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Dynamic Sustainability Assessment of Road Projects

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Abstract: Traditionally, road projects are initiated based on an assessment of their economic benefit, after which the environmental, social and governance effects are addressed discretely for the project according to a set of predetermined alternatives. Sustainable road infrastructure planning is vital as issues like diminishing access to road construction supplies, water scarcity, Greenhouse Gas emissions, road-related fatalities and congestion pricing etc., have imposed severe economic, social, and environmental damages to the society. In the process of addressing these sustainability factors in the operational phase of the project, the dynamics of these factors are generally ignored. This paper argues that effective delivery of sustainable roads should consider such dynamics and highlights how different aspects of sustainability have the potential to affect project sustainability. The paper initially presents the different sustainability-assessment tools that have been developed to determine the sustainability performance of road projects and discuss the inability of these tools to model the interrelationships among sustainability-related factors. The paper then argues the need for a new assessment framework that facilitates modelling these dynamics at the macro-level (system level) and helping policymakers for sustainable infrastructure planning through evaluating regulatory policies.

Keywords: Sustainability performance, Dynamic factors, Sustainability-assessment framework.

1. INTRODUCTION

The construction and operation of public-infrastructure assets can have a significant effect on society and the region [1]. The United Nations (UN) Secretary-General Antonio Guterres emphasised the importance of the sustainability of infrastructure projects during the UN Climate Change Conference of Parties (2018): 'Infrastructure investment will be crucial. The world should adopt a simple rule; if big infrastructure projects are not green (sustainable), they should not be given the green light. Otherwise, we will be locked into bad choices for decades to come' [2]. According to Infrastructure Australia (IA), the broad concept of sustainability lies in the simultaneous concretisation of the quadruple bottom line of sustainability aspects (i.e., social, environmental, economic and governance) [3]. A sustainability-assessment framework helps to incorporate such sustainability aspects of a project into the design, construction and operation of infrastructure assets [1]. The early decades of the twenty-first century are seeking a change in focus on environmental reporting in road agencies [4] because the conventional assessment processes and procedures for infrastructure projects do not necessarily measure the qualitative and quantitative effectiveness of all aspects of sustainability-related to the project [1]. This need for change in the focus of environmental reporting has arisen because of the existence of an agglomeration of sustainability-assessment frameworks, all of which have different purposes, reporting requirements, and outcomes [3].

It is known that different types of road networks and traffic conditions change the dynamic properties of the overall road system performance. In the absence of such detailed field studies in this area, simulation modelling becomes necessary to improve knowledge and understanding of different road design parameters, traffic characteristics, innovative methods utilised and how it affects criteria of sustainability aspects over time (social, environmental, economic and governance).

This paper does not aim to assess whether current assessment tools for infrastructure sustainability are valid and useful. Instead, the specific objectives of this paper are first to provide a comparative review of the different tools and methods used for infrastructure-sustainability assessment, and later to provide a comprehensive overview of the best methods that can be used to measure sustainability performance'. By considering the limitations addressed in the comparative review, a conceptual framework is proposed by utilising the extensive literature review to fill the identified research gap. As roads typically have a design life of 20 to 40 years, the level of consideration of future trends analysing the performance of roads related to environmental impacts, economic risks, and social movements will have a significant impact on their long-term benefits. The following section presents a list of the sustainability-assessment frameworks, principally focusing on comparing frameworks that are used in the roads sector.

2. LITERATURE REVIEW

2.1 Sustainability-assessment Methods for Road Agencies

Sustainability-performance assessment is a methodology 'that can help decision-makers and policy-makers decide what actions they should take and should not take in an attempt to make society or project more sustainable' [5]. In 2012, the International Federation of Consulting Engineers classified these assessment tools into four categories based on their origin and utility (see Figure 1) [6]. Therefore, when considering the sustainability of the project, the significant methods to be followed by the road agencies are first, the decision-support tool of the projects, and second, the rating of the project performance against an industry benchmark.

