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# Simulating the impacts of policy scenarios on the sustainability performance of infrastructure projects

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ABSTRACT

Sustainable development principles have been implemented in various sectors including the construction industry since it was published in the Brundtland Commission Report in 1987. In line with this development, implementation of infrastructure construction projects has been given particular attention as they have more significant impacts on the environment, society and economy. It is considered that proper development and operation of infrastructure projects such as highways can contribute significantly to the mission of sustainable development. However, there is little existing work to provide appropriate methods to assess the sustainability performance of infrastructure projects. The study described in this paper introduces a simulation model, using system dynamics principle, to evaluate the sustainability performance of highway infrastructure projects during the construction and operation stage. The study introduces the indicators which measure the sustainability performance of highway projects and identifies the dynamic factors affecting indicator performance by referring to the relevant feasibility studies of highway projects. A real highway project is presented to demonstrate the application of the simulation model in evaluating the sustainability performance of the project. The case study is used to explore the solutions for improving those poor sustainability performance areas through policy scenarios.



## 1. Introduction

Sustainable development is commonly defined as "*meeting the needs of the present without compromising the ability of future generations to meet their own needs* [1]". As a result, infrastructure projects have been given particular attention as they have significant impact on the economy, social aspects and the environment. It is considered that the proper development and operation of infrastructure construction projects can contribute significantly to the mission of sustainable development.

Infrastructure projects include a wide range of construction works such as power plants, highways, railways, telecommunication facilities, provision of water and sanitation, and safe disposal of wastes. Developing infrastructure projects plays an essential role in economic and social developments. It is estimated that one percent increase in infrastructure stock is associated with one percent increase in GDP [2]. Kessides [3] pointed out that infrastructure projects contribute to economic growth, both through supply and demand channels by reducing costs of production, contributing to the diversification of the economy and providing access to the application of modern technology. Easterly and Rebelo [4] opined that investment in transportation and communication has a positive effect on economic growth. Esfahani and Ramirez [5] asserted that the contribution of infrastructure services is substantial to economic growth.

Noted, are other further studies on the significance of infrastructure provision to raise the quality of life and poverty reduction. A study by Kessides [3] suggests that infrastructure projects contribute towards raising the quality of life by creating amenities in the physical environment and by providing consumption goods (transport and communication services). Infrastructure projects are also important conditions for improving labor productivity and access to employment, and thus the capacity to earn future income and increasing consumer demands. In addition, a number of studies [6–8] pointed out the significant impact of infrastructure projects on poverty reduction through economic growth.

While infrastructure projects make significant contributions to economic and social development, they may cause undesirable consequences to the environment if they are not properly implemented. For example, power plants and vehicle emissions on roads are typical contributors to air pollution. Combustion of fossil fuels leads to greenhouse gas emissions. Overuse of water for irrigation (which accounts for about 90% of water withdrawal in most low-income countries) damages soil and severely restricts water availability for

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both industry and households. Some infrastructure investments, especially road construction, can put unspoiled natural resources at risk and threaten indigenous communities [2,9–11]. Therefore, in line with the promotion of sustainable development worldwide, it is considered important to be able to understand the performance of infrastructure works to economic, social and environmental aspects collectively. It becomes a pressing issue to find ways for gaining better sustainability performance from implementing infrastructure works which will remain extensive in the near future.

There are various traditional methods for project evaluation, including economic appraisal, environmental impact assessment, social impact assessment and life cycle analysis. However, these methods are usually applied to assess the performance of construction projects from the perspectives of economic, social and environmental dimensions respectively. The absence of an integrative approach has been leading to less consideration on the balance between economic, social and environmental performance when implementing an infrastructure project. In recent developments, several studies contributed in developing methodologies to incorporate project performance across economic, social and environmental dimensions collectively. One major weakness however in applying these methods is that they do not consider the impacts of dynamic interactions between various factors on project performance. In fact, it is essential to appreciate the dynamic impacts of various factors on project performance during the process of implementing projects, especially for those large-scale infrastructure projects with extensive investments and long period of construction and operation time. It is therefore the aim of this study to investigate an alternative project sustainability assessment approach which not only considers project performance across economic, social and environmental dimensions collectively, but also takes into account the impacts of the dynamic interactions of various factors on the project performance. This study will focus on the highway projects during construction and operation stages to illustrate the application of a simulation approach using system dynamics principle for evaluating sustainability performance of infrastructure projects.

