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"ROAD USE PHASE" ENVIRONMENTAL INDICATOR FOR SUSTAINABLE PAVEMENT MANAGEMENT SYSTEM

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ABSTRACT

Once a road is constructed, it enters into use or operation phase as part of a road network. The road use phase involves management of road maintenance and rehabilitation activities to keep the road functional based on certain approved intervention triggers, maintenance work standards and budget. Road agencies usually have a Pavement Management System (PMS) in place that prioritizes road sections for maintenance and rehabilitation works. This is primarily based on economic indicators.

With the emergence of sustainable development concept to address the climate change phenomena as a principal concern for human sustenance on the earth, consideration to the environmental issue 'carbon emission' is becoming an internationally agreed requirement. This needs a holistic indicator that can address key road environmental components during the use phase for comparing different maintenance strategies based on their Global Warming Potential (GWP).

This paper presents an environmental indicator concept termed 'Road Use GHG Factor (RUGF)', which could be used to calculate life cycle carbon footprint of alternative road maintenance strategies. RUGF provides combined GWP of key use phase environmental components like rolling resistance, albedo and construction materials. The application of RUGF leads to the development of a comprehensive sustainability parameter 'Road Sustainability Factor (RSF)' that can accommodate different indicators of sustainability in road project development and management. Incorporation of RSF may help upgrade the PMSs to Sustainable Pavement Management Systems (SPMS).

Keywords: Road, Global warming potential, Use phase, Indicator, Sustainable Pavement Management System (SPMS).

INTRODUCTION

There are primarily three components of sustainable development- environment, social wellbeing and economy. One of the key objectives of the environment dimension is reduction of greenhouse gas (GHG) emissions.

Transportation sector contributes nearly one-quarter of global energy related GHG emissions, three-quarter of which comes from the road transport. Continuing economic growth is further increasing the world transport energy use at a rate of around 2% per year over the next few decades (Kahn Ribeiro et al., 2007), which indicates a significant rise of the GHG emission levels. Technological development of vehicle fleet and use of alternative fuels would reduce the emission levels to some extent. However, road infrastructure assets involve significant levels of GHG emissions for their continuous development, maintenance and serviceability needs.

SUSTAINABILITY SCOPING

'United Nations Sustainable Development Summit 2015' held in New York from 25 to 27 September 2015 declared 17 sustainable development goals (SDG) (United Nations, 2015).

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Out of the 17 goals, the following 2 SDGs stand out in the field of infrastructure.

- Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.
- Goal 17: Strengthen the means of implementation and revitalize the global partnership for sustainable development.

Goal 9 mentions about sustainable and resilient infrastructure development through enhanced scientific research and upgrading of the technological capabilities; while Goal 17 mentions about the development, transfer, dissemination and diffusion of environmentally sound technologies (United Nations, 2015). The challenge of sustainable and resilient infrastructure development is multifaceted. An infrastructure should not only be able to sustain its structural integrity under the extreme environmental events and manage subsequent economic and social setbacks; it should also confirm minimized harmful contribution to the environment in its different phases of life - construction, operation and end-of-life. Road infrastructure can contribute significantly to the global effort of sustainable development by addressing the relevant issues in road construction and operation management practices. To facilitate achieving the stated SDGs, there is a need to address appropriate scientific parameters for sustainable road infrastructure delivery and management.

SUSTAINABLE ROAD

A road can be defined as sustainable when it serves the intended function with optimised impact to the environment, society and economy based on updated scientific facts. It involves keeping rideability of the road with necessary road works that can minimise the impacts of road condition to the vehicle fleet, while the works are programmed by optimising the sustainability factors based on certain agreed indicators.

For the environment dimension, researchers recommend for life cycle assessment (LCA) of roads to deliver sustainable roads. This is required because conventional environmental studies cannot address complexities associated with emerging issues such as climate change phenomena, efficient resource use, sourcing of materials, whole of life considerations, waste management, changing community expectations, future proofing and so on (Griffiths, 2008). As a result, the need of a comprehensive LCA framework for road projects is required to facilitate identification of improved sets of sustainability indicators to address the environment dimension (Stripple, 2001, Soderlund, 2008, Chan et al., 2011, Santero et al., 2011b).

