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Using social and economic factors for ranking pavement maintenance and rehabilitation projects

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A B S T R A C T

Current pavement maintenance and rehabilitation project prioritization in Sri Lanka considers only economic factors while neglecting social, political, and environmental factors. In this study, the Analytic Network Process (ANP), which can be used as a multicriteria decision-making tool, was utilized for the evaluation of three different pavement maintenance and rehabilitation projects in Sri Lanka. Social and economic factors that affected the three projects were considered and the inner and outer dependencies among them were evaluated and weighted. Pairwise comparisons were conducted complemented by interviews of transportation experts from the Road Development Authority (RDA) of Sri Lanka. Given that the RDA's current method only considers economic factors, our results highlighted differences between the two methods. Therefore, ANP could be recommended for prioritizing pavement maintenance and rehabilitation projects in Sri Lanka.

1. Introduction

Road transportation is the main transportation mode in Sri Lanka, and thus has a considerable effect on the economy of the country. According to data from Sri Lanka's Department of Motor Traffic, in 2012, the motor vehicle population was 4,877,027, and this increased to 6,795,469 in 2016 (RDA, 2007). In March 2017, the Road Development Authority (RDA) noted that the national road network comprised 12,379.49 km, for which the appropriate sequential maintenance and rehabilitation of roads after construction are essential to ensure service quality and user safety. As a developing country, the allocation of adequate financial resources and assets for the maintenance and rehabilitation of the local road network—increasing annually by 12%—has been a serious problem that lags behind the increasing demand (RDA, 2007). Because of budget constraints, many proposed road projects have been neglected, and they end up as huge rehabilitation and reconstruction projects that require more cost. The economy of Sri Lanka has traditionally been opened to international trade with numerous exports and imports that make up an average of more than 60% of the gross domestic product which is a broad measurement of a nation's overall economic activity. Because Sri Lanka's manufacturing industry has been integrated into the international value chain, efficient transport logistics, in which road infrastructure becomes significant in terms of trade competitiveness, plays a major role (RDA, 2007).

Several methods have been used by transportation experts to analyze decision problems for prioritizing and selecting the projects that have the most critical conditions based on considered parameters; for example, cost–benefit analysis (CBA), strengths, weaknesses, opportunities, and threats (SWOT) analysis, case-based reasoning (CBR), the Analytic Hierarchy Process (AHP), and the Analytic Network Process (ANP). Of these, CBA, SWOT, and CBR methods have been used for a number of decades for this purpose. CBA has been used for the economic evaluation of road projects in developing countries, but this method is insufficient to ensure economic and social development (Talvitie, 2000). Chou (2009) focused on the CBR method using paper-based data on projects and presented the integration of the CBR method, the eigenvector method, and web technologies to recall the experiences of transportation experts to derive the significant weights of attributes accommodating an intelligent and distributed system to identify the most appropriate CBR model. In 1972, Saaty introduced the AHP, which to a large extent avoided the weaknesses of previous methods and techniques (Saaty, 2004). In the AHP method, the decision problem is broken down into criteria and alternatives, thereby developing a hierarchy, and a pairwise comparison method is used for the analyzing process. The ANP method was developed to bring out the dependencies between criteria and alternatives that are assumed to be neglected in the AHP method.

In the ANP, all the influencing factors are compressed into a network with clusters and links. Clusters are comprised of goals, influencing

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factors, and alternatives, while links represent the dependencies within clusters and alternatives. The importance of evaluating these dependencies lies in defining a flow of interconnections, thereby helping to achieve the prioritization of pavement maintenance and rehabilitation projects more practically. Thus, the decision-maker becomes familiar with the way people generally think about a decision problem and this ANP approach helps to bring the decision maker to the correct track without limiting the natural human thinking into a given framework. These dependencies are not evaluated in the AHP method because it assumes that real-world decision problems are linear; however, in practical situations, real-world problems should be structured as networks, not as linear hierarchies.

The present study accommodates the ANP method to prioritize pavement maintenance and rehabilitation projects in Sri Lanka. The main objective was to include the factors that affect the prioritization of pavement maintenance and rehabilitation projects for the decision-making process other than economic factors.

2. Literature review

Some studies have applied the AHP and ANP to pavement maintenance and rehabilitation projects worldwide. Li et al. (2018) derived the highway network maintenance priority, considering five factors related to decision-making: pavement performance, pavement structural strength, traffic loads, pavement age, and road grade. They also suggested including pavement structure type, climatic conditions, and details of the surface materials, in addition to pavement structural, functional, and conditional factors. Ahmed et al. (2017) demonstrated the accuracy of project evaluation assisted by the objective-based AHP approach by considering 28 road sections in Mumbai city. The decision framework was developed using influencing factors such as pavement inventory data (road name, functional class, surface type, carriageway width, length, and number of lanes) and pavement condition data (alligator cracking, patching, rutting, potholes, and raveling). The judgmental values were assigned based on extracted data rather than relying on expert opinion. Wu and Flintsch (2008) introduced a model that supported decision-making for the optimal selection of pavement management and rehabilitation projects accommodating the three proven operational research techniques of k-means clustering, AHP, and integer linear programming. A decision tree was developed including both quantitative and qualitative factors such as distress index, roughness index, roadway class, traffic volume, user satisfaction, and business/recreational importance to local communities. The AHP analysis involved three main criteria: maintenance and rehabilitation costs/benefits, network and local importance (including traffic and accessibility), and overall condition (including pavement quality index according to ride, surface distress, and structural adequacy).

