Railway Reinforced Concrete Infrastructure Life Management and Sustainability Index

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Abstract. Infrastructure healthy enhancement for saving resources in operation procedures is one of the most important objectives for owners on their decision support system based on cost management. In this manner, finding the intervention action priority, as well as the inspection method and maintenance system for each component, with regard to a limited resources amount is investigated in this paper. Defects on infrastructure components create data and these data are undoubtedly useful to increase the knowledge in decision making in practice. In that sense, risk analysis and value of information can be applied using decision trees together with Bayesian networks. For data filtering and noise reduction, a principal component analysis may also be applied to manage a database and prepare useful input variables for the decision tree system.
This paper presented an approach for the maintenance managers to prepare their infrastructure available with a sustainable index with minimum cost. This index would be a tool for decision-makers with regard to the cost management and sustainability aspects.

1. Introduction

Most of the transportation modes are made through railway networks and road infrastructures. Passengers' expectation is directly affected by the quality of structures and equipment during the operation. Saving quality level requires planning and predicting resource consumption based on the status of their materials in their degradation model and maintenance approach. The maintenance approach would be renewed or retrofitted during the operation. Quality will explain by performance indicator which has been affected by several attitudes, especially peripheral climate such as strong corrosion processes in the coastal area or freezes and thaw in deserts that result from temperature degree changes or moisture percentage changes in terms of sustainability and environments [1]. Therefore, there is a wide range of alternatives and conflicting criteria are involved as the root of failure on infrastructure.

Therefore, Multi-Criteria Decision Making (MCDM) has been applied to estimate the infrastructure's element performance during the operation [2]. Recent research, for finding the sustainability index has been focused on several subsets of MCDM to prepare a decision support system such as Preference Selection Index (PSI) [2, 3]. This method is typically chosen when there are no significant weights for attributes. In other research, In order to mine the effective parameters for the indexing model based on Pareto concept and making pair-wise comparison questionnaire serving Analytical Hierarchy Process (AHP) requirements to find the weights of them [4]. AHP method has been adopted for the calculation of the Sustainability Assessment Index (SAI) based on normalized key performance indicators and their weight, which has been calculated by AHP [5]. The theoretical framework developed for extracting the Sustainability Index (SI) is a function that comprises Wellbeing, Resource, Compliance, and resources [6]. For qualitative assessment in the AHP process, recent research has been used the Likert scale and extract sustainability level [7]. The results led to the development of a Sustainability Index model (SIM) useful to assess manufacturing performances or maintenance procedures during the operation with rank alternatives [8]. Also, these results have been developed with respect to the evaluation criteria and the weights of the criteria to prioritize the network systems [9]. These indexes could be extracted for prediction by neural network method to decision making with considering probable scenarios [10]. Since, future generations are important for these studies, prediction, and monitoring of the results with any scenario is necessary for decision-makers. Therefore, sustainable development is a comprehensive solution for the present and future of humans [11].

Table 1. Research method and index extract.

Subject	Extracting index method	Subset method
Coastal climate adaptation planning and evolutionary governance: Insights from Homer, Alaska. [1]	Interviews with key informants	-
Development of Sustainable Performance Index (SPI) for Self-Compacting Concretes (SCC) [2]	MCDM	SPI
Application of preference selection index method for decision making over the design stage of production system life cycle [3]	MCDM	PSI
Sustainability index for highway construction projects [4]	MCDM	AHP
Development of sustainability assessment index for machine tools [5]	MCDM	AHP
Development of a multidisciplinary approach to compute sustainability index for manufacturing plants - Singapore Assessing the feasibility of using the heat demand-outdoor perspective temperature function for a long-term district heat demand forecast [6]	MCDM	AHP
Groundwater sustainability assessment framework : A demonstration of environmental sustainability index for Hanoi [7]	MCDM	AHP
Developing a sustainability index for Mauritian manufacturing companies [8]	Rank correlation-Ordinal association	Kendall coefficient
Life cycle aggregated sustainability index for the prioritization of industrial systems under data uncertainties[9]	LCC	Net present value (NPV), internal return rate (IRR), and pay- back time (PT)).