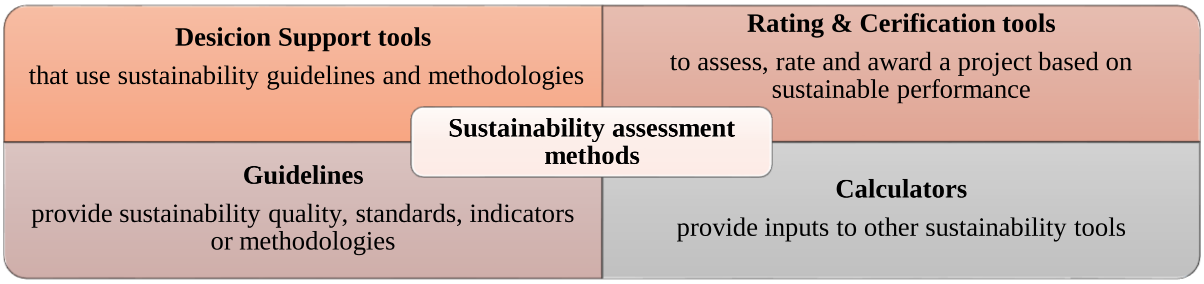


Figure 1. Categories of Sustainability-assessment Tools [6]

Measuring the sustainability performance of an infrastructure project using any of these assessment methods requires applying either qualitative or quantitative criteria or indicators for each of the sustainability aspect [7]. The Global Reporting Initiative (GRI), a non-profit organisation provides offers with a comprehensive list of criteria and indicators to apply when measuring sustainability performance using such assessment tools. The GRI also provides comprehensive guidelines on the type of sustainability information [3].

2.1.1 Decision-support tools

Decision making about public-infrastructure investment is often complicated [8]. While appraising of public works, broader regional environmental factors incorporating political and social domains are important to consider while considering the sustainability assessment [9]. A holistic decision-making framework must capture the decision-making system comprising rules, processes, and outcomes that are framed within a broader context composed of organisational factors and boundaries [9]. The International Federation of Consulting Engineers (2012) has characterised various models as ‘decision-support tools’, and guarantees that these tools are being appraised by systems that utilise multicriteria analysis methods to survey sustainability performance [8]. The most prominently used decision-support tools from the literature review apart from the cost-benefit analysis are presented in Table 1.

Table 1. Tools for Sustainability Decision Support [10]

Tool	Certifying body	Sector	Country
ASPIRE	ARUP	Infrastructure	UK
HalSTAR	Halcrow	Infrastructure	UK
INDUS	Mott MacDonald	Infrastructure	UK
SPeAR	ARUP	Infrastructure	UK
Scottish Transport (STAG)	Transport Scotland	Transport	Scotland

2.1.2 Rating tools/schemes

Numerous sustainability-rating schemes have been launched in the infrastructure sector since the release of the BREEAM rating Scheme, United Kingdom (UK), has led to the development of sustainability assessment. These rating schemes are developed based on different criteria and corresponding credit points that address various dimensions of sustainability [1]. Each of the credits is assigned with a score based on the weighting given to the criteria [1]. Current available existing rating tools and schemes relevant to roads and infrastructure projects are presented in Table 2.

To categorise the criteria of each tool, the present research used Infrastructure Sustainability Council of Australia (ISCA) as a guide because the ISCA manual provides information on which criteria support which of the quadruple bottom lines. While Table 3 presents the percentage of categories based on the ratio of total points for the criteria under each sustainability category to the total points available for the sustainability-assessment tool under consideration. The overall percentage for some of the assessment tools is less than 100% because of the rounding of values. Other rating tools such as INVEST and BE^2ST in Highways were omitted in Table 3 because of the lack of information on their point system.

Each assessment tool presented in Table 2 had in common specific criteria aiming to achieve the four aspects of sustainability (social, economic, environment and governance) in road projects. The weight placed on various aspects of sustainability varied among the different tools. These tools are useful in situations where a project team does not wish to allocate a budget for third-party sustainability evaluation. In such a case, the project team can use one of the self-evaluation tools based on the requirements and focus of the project. The analysis presented in Table 3 shows the percentage of the weight given to each quadruple bottom line in the selected assessment tools.