Smith and Tighe (2005) applied the AHP as a tool for infrastructure management and nine criteria were adopted: ride quality, surface distress, structural adequacy, surface friction, surface drainage, the level of noise, user delay, life cycle cost-effectiveness, and environmental impact. Zhang and Ahson (2004) applied an AHP-based method to prioritize relevant data for the management of the pavement at the Texas Department of Transportation. After examining the importance of data and the frequency of usage, it was shown that the most significant data were related to identifying the specific location of pavement sections in the field, followed by data related to pavement performance and traffic and safety. Data on temperature, policy issues, and existing climatic conditions were prioritized as low. Görener (2012) presented a quantitative-based SWOT analysis to explain how to use the ANP and the AHP methods for prioritizing SWOT factors while comparing both methods.

Kadoić et al. (2017) emphasized that when influence or dependency exists between decision problem criteria, the ANP method is more appropriate to obtain a precise solution because the AHP method does not address dependency between criteria. A street reconstruction project was evaluated by Ivanović et al. (2013) in a city in the southeastern Balkans and an ANP model was developed that included all influencing criteria, namely exterior projects, traffic, environmental facts, costs, and benefits. Each criterion comprised two subcriteria: for example, vehicle kilometers traveled and travel time for the traffic criterion; carbon monoxide (CO) emission and noise level for the environmental criterion; opportunity and infrastructure costs for the cost criterion; revenue and social benefits for the benefits criterion; and two ongoing projects for the exterior projects criterion. Considering small investment opportunities in transport infrastructure development within ten years of time period, Ivanović et al. (2013) defined three alternatives. The opinions of stakeholders, traffic experts, local government, and the local population were obtained to evaluate these alternatives considering the importance of the criteria. Tuzkaya and Önüt (2008) presented a fuzzy-ANP (FANP) model for the transportation mode selection between Turkey and Germany comprising eight criteria: product characteristics, flexibility, reliability, speed, traceability, costs, safety problems, and risks. Under each cluster, 32 subcriteria were included and rail, road, sea, and air were considered as the main modes of freight transportation. Wey and Wu (2007) presented a combined goal programming approach using zero–one goal programming (ZOGP) and ANP for transportation infrastructure project selection; they illustrated this model with an example from Taichung city, Taiwan designed to enhance the transportation infrastructure facilities in the city. The main criteria were land use, planning and design, infrastructure definition, management and maintenance, travel demand, financial analysis and proposals, and promotion and the problem was evaluated by 10 transport experts.

Several optimization-based methods are used worldwide for prioritizing projects in the transportation sector in addition to the AHP and ANP. Rezvani et al., 2015 identified the processes of identifying, prioritizing, and selecting safety projects at highway-rail at-grade crossings by calculating all costs and benefits associated with safety projects. The flow of their framework can be expressed as measuring crash costs (primary and secondary effect costs), cost-based screening (expected crash costs), CBA (cost–benefit ratio), project prioritization, and funding. Although CBA is an important component in evaluation, it is per se insufficient to ensure economic and social development (Talvitie, 2000). Chu and Chen (2012) proposed a threshold-based maintenance optimization model under budget constraints using hybrid dynamic models (HDM). Pavement conditions were categorized into two types: functional conditions and structural conditions. Each condition was represented by international roughness index (IRI) thresholds and pavement age thresholds. The IRI threshold was applied for overlay and fog sealing, and the pavement age threshold for initiating reconstruction. Mathematical relationships were developed using threshold variables and user response to maintenance decisions was evaluated as a lower-level problem with traffic flow and travel time considerations. As additional parameters, maintenance cost, accumulated traffic loadings, and traffic demand for peak hours (traffic volume and capacity) were adopted for the study.

Lee and Madanat (2015) presented a mathematical formulation and a solution to optimize rehabilitation and reconstruction policies for large-scale pavement systems that minimize the life cycle costs of systems with limited budget allocations and user costs. For pavement reconstruction, a number of decision variables were included, such as budget constraints, budget expenditure period, pavement life cycle length, traffic volume and loads, and the characteristics of the roadway segment including structural design. For pavement rehabilitation activities, subsurface structural damage was considered including cumulative traffic loadings that are proportionate to the age of the structure. To analyze the structural damage in underneath layers, an augmented condition state was defined that comprised age, number of years from the most recent construction/reconstruction activity, and pavement roughness. In addition to reconstruction and rehabilitation, corrective and preventive maintenance activities were considered. Cost and performance models, a roughness model, and a deterioration model were developed as functions of traffic loading and structural number. The vehicle operating cost per unit time was formulated as a function of pavement roughness, and travel delay user cost due to reconstruction was represented as a function of traffic volume. Cost effective models for rehabilitation works were then formulated using factors such as overlay thickness, number of lanes, pavement roughness level, and intensity of resurfacing. The reconstruction cost per unit length was defined in terms of structural number and number of lanes, while the pavement design was not considered as a decision variable. The solution approach was determined through single-segment and system-level optimization and discussed under two budget constraints. This framework was applied for a case study consisting of 311 pavement segments in Caltrans District 4 of California's State Highway system to obtain segment- and system-level results.