Predicting subjective measures of walkability index from objective measures using artificial neural networks[10]	ANN	-
Comparison of sustainability models in development of electric vehicles in Tehran using fuzzy TOPSIS method [11]	MCDM	fuzzy TOPSIS
The Lisbon ranking for smart sustainable cities in Europe [12]	Feature selection	principal component analysis-Sensitivity analysis

Based on recent research, the sustainable index is an important index for the bridge management system and green infrastructures and green cities.

2. Aim of the research

This paper presents an approach to developing a practical indexing model in terms of resource management and optimization. It will prepare a decision support system for managers that leads to wider uptake welfare during the infrastructure life cycle for their real owner, people. Since this plan optimizes resource consumption, therefore it will keep the environment safe and prevent nature from contamination. Based on this framework, the manager will make an optimized decision for the material and shape of their structures' element during the design. This framework would also be useful for maintenance managers to decide about their maintenance plan with a comparison between the elements and components of the railway network.

3. Research contribution

This paper is structured as follows:

1. Data collection from overall monitoring, such as visual inspection.
2. Variance measurement and extracting the data value
3. Defining the reliability index
4. Define the effective parameters in terms of sustainability with a questionnaire form
5. Correlation analysis between the reliability index and sustainable parameters
6. Prepare a sustainable model for maintenance managers

4. Methodology

This research would establish a comprehensive mathematical method for extracting the sustainability index for infrastructure as follows.

1. Defect detection and extracting the probability of failure
2. Principal Component Analysis (PCA) and the Value of Information for reducing the useless data
3. Environment features and extracting the sustainability parameters
4. Replacing the roots of the defect (environment features) by the defect and extracting the sustainability index for case study
5. The weight of each parameter shows the importance of the index elements. Based on these weights, a new construction plan and materials regarding their maintenance method will be updated.

The framework of extracting sustainable index has been shown as follows diagram.

