

Most pavement layer materials are reused in roads during major rehabilitation and upgrading, although there still seem to be some concerns regarding the use of recycled asphalt (RA) in South Africa. Research into maximising the use of RA in South Africa is still required.

South Africa is "blessed" with vast resources of mining waste, flyash, phosphogypsum, slags, industrial wastes, etc. Although each of these has specific properties and potential problems when used as construction materials (e.g., deleterious compounds, high variability, unusual properties such as particle size distributions, etc), it is believed that the challenges associated with their use are not insurmountable. Conventionally, waste materials are required to conform to existing specifications (developed for specifying the properties of natural gravels and aggregates). It is considered more appropriate that individual unique specifications for the use of waste materials, assessing their specific properties, should be developed. Concerted and dedicated research programmes would identify the major problems, specifications and methods for using them effectively.

In evaluating the use of waste materials in the provision of infrastructure, the energy already used in the initial development/manufacture of the waste materials (embodied energy) should form part of the life cycle evaluation. Most waste materials have already undergone a significant degree of processing (heating, crushing, separation, etc) in order to render them suitable for their primary intended purpose (e.g. glass), embodying large quantities of energy in the material. The continued use of this waste material in its intended form (i.e. recycling old glass bottles as bottles instead of crushing them for aggregate, developing recycling techniques to reuse old tyres in the manufacturing of new tyres, etc) effectively means that that energy has not been wasted. A thorough analysis is required to ensure that the use of these materials as infrastructure construction materials does not become merely a convenient burial place for a valuable resource.

In planning and managing the use of waste materials in road construction the ultimate goal should always be that this is a short to medium term solution, as the availability of waste materials from the material stream should diminish as more environmentally conscious and sustainable practices are developed for the manufacturing and reuse of such materials. In this regard the available waste should diminish as sustainability becomes a way of life, and as materials such as glass, tyre rubber and building rubble are recycled more efficiently in their original intended form.

EFFECT OF CONTINUOUS USE

The deterioration of pavement structures with time is usually taken for granted. Under repeated loading by heavy vehicles (and the associated localised strains), rutting, shearing and general deterioration of roads take place. However, observation of many well-designed and constructed roads after 20 or even 30 years in service has shown minimal deterioration. A good understanding of the reasons for this would assist in the ultimate design of “perpetual pavements”.

Permanent deformation (particularly in the form of rutting) of roads is the result of compaction of the material into voids remaining after construction. Pavement layers in roads are compacted to a minimum specified density, expressed as a percentage of maximum dry density or apparent relative density. Irrespective of the degree of compaction specified, the compacted layer has a large proportion of voids, anything up to 20 or 30 per cent if compacted at 98% Mod AASHTO for instance. These voids are mostly filled with moisture at the time of construction, but this reduces with time. Loading of the road will naturally rearrange the particles in the pavement layer to fill these voids, resulting in permanent deformation at the surface, manifested as rutting. In theory, once this has occurred, the road should deteriorate no further.

However, the quality of the majority of conventional pavement materials appears to deteriorate with repeated movement (although often infinitesimal) under loading in road structures. These movements, combined with environmental (moisture and temperature) effects, result in a change in the aggregate properties. This could be abrasion of fine material from the particles or the development of plasticity in this fine material, as a result of the release of existing fines or chemical degradation. The effect of this is to reduce the shear strength (friction and cohesion) of the layer and enhance permanent deformation as voids are decreased under the applied loads and localised shear deformation occurs.

If the materials used in the pavement were strong enough to resist abrasion, could not produce plastic fines and were compacted to a density with minimal voids (i.e., graded optimally for minimum voids), deformation would be minimal and the layers should, theoretically, last considerably longer. Research in this area is recommended as this would reduce the need for the continual replacement of pavement layers. This would not only reduce the need for continual replacement of materials within the road, but would also reduce maintenance and rehabilitation with the accompanying traffic disruptions, time delays and extra pollution generated.