Comparative analysis utilising Table 3 reveals that the number of indicators assigned to a category in the infrastructure-sustainability-assessment tools is not directly proportional to the significance of the sustainability aspects (i.e., credit/weight). Figure 2 provides the percentage of weights for each aspect under the sustainability-rating tools in the form of bar charts. For example, while in the ISCA Rating Tool, 35% of the total number of indicators is related to the environmental dimension, the points assigned to these sets of indicators sum up to only 27.2% of the total points. Likewise, 29% of the total number of indicators are related to the governance dimension, whereas the score assigned to these sets of indicators sums up to 34.4% of the total points. Further, the different emphasis has been given to different indicators in different tools, as revealed in Table 3. It is evident most of the tools assign greater significance/weightage to resource management related criteria (e.g., energy, water, resources, and materials).

Table 2. Existing rating tools and schemes relevant to road projects [3]

Sustainability-performance and sustainability-rating tools	Road specific	Decision-support tools			Rating tools and/or schemes			Calculators			Guidelines		
		P, D	C	O, M	P, D	C	O, M	P, D	C	O, M	P, D	C	O, M
IS Rating Tool by Infrastructure Sustainability Council of Australia (ISCA)		✓	✓	✓	✓	✓	✓						
INVEST (Integrated VicRoads Environmental Sustainability Tool): rating tool	YES				✓	✓	✓						
Carbon Gauge Calculator	YES							✓	✓	✓			
I-LAST (Illinois Livable and Sustainable Transportation)	YES				✓	✓							
Bottom Line^2 software										✓			
CEEQUAL					✓	✓							
Envision		✓	✓	✓	✓	✓	✓						
GreenLITES	YES	✓	✓	✓									
Greenhouse Gas Calculator	YES							✓	✓				
eTool Life Cycle Assessment software													
BE^{2}ST in Highways	YES	✓	✓										

Note: P, D = planning and design; C = construction; O, M = operation and maintenance

When the conventional criteria of rating tools and road engineers' perspectives on sustainability road are compared (i.e., after qualitative and quantitative analysis), it is clear that the following considerations of sustainability are the foremost and most common considerations in making road projects sustainable [11]:

1. safety and health: reducing public-property damage and severe and fatal injuries
2. economic development: enhancing the goals and objectives of a project, working with economic development agencies, monitoring sustainable outcomes
3. energy and materials: reducing waste by recycling and reusing materials and reducing energy consumption by using energy-efficient fixtures and renewable energy to protect limited natural resources

4. pollution: reducing air or noise pollution from construction equipment and materials
5. resilience: designing road projects to ensure they have the flexibility to handle future hazards and climate change.

Table 3. Common Categories and Their Indicators Included in Sustainability Assessment Tools

Rating Tools	ISCA		Envision		CEEQUAL		GreenLITES		Greenroads		I-LAST	
Dimensions	**Categories**	**Credit/ Weight**	**Categories**	**Credit/ Weight**	**Categories**	**Credit/ Weight**	**Categories**	**Credit/ Weight**	**Categories**	**Credit/ Weight**	**Categeories**	**Credit/ Weight**
Environment	Energy	9.27	Materials	17	Land use and ecology	600	Water Quality	20	Environment & Water	10	Environment	51
	Green Infrastructure	3.54	Energy	15	Landscape and historic environment	450	Material & Resources	66	Material & Design	6	Water Quality	36
	pollution	1.45	Water	9	Resources	1450	Energy & Atmosphere	104			Lighting	16
	Materials and resource recovery	5.99	Siting	7	Pollution	400	Sustainable Sites	81			Materials	43
	Water	6.54	Conservation	16							Design	27
	Ecology	4.54	Ecology	7								
			Emission	16								
Economic	Business case	14.51	Economy	10								
	Benefits realisation	4.54										
Social	Stakeholder engagement	9.08	well being	9	Transport	400			Access & Livability (AL)	10	Transportati on	42
	Legacy	4.36	Mobility	2	Communities and Stakeholders	550			Utilies & Controls	8		
	Heritage	2.18	Community	5					Construction Activities	11		
	Workforce	9.08										
Governance	Culture & context	3.87	Resilience	40	Resilience	600	Innovation	7	Creativity &Effort	4	Planning	19
	Leadership	9.08	Collaboration	10	Management	550			Project Requirements	12	Innovation	6
	Sustianble Procurement	11.34	Planning	12								
	Resilience	5.32										
	Innovation	10										