Dadashi and Mirbaha (2019) presented a ranking approach based on integration of data envelopment analysis (DEA) and Monte Carlo simulation to prioritize road safety improvement projects, minimizing the uncertainties in average crash frequency and project costs. Mathematical relationships were formulated considering each safety retrofit project as a decision-making unit (DMU) and inputs and outputs were costs and benefits of countermeasures. A range of efficiency scores for each DMU was obtained from the developed model and the effect of uncertainty on the relative efficiency was evaluated using a coefficient of variation as an indicator for the variation. Sadeghi and Moghaddam (2016) proposed a multidimensional approach for prioritizing road safety projects where uncertainties are taken into account in benefit estimations of projects in relation to the reduction of accidents and costs. The method helped decision-makers to select the most cost-effective project using DEA with an uncertainty assessment.

Novak et al. (2015) evaluated the outcomes associated with an innovative change in a state-level transportation project prioritization process in the United States by developing and implementing a novel multicriteria analysis tool. Several project classes were considered for the prioritization, such as roadway, paving, bridges, bikes/pedestrians, traffic operations, and park and ride. Those project classes were scored by a pool of stakeholders from different responsible transportation agencies based on evaluation criteria. A metropolitan planning organization introduced evaluation criteria such as economic vitality, safety and security, mobility and connectivity, environment, energy and quality of life, preservation of existing system, efficient system management, and prior listening in transportation improvement planning, while the Vermont Agency of Transportation introduced evaluation criteria for each project class separately. The prioritization of road network expansion projects was addressed by Bagloee and Asadi (2015) using dynamic project prioritization concepts, algorithms, and numerical evaluations. The dynamic variation of travel demand during the project construction stages was considered, and to deal with the complexities of projects with a vast number of influencing factors, a heuristic methodology was developed. Mathematical functions were formulated to obtain a benefit curve that represented the benefits of projects with respect to travel time or amount of saved user costs. The interdependency of projects was evaluated by formulating a neural network and traffic assignments were conducted for project benefit evaluation.

In Sri Lanka, optimization-based methods that require mathematical formulations based on different information are not utilized by the transport agencies due to the insufficiency and unavailability of reliable data. Moreover, awareness of these types of methods is generally lacking. In the current RDA approach for project prioritization, the estimated capital cost and net present value for the projects are required and the Highway Development and Maintenance Management System software, HDM-4, is used for the analysis. Therefore, optimization-based methods with complex mathematical functions are considered rather too advanced and their implementation is not practical in the real-world decision problems within the country. In this case, multicriteria decision-making tools will be more beneficial in decision-making. These tools require fewer data than optimization-based methods and their methodological complexity is also lower. In Sri Lanka, transport projects are affected by several factors, such as economic, social, environmental, political, and risk factors. However, the current project prioritization method is only capable of analyzing the economic viabilities of projects, and the responsible agencies presently have no plan to proceed with a clearly defined framework for the evaluation of all influencing factors. To overcome this issue, the ANP method could be introduced for the decision-making process in Sri Lanka. This method is capable of considering and integrating all influencing factors to obtain a final ranking for candidate projects. The general procedure followed in this study is the same as in previous ANP studies but the influencing factors are specific to the candidate projects and the country.

3. Methodology

The general procedure of the ANP comprises the following steps.

- Identification of the decision problem.
- Identification of the goal, criteria, subcriteria, and alternatives for the problem.
- Preparation of the complete network of clusters including identified goal, criteria, subcriteria, and alternatives, and mapping all dependencies.
- Pairwise comparisons of each dependency across the network elements are conducted by transportation experts, weighted according to Saaty's fundamental scale (Satty, 2004).
- Formation of the supermatrix by laying out the clusters in the order they are numbered and all the elements in each cluster are included both vertically on the left and horizontally at the top.
- Formation of the weighted supermatrix.
- Formation of the limit matrix.
- The final priorities and rankings of the alternatives are obtained.

Five different phases were followed in this study for obtaining the final priorities of the alternatives.

3.1. Phase 1: Identification of pavement maintenance and rehabilitation projects

Three different pavement maintenance and rehabilitation projects that are proposed to be implemented were selected for the study and all necessary information was collected from the RDA, Sri Lanka.