The embodied energy of the existing road infrastructure should also form part of the evaluation of alternatives when rehabilitating or maintaining existing roads. A large quantity of energy is consumed during the hauling and compaction of road materials into a pavement structure. This energy is often wasted when such layers (that may still be in a good condition to carry traffic) are ripped and recompacted or replaced just because this is a requirement of an existing specification. The use of such layers in their existing condition (thereby capturing the initial construction energy as well as the traffic compaction energy) lowers the overall energy requirement of the transport facility. More thorough attention to existing in situ material properties during rehabilitation planning and design should allow many layers of material that are currently ripped and recompacted as a standard course of action to be left intact.

EFFECTS OF INNOVATIVE MATERIALS

As the era of peak oil production approaches (Coleman, 2008) the need to reduce energy and fuel usage during construction will increase. The alternative of using biofuels, often made from agricultural products historically cultivated for food, is not a viable future route. The best means of reducing energy usage is to improve construction methods so that less operating time is required as well as to reduce the temperatures required for hot application of materials, primarily bitumen.

As oil production decreases (and the price increases with increased demand for a smaller supply), the availability of bitumen will also decrease. There is no doubt that this is a unique material, but an alternative derived from a renewable resource will have to be developed. Again, this renewable resource should not make use of products that are currently considered primary foodstuffs.

In this regard it is also important that the applicability of innovative materials be evaluated, incorporating their effect on the social and natural environment and their required embodied energy to render them efficient infrastructure construction materials. If the required total energy to produce the innovative material is higher than that of appropriate natural or traditional materials, the usage of such innovative materials should be questioned. Ultimately, materials should be applied in those areas where the benefit/cost ratio of their application (incorporating economical and energy costs) is the highest.

In order to ensure that such benefit/cost analyses can be performed for road infrastructure construction, it is recommended that the energy requirement of various road construction materials are determined and incorporated into standard tender documents for new / rehabilitation construction. In this way, the total energy and economic cost of designs can be incorporated when tenders and alternatives are evaluated, leading to more energy efficient and sustainable infrastructure.

PERPETUAL INFRASTRUCTURE

The concept of perpetual pavements has gained momentum over the past number of years (Steyn, 2008). Although it may appear to be new, ancient roads such as the Via Appia in Italy still provide structural strength after about 2 300 years. In more recent cases, roads such as portions of the N12 (eastern Gauteng) provide excellent service after more than 30 years of heavy truck traffic. A recent evaluation of this pavement has shown it to have more than 15 years of remaining structural life, even under severe wet conditions (Steyn *et al*, 2008). Various other pavements in South Africa that were initially well constructed remain operational, often only requiring maintenance to ensure adequate surface texture and integrity. The challenge is to evaluate these structures and identify the material, structural, construction and maintenance combinations that allowed these pavements to remain in a serviceable condition under traffic – essentially becoming perpetual pavements.

IMPROVED CONSTRUCTION METHODS

The effective compaction of pavement layers requires water to reduce surface tension effects and allow movement between the particles. It should be noted that compaction water does not act as a lubricant in the true sense of the word (water is a poor lubricant) but is necessary in quantities in excess of that which causes surface tension effects between the particles (soil suction).

The water required for construction generally needs to be potable or nearly potable in order to avoid problems related to soluble salt in roads (MoCWT, 2001) and deleterious reactions in concrete (Taylor, 1994). This water is invariably obtained from groundwater or river sources. It is often difficult, on social grounds, to justify the use (and transportation) of large quantities of water for construction when local communities struggle to obtain adequate potable water to even survive, often walking long distances to obtain it.

In order to conserve water it is thus essential that techniques for dry compaction be improved. It has been shown that many materials have a second maximum dry density peak over and above the traditional peak at optimum moisture content, at very low moisture levels (usually below 3%). Limited work on dry compaction has been carried out concluding that the majority of materials can be compacted at moisture contents at or below about 3% (O'Connell, 1997) although the findings were that the air voids are very high and the strength development is not as good as when wet compacted. Local experience has confirmed that although it is possible to achieve acceptable compactions at low moisture contents, the strength obtained is usually less than that obtained during dry compaction as no strength due to soil suction (developed during drying back) develops. This is critical for unsealed roads but is of less significance for lower layers in paved roads.