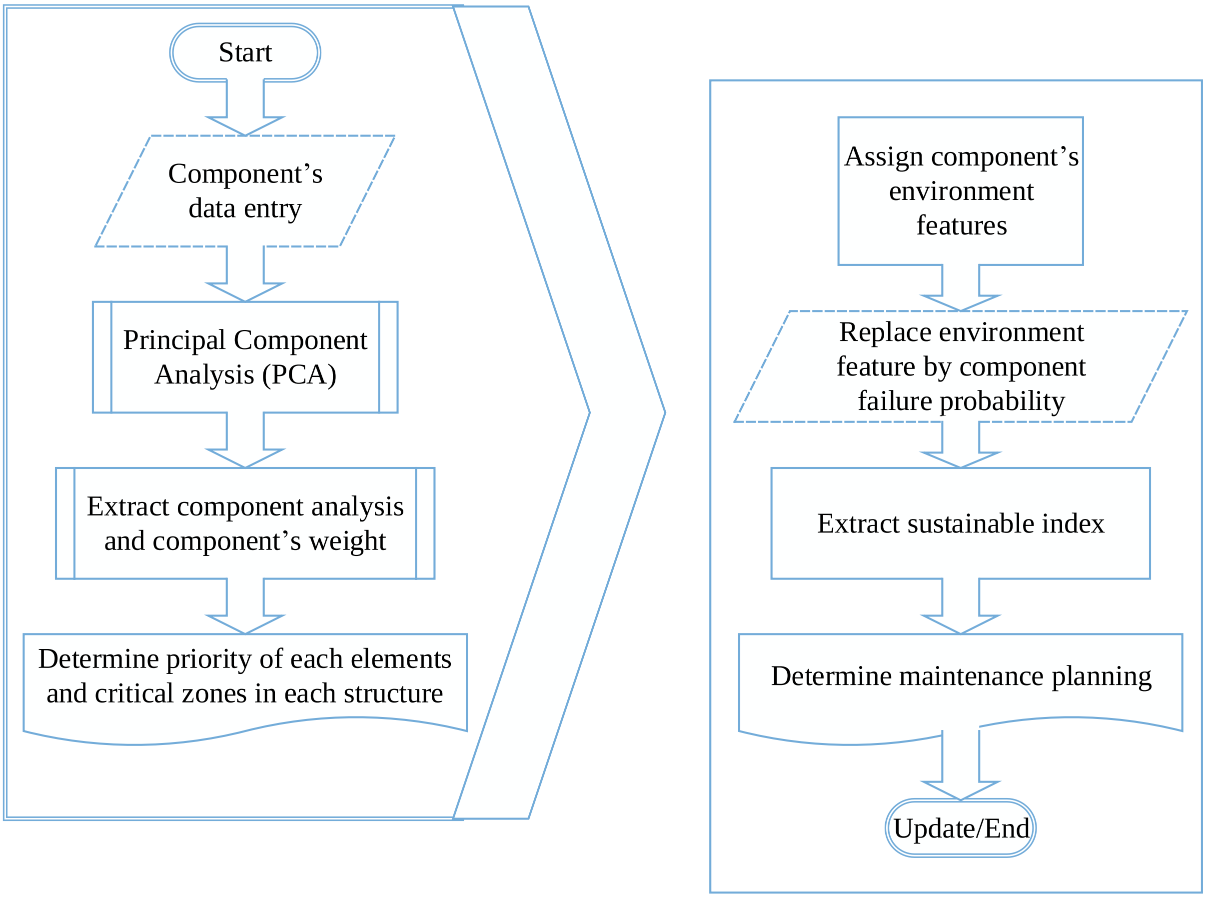

Figure 1. Flow diagram of extracting sustainable index.

5. Data collection

This research would be establishing a comprehensive mathematical method for extracting the sustainability index to assess infrastructure in terms of sustainability. This research has been focused on the Tehran Subway Bridge for monitoring and quality assessment during the operation. Based on the inspection checklist, five bridges are determined and inspected as a sample by expert inspectors.
These bridges have been assessed by the items of the national code [13]. Parameters with subjective attitudes have been ranked based on their environmental status and the other geotechnical features between 1 to 4 or 1 to 5. Some of these parameters would be determined according to the observed defects in each element of the bridge. Since these parameters are not the same range, they will be normalized by formula as follows.

$$Z = \frac{x - \mu}{\sigma} \quad (1)$$

In this formula, μ is the arithmetic mean and σ is the standard deviation of the distribution. Row data after normalization process transfer to the Principal component analysis (PCA) framework. Based on the Scree plot and their Eigenvalue, three components have the most value of information.

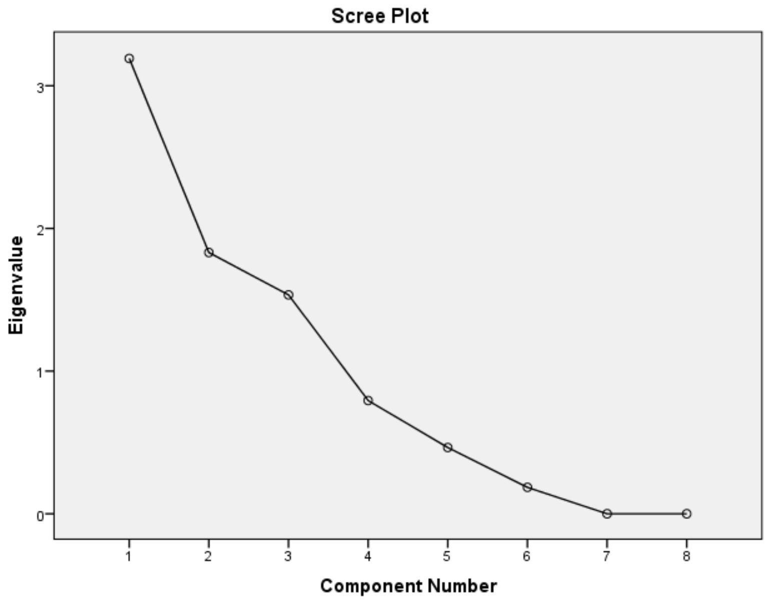

Figure 2. Scree plot for component's eigenvalue based on PCA analysis.

Sustainable structures during their life cycle have to fulfill the thresholds regarding their components and the environment's features based on their weight. By considering these tools, it will be possible to manage assets along their lifetime in a more sustainable and efficient way [15]. Therefore, PCA has been used and 3 components have been extracted by the PCA method for 8 environment features with their weights as follows. Based on Table 2, Li represents the probability of liquefaction and also other environmental features such as Ls and Rf and the other. This method will keep the valuable data and reduce the main by ranking the parameters in each component [17].