## 2. Indicators for Measuring the Sustainability Performance

A number of studies have been conducted to examine the infrastructure project sustainability from different perspectives. For example, Colorni et al. [12] applied decision support system to assess the environmental impact of transport infrastructure. Tsunokawa and Hoban [13] introduced several methods in designing and executing effective environmental assessments to road projects from planning to construction to maintenance. Organization for Economic Co-operation and Development (OECD) [11] proposed a set of attributes to indicate the economic, environmental and social impacts caused by transport infrastructure. The study by Kennedy [14] described the environmental impacts associated with roads and the mitigation measures for reducing the magnitude of their effects. Belli et al. [15] presents an economic evaluation method for evaluating the economic benefits of transport projects. Shen et al. [16] developed a prototype model for accessing the sustainability of construction projects in life cycle based on system dynamics. A study by Ugwu and Haupt [17] proposed an indicator system for assessing the sustainability of a built infrastructure. Research efforts have also been given to examine the sustainability for different types of infrastructure, such as transport infrastructure, wastewater infrastructure, and energy infrastructure [18–20]. There are still other works studying the sustainability of infrastructure projects from different social groups [21,22]. However, it appears that these studies have some limitations in providing effective indicators for evaluating the sustainability performance of highway projects. This paper will formulate a list of key indicators for guiding the evaluation on sustainability performance of highway projects before the project is implemented.

The examination on the existing studies and feasibility study reports of highway projects leads to the formulation of a list of candidate indicators for measuring the sustainability performance of highway projects. To ensure the comprehensiveness and appropriateness of the identification of the indicators, two workshops were conducted in China. Construction professionals including directors and departmental managers in construction companies, consultants, as well as governmental officers concerned, were invited to comment on the comprehensiveness, suitability and clarity of individual indicators. As a result, a preliminary list of 33 indicators for measuring the sustainability performance of highway projects were formulated, as presented in Table 1.

To measure the relative significance of these 33 indicators, a questionnaire survey was therefore conducted in China to collect professional views on the levels of importance of indicators in terms of their contribution to project sustainability. The respondents were requested to rate the indicators according to a five point Likert scale based on their hands-on experience on project evaluation practice. The measurement of the Likert scale is translated as follows: 1 — not suitable, 2 — unimportant, 3 — common indicator, 4 — important, and 5 — most important. The questionnaire was piloted firstly in three cities in China: Beijing, Taiyuan and Shenzhen. Because no adverse comments were received from the interviewees, the questionnaire was taken as the final empirical questionnaire for the investigation. A total of 73 valid responses were received for analysis, and the overall response rate was about 30%. The 73 returned questionnaires consisted of 16 respondents from main contractors, 15 from client organizations, and 23 from consultants from various disciplines that

**Table 1**
Preliminary list of indicators for evaluating sustainability performance of highway projects and their relative significance.

| Dimensions | Proposed indicators | Code | Mean | Standard deviation |
|---|---|---|---|---|
| Economic aspects | Market supply and demand analysis | I1 | 3.21 | 0.53 |
| | Project budget | I2 | 3.17 | 0.67 |
| | Project financing channels | I3 | 2.98 | 0.76 |
| | Project investment planning | I4 | 2.82 | 0.65 |
| | Life cycle cost | I5 | 4.35 | 0.52 |
| | Life cycle benefit/profit | I6 | 4.35 | 0.52 |
| | Financial net present value | I7 | 4.81 | 0.69 |
| | Financial internal rate of return | I8 | 4.72 | 0.73 |
| | Financial benefit–cost ratio | I9 | 4.32 | 0.62 |
| | Payback period | I10 | 4.20 | 0.72 |
| | Economic net present value | I11 | 4.67 | 0.68 |
| | Economic internal rate of return | I12 | 4.20 | 0.71 |
| | Economic benefit–cost ratio | I13 | 4.10 | 0.84 |
| | Technical advantage of construction project | I14 | 2.78 | 0.87 |
| | Reliable mobility | I15 | 3.48 | 0.76 |
| Environmental aspects | Ecological effect evaluation of project | I16 | 4.25 | 0.79 |
| | Air pollution | I17 | 4.72 | 0.56 |
| | Noise emissions | I18 | 4.80 | 0.53 |
| | Water quality (surface and groundwater) | I19 | 3.60 | 0.77 |
| | Waste | I20 | 3.60 | 0.87 |
| | Productive soil loss | I21 | 3.73 | 0.79 |
| | Erosion | I22 | 3.93 | 0.77 |
| | Soil contamination | I23 | 3.67 | 0.85 |
| | Habitat loss and damage | I24 | 3.87 | 0.72 |
| Social aspects | Location efficiency | I25 | 4.02 | 0.69 |
| | Impacts of community development | I26 | 3.98 | 0.71 |
| | Impacts on life standard | I27 | 3.65 | 0.81 |
| | Impacts on historic, scientific, social and amenity values | I28 | 3.42 | 0.65 |
| | Harmony between the project and various features of the landscape | I29 | 3.28 | 0.75 |
| | Short-term health | I30 | 3.67 | 0.83 |
| | Long-term health | I31 | 3.85 | 0.79 |
| | Road safety | I32 | 4.87 | 0.68 |
| | Job opportunities | I33 | 4.16 | 0.78 |