3.1.1. Project A: Kaduwela–Hanwella road segment (AB10)

This segment of the national road network has a length of 13.5 km, and two traffic lanes with an average daily traffic (ADT) of 34,315 vehicles. It is proposed to widen the road segment to four carriageways according to the RDA estimations, and the estimated budget for the project is 2.732 billion LKR (172 LKR = 1 US$ in 2018). The current IRI value of the asphalt pavement is 4.42 m/km and the roadway gives access mainly to Pettah and Avissawella via Kaduwela. The roadway crosses a few traffic-generating zones that are economically significant, such as Avissawella Industrial Zone, Seethawaka Botanical Garden, popular schools, and Leisure World Sri Lanka. The land use beside the roadway is general semiurban, which allows for residential buildings in the community and low-scale commercial activities.

3.1.2. Project B: Kaduwela–Malabe road segment (B263)

This is a section of the New Kandy Road that has two traffic lanes, a length of 3.5 km, and an ADT of 51,731 vehicles. The number of road users is higher in this section because it gives access to more demanded destinations such as Pettah, Kollupitiya, Athurugiriya, and to the Southern Expressway. It is also close to traffic-generating zones such as Sri Lanka Institute of Information Technology, popular schools, and the government office complex at Baththaramulla. The road segment is also proposed to be widened to four carriageways according to the RDA estimations, and the estimated budget for the project is 1.509 billion LKR. The current IRI value of the asphalt pavement is 3.775 m/km and the land use beside the roadway is rapidly increasing with residential and commercial activities.

3.1.3. Project C: Kaduwela–Balummahara road segment (B214)

This road segment has a length of 16 km and two traffic lanes, and is also a segment of the New Kandy Road with an ADT of 36,315 vehicles. It mainly gives access to the Kandy Road (a main trunk road in Sri Lanka) from Kaduwela and there are a few associated traffic-generating zones, such as Biyagama Industrial Zone and popular schools. The road segment is also proposed to be widened to four carriageways from Kaduwela to Biyagama according to the RDA estimations, and the estimated budget for the project is 3.627 billion LKR. The current IRI value of the asphalt pavement is 5.03 m/km and the land usage beside the roadway is general semiurban with local residential and commercial activities.

3.2. Phase 2: decomposing the research problem into a network

Core pavement management activities and all factors that affect the selected candidate projects were identified within the process of preparing the network because it represents the decision problem as a framework or structure. When decomposing the problem, the elements were related to any aspect of the problem such as duly estimated or roughly estimated, and tangible or intangible. The developed network is presented in Fig. 1.

In this decision problem, goal/objective aimed to identify the specific, most predominant project (Cluster-1) among the alternatives of three selected candidate projects (Cluster-6). Costs and benefits were identified as the key and governing parameters associated with the three candidate projects.

Under the costs parameter, the types of infrastructure costs and the geometrical features of roadways were considered as main criteria. *Project costs* (Cluster-3) and *geometry of the road segment* (Cluster-2) were included in the network, considering costs. Pavement maintenance costs and future rehabilitation costs were identified as types of infrastructure costs. The length of the road segment, the number of traffic lanes in the roadway, and the number of horizontal and vertical curves were identified as the geometrical features, and these comprised the subcriteria of Cluster 2.

Under the benefits parameter, social and economic benefits are included and user safety, comfortability, and level of serviceability were identified as the main factors that created the two main criteria of *current pavement quality* (Cluster-4) and *traffic* (Cluster-5). Under the *current pavement quality* criterion, subcriteria were identified as cracks in the surface, potholes in the surface, last rehabilitation/maintenance work, and the duration since the last rehabilitation/maintenance work. With people's increasing demands for better living conditions/standards, riding comfort on their daily travel is expected on roads. Therefore, to improve the comfortability of drivers and passengers, the existing asphalt pavement conditions, and the frequency and type of rehabilitation were evaluated. *Traffic* criteria were adopted to study the level of serviceability of selected roads to improve user safety and comfortability, and to reduce the economic loss of users due to congestion. As subcriteria, ADT, the number of heavy vehicles, and traffic generators were considered. By adopting these *current pavement quality* and *traffic* criteria, it is expected