Table 2. Component Matrix

	Component		
	1	2	3
Liquefaction (Li)	.825	.448	-.084
Land **s**lide (Ls)	-.012	-.681	.258
Rock **f**all (Rf)	-.811	-.252	.031
Thunderstorm (Th)	.313	.034	.931
Flood (Fl)	.675	-.475	.484
Climate (Cl)	.825	.448	-.084
Density Of **S**oil (Ds)	-.558	.648	.306
Underground void **D**istance (Ud)	-.553	.506	.508

It is necessary for monitoring the mean value and variance changes for each feature, which would be important for sustainable structures. For example, increasing the mean value for flood shows the increasing probability of the Scour surrounding the piers of the bridge. Since climate change would be effective in increasing the crack growth of concrete elements, these features would be related to these types of defects. These relations are shown as follows.

Table 3. Impact of environment features on bridge.

Defects type	Dependent element	Cl	Fl	Th	Ls	Li	Ds	Ud	Rf
Deck stability	Deck			■					■
Drainage	Drainage/Pier/ Deck/ Foundation	■	■					■	
Foundation/embankment settlements	Foundation/Abutment	■	■		■	■	■	■	
Railway track geometry defect (Gage widening, Alignment, Twist, Longitudinal level[14])	Railway track	■							
Bridge thermal movement	Deck/Railway track	■							
Temperature stress cycling	All bridge's element	■							
Deterioration	All bridge's element	■							
Scour	Pier/Foundation		■				■		

Observation from inspection determines the status of the bridge's elements as follows. Some of these elements related to defects and they were affected by environments' features according to the last table.

Table 4. Number of registered defects based on bridge's elements

Bridge number	Defect on railway track	Defect on deck	Defect on Abutment	Defect on Pier	Defect on foundation
1	6	0	0	0	0
2	3	1	0	0	0
3	7	4	1	0	0
4	1	3	0	0	0
5	0	4	1	0	0
6	1	3	0	0	0
7	1	0	0	0	0

For finding the sustainability index, it is necessary to find the risk according to weight for their defects. The probability of failure will be extracted as the following formula [16]. For each bridge (see table 4), V is an approximate measure representative of their volume regarding length (L) and width (W). The number of defects in each element has been determined by visual inspection [18] (F) based on table 4. This shows that a larger bridge has more capacity for a defect in its components when compared with a smaller one. Probability of failure (P-f) are normalized by dividing them with the average of all failure densities.

$$P_f = \frac{\Sigma F}{\int V dv} \tag{2}$$

$$V \simeq L \times W \tag{3}$$

Based on Table 3 and Table 2, the sustainability index has been presented as follows. Bridge number 4 in this step is a sample for calculating the sustainability index for the instability of the deck. With this result, it is necessary to consider the risk of reinforced concrete elements and their defects during the operation with regard to rockfall and thunder. It is obvious for other bridges in the same area, impact factor is the same but the probability of defect will change based on their structural features. Therefore, the sustainability index will change for each bridge, and the final grade will determine by their environment features and structures.

Table 5. Sustainability index for a bridge in case study

Bridge number	Number of defect on element [table 4]	Defect type	Approximate volume (m^3)	Probability of defect [table 4] (%)	Impact [table 2&3]	Sustainability index
4	3	Instability of deck	709.8	0.42	0.931Rf+.031Th	0.42(0.931Rf+.031Th)

6. Conclusion

The sustainability index would be a combination of environmental features to make a decision during the operation or designing of the structure. In this approach after putting up the probability of environment features such as rockfall or climate, finding the location, material and bridge structure type would be possible by benchmarking and expert judgments. With this index it is possible to locate the bridge with a minimum life cycle cost and maximum sustainability. Finding the optimum plan with regard to climate change and seasons is also possible during the operation. For example, in winter railway track face with a wide range of changes in some area and this issue consequently effects on increasing the railway track failure such as rail and fastening system breakage. Therefore, finding the proper place, the best material and optimum maintenance plan would be possible with the sustainability index.

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