LCA, often termed as a “cradle-to-grave” approach, involves a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy, and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle (USEPA, 2010). Study identifies that the LCA studies carried out on road projects to date have not addressed all the life phases effectively (Santero et al., 2011a, Alam et al., 2013). The need of a comprehensive life cycle system boundary model, that recognizes the major environmental components impacting GHG emission levels of roads, is identified as a main requirement to overcome this impediment (Zhang et al., 2010, Yu and Lu, 2012, Ting et al., 2012). Alam et al. (2013) identified high impact road environmental components for different phases of life and proposed a LCA system boundary model for future LCA studies of road projects. This is presented in Figure- 1. This model considers five phases of road life as a more industry accepted practice.

To facilitate the development of sustainable infrastructures, ‘Sustainability Rating Schemes’ have been developed. These include: “all-infrastructure type” schemes such as IS (Australia), Envision (USA), and CEEQUAL (UK); and road specific schemes such as Invest (Australia), and Greenroads (USA) (Alam and Kumar, 2013a). Study of these schemes indicates that these schemes do not fully address certain environmental components particularly the use phase and maintenance phase components like rolling resistance, albedo, traffic congestion etc. (Alam and Kumar, 2013b).

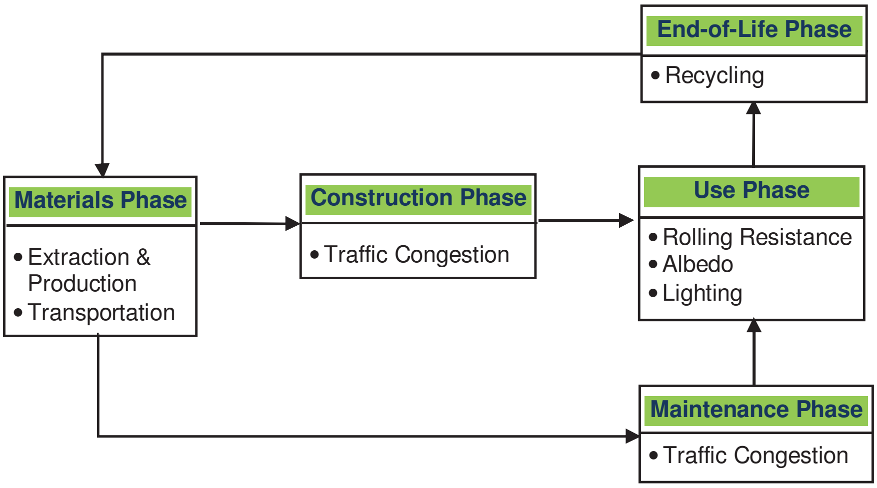

Figure 1: Road LCA System Boundary Model (Alam et al., 2013)

SUSTAINABLE ROAD ASSET MANAGEMENT

After construction, a road starts its operation phase as part of a road network. The road pavement is subjected to environment and traffic induced deteriorations, which need routine and periodic maintenance works, to keep the road serviceable. It also needs improvement through rehabilitation or reconstruction works, the level of which depends on the effectiveness of the maintenance regime in place, the level of traffic it serves and the environmental conditions. The maintenance program is managed through a corporate intervention criteria based on constrained funding allocations, local climate, road type classification and political considerations. Roughness level and effective performance life of the sealing surface usually determine the timing of periodic maintenance works, while economic indicators like benefit cost ratio (BCR), or net present value (NPV) direct intervention option. The conventional corporate tool for delivering pavement works is popularly known as 'Pavement Management System (PMS)'.