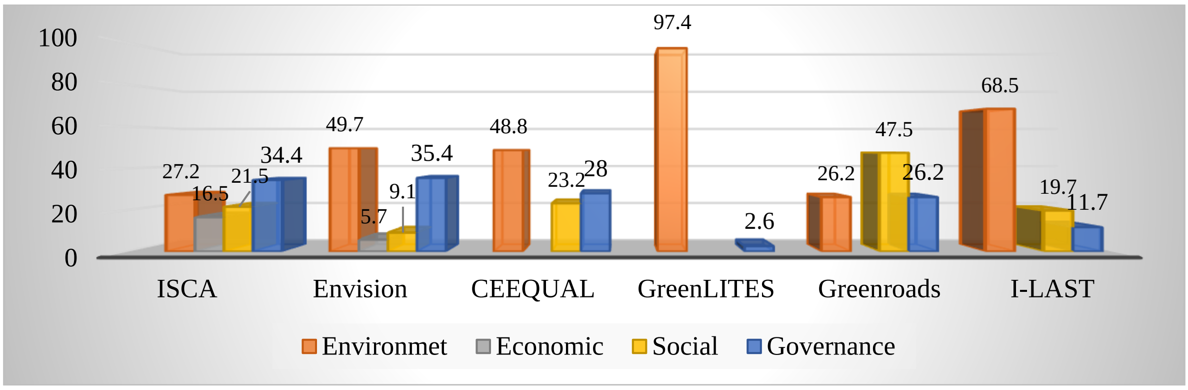


Figure 2. Percentage of Weights for each aspect under the Sustainability-rating Tools

2.2 Limitations of Rating Tools

Approaches for project evaluation other than sustainability-rating tools are available, for example, economic analysis, financial analysis, life-cycle analysis, environmental impact assessment, and social impact assessment. However, while all of these assessment methods can help to evaluate the performance of infrastructure projects in multiple dimensions, including social, economic, and environmental, these approaches are often used individually or separately [12]. The separate evaluations do not balance, and trade-offs between different aspects of evaluation lead to the risk of overlap, omission, and inconsistency in evaluating the sustainable performance of a project [13]. A lower level of consideration of the dynamic relationships and cohesion between different sustainability criteria also makes it difficult for different project stakeholders to act in cohesion to improve a project’s sustainability performance [14].

2.3 Dynamic Approach in Sustainability Assessment

Zietsman and Rilett have proposed two basic principles of sustainability-related to transportation infrastructure, stating that these principles must also be mimicked by the assessment tools [15]. The two principles are multidimensionality (interrelationships between the sustainability aspects of a project) and dynamics (necessity to adapt to the changing needs of society and future generations over time) [14]. However, these rating tools are unable to address and express the complex relationships among the various sustainability criteria, and each criterion must be assessed in isolation irrespective of the fact that all criteria are interrelated and must be dynamic [14]. Therefore, a conceptual framework proposed in this paper applies a dynamic approach using System Dynamics (SD) modelling approach that can not only consider interrelationships of the variables collectively but also take into account the impact of dynamic variables.