During the recent construction of experimental sections in a relatively hot and dry area, the use of a road recycler for application of the water and mixing of the material resulted in the need for notably less water (and more rapid construction) than was used in similar experiments built two years previously using conventional construction under similar conditions. This type of innovation can definitely assist in reducing the demand for non-renewable resources.

This issue links with the calculation of the energy requirement and sustainability of road construction materials. The compaction energy required for dry compaction may be higher than that of traditional wet compaction, but the total energy requirement, due to the lower water requirement, may make this a viable alternative. The embodied energy of the final product should thus guide the decision regarding optimal construction materials and techniques. It would also be a location-specific alternative, as areas with excess amounts of potable water may be more suitable (energy-wise) for wet compaction.

Construction methods have a major influence on the product delivered to the road user. Modern construction methods and equipment (e.g., High Energy Impact Compaction) apply extreme loads and use intelligent equipment that can monitor properties such as the stiffness of the compacted material continuously, thereby saving on the total energy input when a standard method specification is being followed (Geldenhuys and Wilken, 2003). Use of such equipment allows appropriate / optimum construction to be endeavoured, often leading to a more cost effective product. Additional research in this area (also focusing on the energy impact of other construction equipment) is urgently warranted.

CLIMATE CHANGE AND ENERGY

In addition to the issues discussed, the impacts of infrastructure development on climate change and energy usage should not be neglected. There is no doubt that climate change is occurring and that this will change aspects such as the availability of construction water, moisture regimes in roads, road temperatures and aspects such as flood levels and flood return periods and increased periods of high intensity rainfall (TRB, 2009). These will all impact infrastructure development and research into such impacts should be initiated.

Global energy shortages too are likely to impact on infrastructure provision. Road construction consumes large quantities of energy (mostly diesel) and generates relatively high volumes of solid and gaseous emissions. These emissions emanate from site operations such as diesel powered plant and vehicles, pumping of water, heating and application of bitumen, as well as earlier in the process during the production of cement, lime, bitumen, fuel, crushed stone, etc. These issues will need to be addressed in order to reduce, or at least better control, such environmental issues in future.

It is imperative that issues related to global climate change that will impact on the design, construction and operation of road networks be identified and studied to allay any long term effects before they become urgent problems.

The global effects of potential changes in infrastructure development techniques, transport modes and transport patterns should form part of the evaluation of alternatives for the provision of transport infrastructure. This is influenced by social and geographical aspects. In rural areas (and countries such as South Africa where travel distances are long) traditional transport modes such as cars and trucks are likely to remain the major transportation modes for at least the next 50 years. Therefore, traditional road infrastructure will still be required. However, the focus on smaller and more fuel efficient vehicles may affect the actual loads applied to the infrastructure (perhaps a greater number of lighter goods vehicles), which may affect the longevity of current and new pavements. In this regard it is important to evaluate the total energy requirement, social developments, transport mode developments, and related developments in the long term planning for road materials in transport infrastructure provision. Allied aspects, such as increased congestion resulting from the additional traffic would need to be considered as well.

CONCLUSIONS

This paper has attempted to introduce a number of concerns and ideas and identify areas that require research in order to optimise the sustainable use of our diminishing natural capital. One of the common threads through this discussion appears to be the need to acquire a better understanding of the properties and behaviour of the abundantly available “innovative” materials and to develop techniques for their successful use in roads of the future.

Many of the issues identified in this paper can be partly alleviated by optimising pavement designs such that the use of non-renewable materials is minimised, energy efficient construction techniques (e.g. the use of bitumen emulsions instead of penetration bitumen) are employed and the pavements are designed and maintained to last as long as possible. However, it is essential that many of the issues identified are assessed and solutions identified early so that the industry is not taken by surprise. This will require deep insight as well as significant innovative research and development. The Greenroads sustainability rating system recently introduced in the United States should be assessed for adaptation for use in South Africa.

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