The different PMS systems used by different road agencies are generally based on their need and the ability to manage complex systems. One of the pioneer models is the World Bank funded Highway Development and Management (HDM) model, which forms the basis of many other models. The current version is knowns as 'HDM-4 Version 2' and is managed by HDM Global under the auspices of PIARC-the World Road Association (HDM Global, 2015). HDM-4 has options for environment assessment that involve energy balance analysis and vehicle emissions computation to enable planners and policy makers to understand the energy implications and environmental impacts of alternative road transport projects and policies (HDM-4, 2005). Energy balance analysis provides life-cycle energy consumption combining energy used for vehicle and fuel production, and to power and operate the vehicles including due consideration to road characteristics and condition, traffic characteristics, fuel consumption, engine oil consumption, tyre wear and vehicle parts consumption. Assessment of vehicle emission involves quantification of exhaust emissions (air pollutants) e.g. hydrocarbon, carbon monoxide, nitrogen oxide, sulphur dioxide, carbon dioxide, particulates and lead. The stated computations are not included in the economic evaluation, but has scope for multi-criteria analysis using analytical hierarchy process for project analysis to compare project alternatives.

Sustainable development requires quantification of life cycle environmental impacts of a project in a way that can effectively address, among others, the most pervasive sustainability issue- the global warming phenomena. As a result, global warming potential (GWP) is becoming the most popular unit of measure for environmental LCA studies because of its implication to the global warming aspect and the consequent climate change issues. The GWP is a relative measure of how much heat a GHG traps in the atmosphere. Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), water vapor and fluorinated gases e.g. hydrofluorocarbons (HFC), perfluorocarbons, sulfur hexafluoride etc. are known as GHGs that have varying GWP based on their concentration or abundance in the atmosphere, strength and lifetime (Ehhalt et al., 2001). GWP is generally expressed as a factor of CO_2 and calculated over a specific time interval, commonly 20, 100 or 500 years, i.e. the GWP of CO_2 is considered as unit (1), and the GWP of all other GHGs are converted to equivalent CO_2 based on their lifetime and GWP levels as presented in Table- 1. Figure- 2 shows the level of GWP (giga ton of CO2-eq/year) by different anthropogenic (originating from human activity) GHGs over the period of 1970 to 2010 (IPCC, 2014).

Table- 1: Emission metric values of four major greenhouse gases (IPCC, 2014)

GHG	**Life time (yr.)**	**Global Warming Potential (GWP)**	
		Cumulative forcing (CO_2-eq) over 20 years	**Cumulative forcing (CO_2-eq) over 100 years**
CO_2	Not defined	1	1
CH_4	12.4	84	28
N_2O	121	264	265
HFC	1.5	506	138