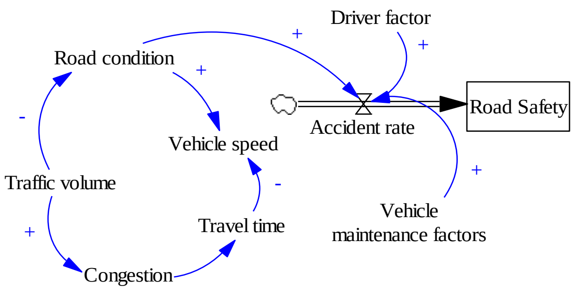
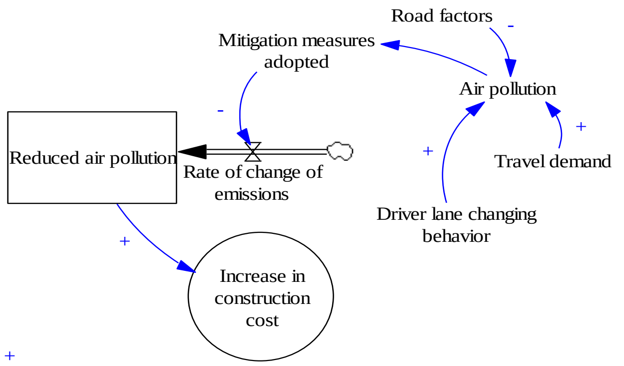
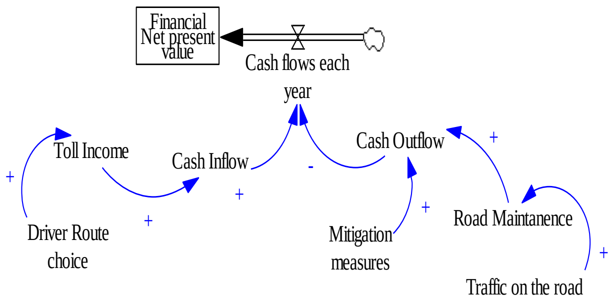
2.3.1 Examination of dynamic interactions between sustainability criteria

The growth of the dynamic aspects of any public-investment project can be explained on two levels: the dynamics at the macro-level (system level) and the dynamics at the micro-level (individual level) [16]. In the context of road-infrastructure projects, the dynamics at the micro-level arise from the road users who utilise the investment project during the operational phase. The road user has a substantial effect on the project because they create a demand that significantly affects the performance of the project [16]. Further, road users while utilising the road during travelling interact with one another following their individual decisions and the imposed rules that change over time. These micro-level dynamics that the road user creates influence the macro-level system dynamics of the project. Thus, it is difficult to predict the performance of a project concerning its macro and micro-dynamics through a traditional cost-benefit analysis and the available sustainability-assessment tools, which are usually static [17]. However, this paper only focuses on macro-level dynamic variables of sustainability as data needed for micro-level (road user behaviour) dynamics is much complicated and requires additional modelling methods along with system dynamics.

The macro-level dynamics are explained by considering one criterion from each of the sustainability aspects explained in Table 4. For example, the noise emissions from the environmental aspect can be affected by the traffic volume generated, and the pricing strategy from the economic aspect can be affected the route choice behaviour of road users [18]. Similarly, when a noise-mitigation measure is adopted, the cash outflow of the infrastructure project increases [18]—a graphical representation of these dynamic interactions among the criteria are presented in Table 4. The causal-loop diagram has been utilised to describe these interrelationships in the system-dynamics domain. In system dynamics, relationships among the criteria is a closed-loop system to prevent any obstacles in information flow [19]. The feedback effect of closed-loop system can be positive or negative. A positive effect is when an increase or decrease in any criteria results in an increase or decrease, respectively, in related areas [19].

In contrast, with a negative effect, an increase or decrease in any variable will result in a decrease or increase, respectively, in related areas. Positive (+) signs on the arrows in the causal loop diagram indicate a reinforcing (increasing) effect of one parameter on another parameter, whereas negative (-) signs indicate a balancing (decreasing) effect of one parameter on another parameter [20]. Some of the significant feedback loops of the different aspects of sustainability are described in Table 4.

Table 4. Dynamic Interactions between Sustainability Criteria [21]

<table>
<tr><th>Dynamic Interactions Between Sustainability Criteria</th><th>Explanation</th></tr>
<tr><td>
</td><td>Social criteria: Increasing traffic volume and congestion will cause an increase in travel time. An increase in travel time means the average driving speed decreases. As a result, driver-related contributions to the accident rate decrease, which leads to a decrease in the rate of road accidents [21].</td></tr>
<tr><td>
</td><td>Environmental criteria: Demand for the route increases the average trips generated for a specific route by increasing the volume of traffic. The increase in congestion leads to poor road-surface quality, which is one of the main factors affecting fuel consumption. The mitigation measures (e.g., vegetative cover) can lead to an increase in the construction costs, thus affecting the economic criteria of the project.</td></tr>
<tr><td>
</td><td>Economic criteria: A project's financial net present value depends on cash inflow and cash outflow. If the primary source of cash inflow is to be toll-generated tax, then drivers' route choice affects this cash inflow. As traffic volumes increase, the level of damage increases. Therefore, annual routine-maintenance costs increase.</td></tr>
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2.4 Conceptual Framework for Dynamic Sustainability Assessment Analysis