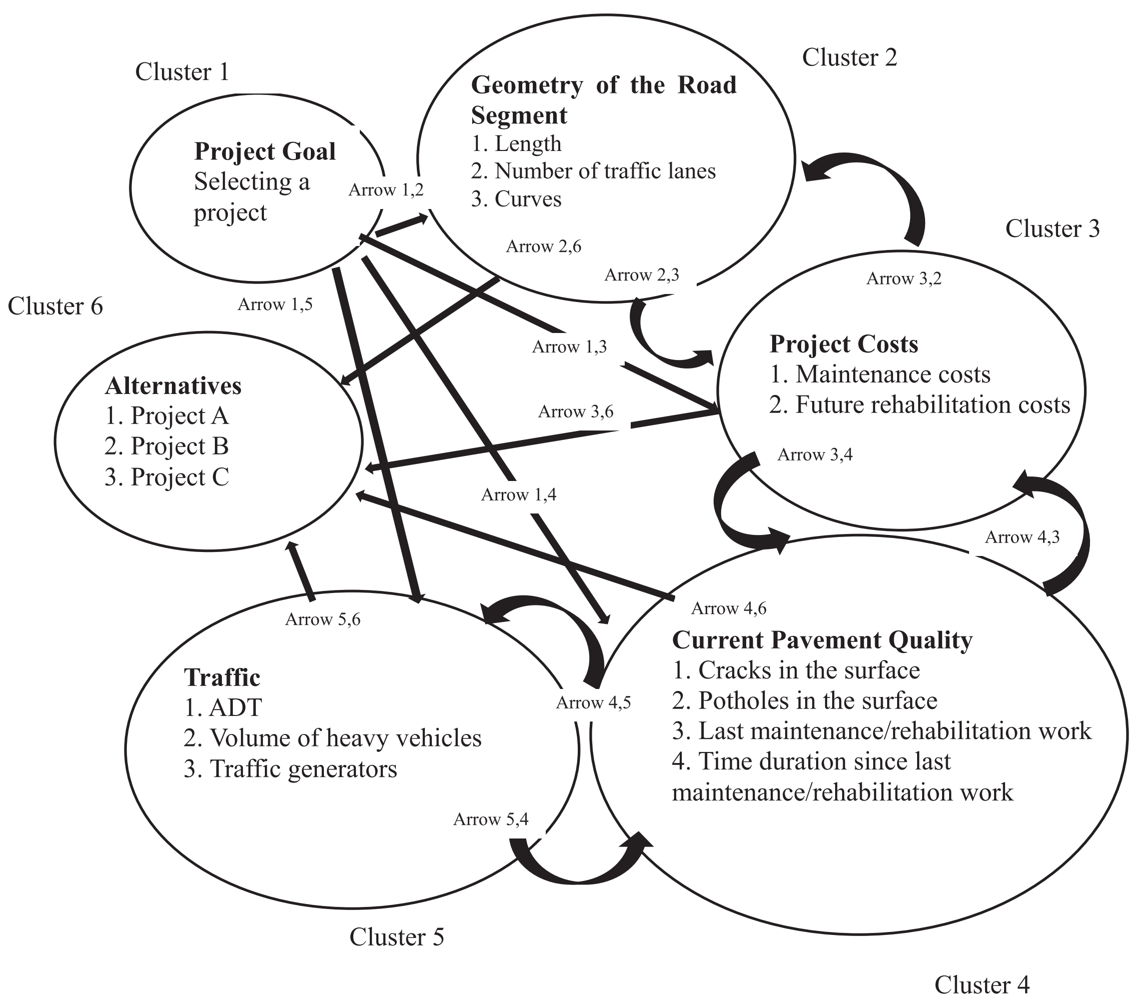

Fig. 1. The network model.

to focus on the society by addressing safety, comfortability, and economy of human beings.

Several relationships within the criteria and subcriteria can be identified in addition to the relationships between the *goal* criteria and the criteria *alternatives*. In Fig. 1, the arrows represent the inner dependencies and outer dependencies among nodes of the network. These dependencies can be briefly expressed as follows.

- *Project costs* (Custer-3) and *geometry of the road segment* (Cluster-2) (Arrow 3,2 and Arrow 2,3). When the number of traffic lanes, proposed length, and other geometrical features (alignment, curves, etc.) improve/increase, the project, maintenance, and rehabilitation costs will vary; when the road maintenance and rehabilitation costs are limited, improvement of the geometrical features will also be limited or avoided.
- *Project costs* (Cluster-3) and *current pavement quality* (Cluster-4) (Arrow 3,4 and Arrow 4,3). If a pavement continues to rupture, pavement maintenance and rehabilitation costs will increase; when the budget allocation is inadequate or limited, the expected pavement quality will not be achieved.
- *Current pavement quality* (Cluster-4) and *traffic* (Cluster-5) (Arrow 4,5 and Arrow 5,4). Pavement quality degrades with usage and road usage will be minimized when the road pavement continues to rupture.
- *Project goal* (Cluster-1) relates to all main criteria (Arrow 1,2, Arrow 1,3, Arrow 1,4, and Arrow 1,5) and all criteria relate to the alternatives (Cluster-6) (Arrow 2,6, Arrow 3,6, Arrow 4,6, and Arrow 5,6).

Therefore, all the arrows that represent dependencies between elements in the network are significant for understanding the problem more effectively and all presented interrelationships should be evaluated and computed.

3.3. Phase 3: Arranging interviews with RDA professionals

The main purpose of interviewing RDA professionals, who are currently involved in the pavement maintenance and rehabilitation project-planning activities in the country, was to compare network elements based on their knowledge and experience. Interviews with nine transportation experts were conducted for this purpose.