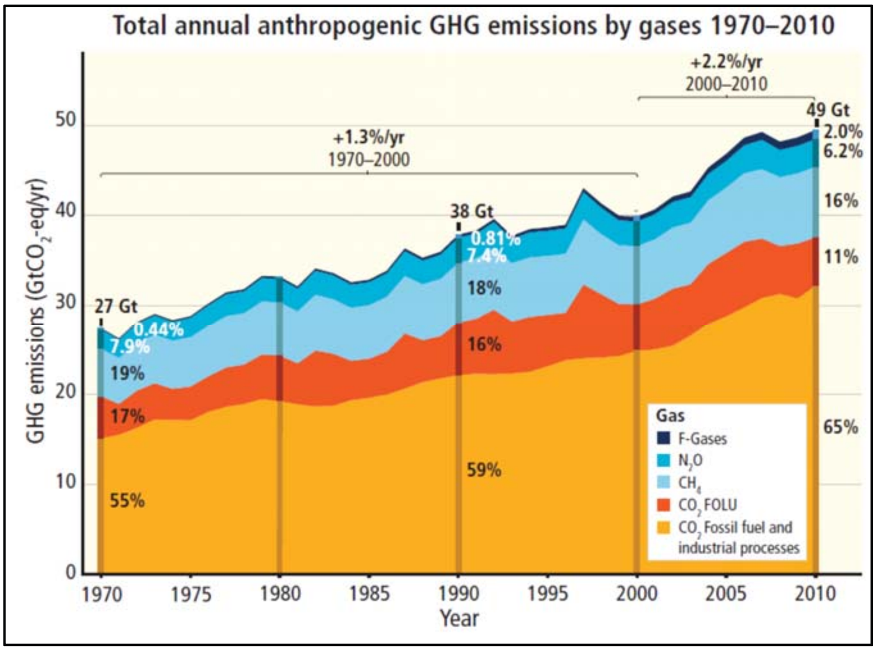

Figure- 2: Total annual anthropogenic greenhouse gas (GHG) emissions (giga ton of CO2-equivalent per year, GtCO2-eq/yr.) for the period 1970 to 2010 by gases: CO2 from fossil fuel combustion and industrial processes, CO2 from forestry and other land use (FOLU), CH4, N2O, fluorinated gases covered under the Kyoto Protocol (F-gases). (IPCC, 2014)

From a road engineering viewpoint, there is a need to minimize contribution of Global Warming Potential. The following areas need consideration:

- Focus- 1: Minimize environmental impacts including GHG emission from road works, both construction and maintenance.
- Focus- 2: Manage road network in a way that minimizes environmental impacts including GHG emission from the vehicle fleet that uses the road.

To address the above stated focusses there is a need to upgrade the PMS to Sustainable Pavement Management System (SPMS) covering all the possible dimensions of sustainability. It is generally understood that some of the social and environmental issues are often subjective and difficult to quantify under a common unit of measure. It may also be difficult to accommodate too many indicators in a tool that intends to deliver complex life-cycle/ multiyear investment analysis of a road network comprising many roads subdivided into thousands of road sections. This research is an attempt in developing an indicator to address the GWP issue towards the development of SPMS.

The current PMSs such as HDM-4 has scope for discrete environmental assessment of energy use and vehicle emissions. However, it can further be improved to deliver GWP levels of alternative project options including the do-nothing scenario. A review of the HDM-4 environment model indicates that further work could consider incorporation of:

a) Emissions from road construction and maintenance activities that include materials and equipment components for extraction, preparation and laying processes.
b) Energy balance studies for fuel, engine oil, tyre and parts consumptions by considering updated road condition models for life cycle road works effect.
c) Emissions from traffic congestion due to road works.
d) Emissions from non-parts parameters of vehicle repair and maintenance activities.
e) Emissions from other high impact road environmental components such as albedo, lighting and signage, end-of-life management and carbonation etc.

THE WAY FORWARD

A comprehensive environmental indicator to address major environmental components of the road use and maintenance phases (refer to Figure- 1) should be able to compute the level of life cycle GWP for different scenarios of maintenance intervention. At present most of the road agencies usually consider international roughness index (IRI) as a major trigger along with other parameters such as rutting, cracking, surfacing age etc. to decide on maintenance intervention program of their road networks. The alternative intervention options are weighted for their economic outcome based on BCR or NPV and generally the most economic one is selected based on industry perspective. The GWP based environmental indicator can be a supplement to the existing indicators for the delivery of sustainable roads.

Alam et al. (2014) proposed a new road environmental indicator termed RUG Factor (Road Use GHG Factor) that primarily includes the most impacting environmental components of the use and maintenance phases (Figure- 1). The two phases are combined, because maintenance works are essential part of the use phase to keep a road serviceable. The components are: (a) rolling resistance divided into road roughness factor and pavement structure factor, (b) albedo factor, and (c) material factor. These are shown in equation- (i). However, RUGF has the provision for inclusion of other environmental components gradually as the relevant science progresses.

$$\textbf{RUG Factor} = \mathrm{RRF} + \mathrm{PSF} + \mathrm{AF} + \mathrm{MF} \tag{i}$$

Where,

RRF = Road Roughness Factor PSF = Pavement Structure Factor
AF = Albedo Factor MF = Material Factor

Detailed equation for all the above factors and their sub-factors are being developed by the authors to facilitate the estimation of RUG Factor for different road maintenance options. As noted above, the current versions of PMSs have the scope for delivering the RUG Factor with some modification and addition of emission relevant models. As a result, comparison of different maintenance options based on their life cycle GHG emission levels is possible. Thus, the selection of best possible sustainable treatment option may promise the least possible contribution to the global warming phenomena from road works and uses.