Research efforts have been carried over the last few decades towards studying the modelling process in adopting the system dynamics methodology [18] [19]. Figure 3 presents the various steps required for executing an SD model that can be utilized for dynamic sustainability assessment of road projects. The first step requires an understanding of the system and its components. This is necessary to identify the major cause and effects and derive feedback and causal loops of different variables. Later, the system model is constructed, logical and mathematical formulations among different components are drawn. While road infrastructure sustainability assessment using such modelling process can be a complete quantitative approach. However, in the case of a new system, it is very hard to decide which components are important in developing the SD model and relations that exist among them [20]. Under such circumstances or when the system has a high degree of complexity, it is better to have a clear purpose of modelling and focus on the problem, its causes, and subsequent effects [20]. Finally, the model should be run for simulating different scenarios, estimating the impact of alternative policies, and summarizing policy recommendations.

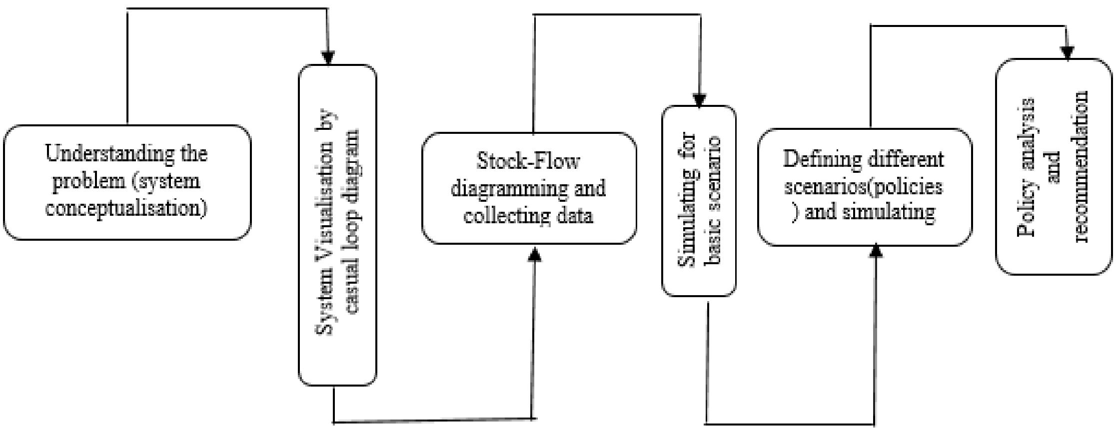

Figure 3. The modelling process in applying System Dynamics approach

The proposed modelling approach shown in Figure 3 allows the modeller to quantitatively estimate and evaluate road system performance, and analyze the behaviour in response to external changes, for example, regulatory policies like trip sharing, car ownership, etc.

3. CONCLUSION

The currently available approaches to dynamic sustainability assessment are minimal and limited. In particular, the attempt to consider the micro-level and macro-level analysis of the dynamic evaluation of sustainability performance is rarely found in road infrastructure projects. The behaviour of road users is the essential element to be considered by project organisers because it significantly affects the overall sustainability performance of the project. Given that the road-user behaviour emerges from diverse aspects, and is therefore difficult to predict and require additional simulation techniques utilised by traffic engineers. Thus, this paper provides a valuable approach for analysing macro-level system dynamics to deliver sustainable road networks by proposing a conceptual framework that helps policymakers to simulate a series of experiments. The great advantage of the proposed framework is that it allows evaluation through consideration of dynamic environments such as changes in population growth and needs, political agendas, and regional climate change.

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