In accordance with the ANP method, a questionnaire was prepared and pairwise comparisons were conducted on network elements to derive a scale of relative measurements. Weights that ranged from 1 to 9 according to Saaty's fundamental scale (Table 1) were applied for each pairwise comparison by the transportation experts. As an example, one interview question was "With respect to the goal, which criterion is more important: project costs or current pavement quality?", and questions of a similar nature were included in the questionnaire as appropriate and responses recorded. If project cost was considered by one expert to be of stronger importance than current pavement quality, then a weight of 5 was recorded.

Table 1
Saaty's fundamental scale.

Weight of importance	Definition of the weights	Description
1	Equal importance	Contribution to the objective is equal
2	> Equal (Weak/ slight)	Contribution to the objective is equal to moderate
3	Moderate importance	Experience and judgment moderately favor one element over another
4	> Moderate	Experience and judgment favor moderately to strongly
5	Strong importance	Experience and judgment strongly favor one element over another
6	> Strong	Experience and judgment favor strongly to very strongly
7	Very strong importance	One element is favored very strongly over another
8	Very, very strong	One element is favored very very strongly over another
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation

3.4. Phase 4: Computation and reaching decisions

3.4.1. Conversion of relative weights into a matrix form

For each dependency, weights were presented as a matrix that consisted of all relevant nodes on the left-hand side and the top. When entering weights into a matrix, the priority was given to rows. Table 2 presents the relative weights of alternatives with respect to the project cost criteria. For example, if in the pairwise comparison of projects A and B relative to the project cost weights, project A was strongly favored over project B (weight 7), this was entered in the matrix element at row A, column B, indicating the value of 7, and the element at row B, column A indicating the reciprocal value as 1/7. This order was followed for all combinations while composing matrices. Comparisons of the same nodes are indicated as 1 in the matrix; if dependencies do not exist, this is indicated by zero (Saaty, 2004; Kadoić et al., 2017).

3.4.2. Derivation of priorities for each element

The priorities were derived by dividing the total of each row by the column total and these priorities are termed as local priorities or priority vectors. For each node, combinations of local priorities were defined.

3.4.3. Formation of the supermatrix

The supermatrix was composed by aligning all nodes in the network horizontally and vertically (Table 3) and relevant local priorities were fed into the matrix. Each block of column vectors defined an entry in the supermatrix. Because the alternatives do not influence the other clusters and there are no inner dependencies among them, the alternatives were not included in the supermatrix and their priorities were derived by omitting them. When the criteria do not depend on the alternatives, the latter may be kept out of the supermatrix and evaluated according to the performance or dominance modes after the limiting priorities of the criteria are obtained from the limit matrix. Otherwise, if some criterion depends on the alternatives or if there is an inner dependence among the alternatives, they must be included in the supermatrix (Saaty, 1996). All nonzero elements in the matrix represent the connections/dependencies from one node to another node in the network. Table 3 presents the structure of the developed supermatrix for each data sample.

3.4.4. Formation of the weighted supermatrix

The local priorities in the supermatrix were converted into global priorities, multiplying the corresponding blocks of column vectors in the supermatrix by the priorities defined for each criterion relative to the governing criteria of the project goal cluster. The resulting matrix was termed the "column stochastic" as all columns in the matrix sum to 1.

3.4.5. Formation of the limit matrix

The weighted supermatrix was powered to obtain the limiting priorities.

Table 2
Conversion of relative weights into matrix form.

Project cost	A	B	C
A	1	7	1/2
B	1/7	1	1/8
C	2	8	1
Column total	3.142857	16	1.625

Table 3
Structure of the supermatrix.

		Project costs		Current pavement quality				Traffic			Geometry of the road segment		
		Project maintenance costs	Future rehabilitation costs	Cracks in the surface	Potholes in the surface	Last rehabilitation and maintenance work	Time duration since last rehabilitation/ maintenance work	ADT	Heavy vehicles	Traffic generators	Length of the road segment	Traffic lanes	Horizontal and vertical curves
Project costs	Project maintenance costs	0.07500	0.07500	0.02581	0.02765	0.02151	0.01613	0.00000	0.00000	0.00000	0.15000	0.15000	0.10000
	Future rehabilitation costs	0.02500	0.02500	0.00645	0.00461	0.01075	0.01613	0.00000	0.00000	0.00000	0.05000	0.05000	0.10000
Current pavement quality	Cracks in the surface	0.02543	0.03302	0.00710	0.00710	0.00710	0.00710	0.05105	0.00734	0.01629	0.00000	0.00000	0.00000
	Potholes in the surface	0.14986	0.13800	0.09998	0.09998	0.09998	0.09998	0.08821	0.10331	0.08589	0.00000	0.00000	0.00000
	Last rehabilitation and maintenance work	0.16209	0.12997	0.02078	0.02078	0.02078	0.02078	0.01371	0.02147	0.02628	0.00000	0.00000	0.00000
	Time duration since last rehabilitation/ maintenance work	0.16236	0.19901	0.03344	0.03344	0.03344	0.03344	0.01371	0.03455	0.03821	0.00000	0.00000	0.00000
Traffic	ADT	0.00000	0.00000	0.23574	0.23574	0.23574	0.24832	0.24843	0.24843	0.24843	0.00000	0.00000	0.00000
	Heavy vehicles	0.00000	0.00000	0.50563	0.50563	0.50563	0.49683	0.52706	0.52706	0.52706	0.00000	0.00000	0.00000
	Traffic generators	0.00000	0.00000	0.06508	0.06508	0.06508	0.06131	0.05784	0.05784	0.05784	0.00000	0.00000	0.00000
Geometry of the road segment	Length of the road segment	0.18461	0.24034	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.04803	0.04800	0.04803
	Traffic lanes	0.18461	0.09160	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.55164	0.55160	0.55164
	Horizontal and vertical curves	0.03077	0.06807	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.20033	0.20033	0.20033
Column Total		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000