ROAD SUSTAINABILITY FACTOR (RSF)

As stated earlier, economic indicators have been established, and a comprehensive road environmental indicator termed 'RUG Factor' has been proposed. A comprehensive social indicator would also be available at a future date. Combining these indicators a complete parameter called 'Road Sustainability Factor (RSF)' is presented below:

$$\mathbf{RSF} = \text{EnvI x } W_{\text{EnvI}} + \text{EconI x } W_{\text{EconI}} + \text{SocI x } W_{\text{SocI}} \tag{ii}$$

Where,

EnvI = Environmental Indicator, which is the proposed RUG Factor
EconI = Economic indicator, e.g. BCR, NPV
SocI = Social Wellbeing indicator, needs to be developed
W_{EnvI}, W_{SocI}, W_{EconI} = Relative weighting of different sustainability indicators- to be developed.

Until the SocI is developed, the PMSs can consider the other two indicators to deliver sustainable roads. To address the social issues, the current practice of separate qualitative intervention of the maintenance and rehabilitation works may continue.

EnvI and EconI in equation- (ii) can be allocated with weightings based on current level of understanding until the development of SocI to assess the impact of RSF in delivering sustainable roads. However, there is a need of further study to allocate appropriate weightings to the three indicators. This study primarily considers a trial basis allocation of '2' for W_{EnvI} and '1' for W_{EconI} based on a primary research finding on the three sustainability rating schemes- IS, Envision and CEEQUAL. The study of the credits/issues of the planning and design module of the schemes show that a little more than 50% weighting goes to the environmental credits, around 25% to the social wellbeing credits and the rest to the other dimensions (management/economy) of sustainability. Sensitivity analysis with different weightings is being under development by the authors to understand the impact of RUG Factor (RUGF) on RSF. With the proposed trial weightings, the RSF can be reflected in the following equation:

$$\mathbf{RSF} = 2\text{ EnvI} + \text{EconI} + \text{SocI (now qualitative, so not included in calculations)} \tag{iii}$$

The implication of the RSF for delivering sustainable roads can be explained as detailed in Table- 2. The findings are based on life cycle analysis for a defined period of 50 years of a 1 km section (2 lanes) of a major highway in Queensland, Australia done under this study. Transport and Main Roads, Queensland PMS tool known as 'SCENARIO' is used for traditional economic indicator directed treatment option analysis (TMR, 2011). Road deterioration models used in SCENARIO are based on HDM, calibrated to local conditions with support from Australian Road Research Board (ARRB). It is noted that ARRB is a consortium member of HDM Global that manages the HDM-4 (HDM Global, 2015). GWP levels of the alternative treatment options are calculated using the RUG Factor model developed under this study. The treatment options include different rehabilitation works such as cement stabilized base followed by sprayed seal surfacing, granular base followed by sprayed seal surfacing, granular base followed by asphalt surfacing, foam bitumen stabilized base followed by sprayed seal surfacing, foam bitumen stabilized base followed by asphalt surfacing, and full depth asphalt rehabilitation; and periodic maintenance works such as sprayed seal, corrector course followed by sprayed seal, and asphalt overlay. Routine maintenance is considered as a common and equal treatment for all the competing treatment options distributed over the assessment period of 50 years. For example, one of the five treatment options presented in Table- 2, Option- A includes one cement stabilization based rehabilitation at the 4th year, one corrector + seal treatment at the 17th year, one foam bitumen stabilization based rehabilitation at the 37th year and routine maintenance every year over the 50 years life cycle assessment.

In Table- 2, the highest NPV[1] is considered as unit (1) for its highest economic outcome and the other NPVs are weighted accordingly, while the lowest RUGF (GWP) is considered as unit (1) for its lowest contribution to the global warming phenomena and the other RUGFs are weighted accordingly. The NPV and RUGF weightings are then combined together using equation- (iii) to get the RSF for each of the treatment options. Analysis of the Table- 2 shows that the ranking of the treatment options based on NPV changes when the RUGF is considered. The RSF ranking of Treatment Option -A is the 4th best, while it is 1st based on NPV. Considering RUGF as a separate indicator, Option- A comes as the 5th ranked or worst one for GWP contribution. The implication of this analysis is that the conventional economic selection may choice any one of the treatment Options- A and B for their very competitive NPV of $1.541 million and $1.521 million respectively. Now, the application of RUGF shows that the Option- A has 6,500 ton more GWP contribution than the Option- B. In consequence, the higher RSF value gives significant edge to the Option- B over the Option- A. The RSF value also makes Option-D (RSF rank 2) a strong choice because of significant level of life cycle carbon reduction, which is 17,000 ton less than the Option- A. So, the road agency can consider the new indicator to weigh their decision further for a more sustainable treatment selection. A PMS can design numerous treatment options with a consequent bigger scope for RSF assessment and sustainable delivery.

The proposed RSF parameter is relevant for both project and network level applications of road asset management practices. For project level analysis, RSF values can help selecting the best sustainable treatment option from a life cycle viewpoint. On the other hand, for network level analysis the most qualified candidate road sections can be selected based on RSF based treatment outcomes for a defined analysis period of say 10, 15 or 20 years under the constrained funding regime in general. The common maintenance intervention triggers such as IRI or seal-life age can also be supplemented with the new environmental indicator RUG Factor for sustainable decision making. For example, the RUGF to be computed with the predicted road conditions, traffic levels and maintenance works can have an agreed threshold level, which will be considered along with IRI and/or seal-life age to qualify road sections for further improvement.

Table- 2: Pavement treatment option analysis based on RSF assessment

Treatment Strategy	Econl		Ranking based on NPV	Envl		Ranking based on RUGF	RSF (2f+c)	Ranking based on RSF
	NPV (million $)	NPV Unit		RUGF (GWP: ton CO2-eq)	RUGF Unit			
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
A	1.541	1.00	1	152,000	0.888	5	2.776	4
B	1.521	0.99	2	145,500	0.928	3	2.843	1
C	1.457	0.95	3	146,000	0.925	4	2.795	3
D	1.279	0.83	4	135,000	1.000	1	2.830	2
E	1.237	0.80	5	137,500	0.982	2	2.766	5

CONCLUSION

As a major infrastructure asset of the built environment, road networks contribute significant level of emissions towards the build-up of the global warming phenomena. Therefore, development of Sustainable Pavement Management System (SPMS) to facilitate the delivery of more sustainable roads is an important requirement to reduce the carbon footprint of road networks. A SPMS should be able to effectively reduce the GWP impacts of a road network through the use of appropriate indicators in delivering maintenance and rehabilitation work programs. So, it needs supplement to the conventional economic indicators by other indicators addressing different dimensions of sustainability in a balanced

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[1] **Net Present Value** (**NPV**): The difference between the present value of cash inflows (benefits) and the present value of cash outflows (costs) over the life time of a project.

way. The RUG Factor has been found as a strong environmental indicator that can represent life cycle GWP potential of the use phase of a road by combining both road work effects and road user effects. Integration of this indicator with the conventional economic indicators provides a new parameter termed road sustainability factor (RSF). Impact assessment of alternative life cycle maintenance strategies of a road section shows that appropriate application of RSF may facilitate the development of SPMS. Further studies focusing the development of a comprehensive indicator for the social wellbeing dimension and optimized weighting sharing among the different dimensions of sustainability are recommended for assessing the full impact of RSF in delivering more sustainable road networks.

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