3.4.6. Synthesis of final priorities of alternatives

Because the alternatives were kept out of the supermatrix, their influences were compared separately, with respect to the clusters that they were connected. From the limit matrix for each data sample, limiting priorities for each subcriterion were obtained. Then, the priorities for each subcriterion were multiplied by the priority of the corresponding main criteria obtained with respect to the alternatives, and three sets of final priorities were obtained for the three alternatives. These final priority values were considered under two main factors, namely costs and benefits. Final priorities under project cost criteria and geometry of the road segment criteria fell under the costs factor; the other two main criteria, traffic and current pavement quality, fell under the benefits factor. Relevant final priorities were summed separately to calculate the benefit–cost ratio, and the ratio with the largest value was chosen. The same procedure was carried out for all nine decisions by the experts and rankings were obtained of alternatives for each sample separately. Table 4 presents the calculated benefit–cost ratios for each alternative.

3.4.7. Aggregation of final priorities of alternatives

Nine ranking sets were compared and the most predominant alternative was chosen as the final candidate project to be implemented.

3.5. Phase 5: Comparing the ANP results with those from the RDA's current approach

The RDA uses economic analysis, which is a net present value (NPV)-based method to prioritize pavement maintenance and rehabilitation projects. This is conducted using the decision-making tool, HDM-4, for checking the engineering and economic viability of investments in road projects. HDM-4 uses both the values of net benefits and internal rate of return as the efficiency criteria to make decisions. The World Bank has developed HDM-4 for worldwide project analysis, program analysis, strategic analysis, and research, policy, and regulation analysis. Under project analysis, the maintenance of existing roads, improvement of existing roads, new construction, stage construction, and project evaluation can be carried out. The influence of social, political, and other factors is not included in this tool, yet results from economic analysis are subject to vary with political and social factors. In 2018, all three road segments considered in this study were proposed for rehabilitation by widening to four carriageways. The results obtained from the ANP method and those generated from the method used by the RDA for prioritizing pavement maintenance and rehabilitation projects were compared and contrasted, and recommendations and conclusions drawn.

Table 4
Priorities of alternatives determined by the nine experts using the ANP.

Data Sample	Alternative	Benefit–cost ratio	Ranking	Prioritized alternative
1	A	30.88	2	B
	B	72.27	1	
	C	17.88	3	
2	A	48.19	3	B
	B	143.5	1	
	C	55.25	2	
3	A	0.82	2	B
	B	0.98	1	
	C	0.45	3	
4	A	16.49	2	B
	B	53.86	1	
	C	10.95	3	
5	A	34.15	3	B
	B	942.44	1	
	C	90.02	2	
6	A	111.9	3	B
	B	345.61	1	
	C	155.91	2	
7	A	0.38	2	B
	B	0.96	1	
	C	0.32	3	
8	A	4.05	3	B
	B	31.9	1	
	C	7.25	2	
9	A	3.72	3	B
	B	7.56	1	
	C	6.72	2	

4. Results and discussion

Most decision problems cannot be decomposed as linear structures because dependencies or influences exist between higher- and lower-level elements. The process of pavement management and prioritization in Sri Lanka is affected by a range of social, economic, environmental, political, and other influences. Therefore, measuring simply the economic viability of investments in such projects is not sufficient to capture the overall aspects of a successful functioning of a project, thereby emphasizing the need for a multicriteria analysis in project prioritization. The observation on these selected influencing factors in this study goes in depth, since the influences carry clear and obvious interrelationships among them. In this study, we took the social and economic influences into account, which in turn highlighted interrelationships between the selected criteria, such as between project cost and current pavement quality, between project cost and road geometry, and between traffic and current pavement quality criteria. Therefore, in addition to evaluating the relationships between the decision problem and social and economic influencing factors, the interrelationships between these influences should be computed for a more effective approach to the decision problem. This demonstrates the need for a network structure of elements for pavement maintenance and rehabilitation project prioritization in Sri Lanka, rather than utilizing a linear hierarchical approach. In the developed network, all outer and inner dependencies were represented as a ratio scale in a matrix column.

Three candidate projects were evaluated considering social and economic influences with a focus on cost and benefit parameters. Data were analyzed after interviews with nine experts from the RDA, and their clear priority was obtained for project alternative B, the Kaduwela–Malabe road segment (Table 4). The benefit–cost ratio varied between samples considerably, from 942.44 to 0.32, due to the different judgments and opinions of the experts in pairwise comparisons. In such cases, it is better to integrate judgments from all experts; many aggregation methods exist for AHP and ANP, such as aggregation by means of direct information, aggregation by means of indirect information, and aggregating priorities using mathematical extensions (Ossadnik et al., 2016). In this study, preference was given to examining the individual opinions, and these were analyzed separately to ascertain differences and similarities in the experts' judgments.

In the NPV-based economic analysis, which is used by the RDA, only economic parameters are considered, while neglecting social and other influencing parameters. Table 5 presents the results obtained from the NPV-based economic analysis for each project considered in this study. For project C, data were available only for the Kaduwela–Biyagama road segment, which was the section with the highest NPV/estimated capital cost (ECC) ratio. Therefore, according to the NPV-based economic analysis, project C, the Kaduwela–Balummahara road segment, is given priority. Thus, it was found that the results differed according to whether the ANP method or the NPV-based method was used. The ANP is a multicriteria decision-making tool that includes both social and

Table 5
Results from the NPV-based method.

Project	Estimated capital cost (ECC) (billion LKR)	NPV (billion LKR)	NPV/ECC ratio
A	2.732	40.593	14.86
B	1.509	23.671	15.69
C	3.627	102.726	28.32

economic factors, whereas the NPV-based method only considers economic factors. In contrast, the contribution of the transportation experts complemented the ANP process. Therefore, it can be concluded that the selected decision-making problem for the study was effectively approached with social factors in addition to economic factors, and the solution from the ANP method, Project B, was more validated compared with the results from the NPV analysis. The most critical factor that generated the differences in results was that both economic and social factors were involved in the ANP. In sum, economic benefits are represented by project cost and road geometry criteria with their respective subcriteria, while social benefits are represented by current pavement quality criteria and traffic criteria with their respective subcriteria.

The ANP method can be seen as a multicriteria decision-making tool that models the decision problem as it appears in the real world. Logical thinking is required for structuring the problem in to a network and to come up with more precise definitions of nodes and interconnections. To evaluate these interconnections/dependencies, a pairwise comparison technique is used that develops a common relative ratio scale between all combinations. Another positive feature of the ANP method is the contribution of knowledge and experience from relevant experts, although such input may not be considered as fair evaluation since the ideas and decisions may vary from expert to expert. In addition, the ANP method is time-consuming as it takes time for structuring the problem, conducting surveys/interviews to grab the opinions of transport experts and for analyzing comparing to other methodologies. Another possible limitation of this multicriteria decision-making tool is the current lower awareness of this method among professionals in Sri Lanka because the ANP approach is not commonly used.

5. Conclusions

The study was carried out to prioritize pavement maintenance and rehabilitation projects using the ANP method. Three projects from the Sri Lankan national road network that required maintenance and rehabilitation work were selected for the study. The three candidate projects were the rehabilitation of the Kaduwela–Hanwella road segment, the Kaduwela–Malabe road segment, and the Kaduwela–Balummahara road segment. Complying with the ANP method, all main criteria and subcriteria that influenced the project prioritization were identified. The study goal, criteria, subcriteria, alternatives, and dependencies were integrated into a network composed of several clusters and the network represented the decision problem in a structural manner. To align all the dependencies to a common scale for a better understanding of their priorities, a pairwise comparison method was adopted. This was conducted according to Saaty's fundamental scale through interviews with nine transportation experts involved in pavement maintenance and rehabilitation project planning in Sri Lanka. The obtained weights were converted into a matrix to obtain the priorities, and the supermatrix, weighted supermatrix, and limit matrix were composed. The final priorities of alternatives were derived for each sample and the final results were obtained. The maintenance and rehabilitation of the Kaduwela–Malabe road segment (Project B) obtained the highest priority among the three candidate projects according to the ANP method. In contrast, the RDA performs NPV-based economic analysis using the software HDM-4 to prioritize projects, and the rankings of the three candidate projects were also generated using that method. In that case, however, the maintenance and rehabilitation of the Kaduwela–Balummahara road segment (Project C) obtained the highest priority.

In the ANP method, pairwise comparisons were evaluated by transportation experts and this is an essential component of the method. Because the comparisons are affected by the knowledge, practice, and work experience of the individuals, the selection of these experts for interviews should be conducted with care. It is recommended that contributions are obtained from experts who are directly involved in pavement maintenance and rehabilitation project-planning activities. In addition, the questionnaire should be clear and easy to understand and follow without spending time unnecessarily; the time to complete the questionnaire should not exceed 30 min.

In this ANP method, the validity of the results mainly depends on the network structure modeled at the beginning of the study. Therefore, the problem, possible alternatives, influencing criteria and subcriteria, and dependencies should be clearly identified. In this study, the main objective was to consider social factors in addition to economic factors, and costs and benefits were considered as governing factors of the decision problem. The assistance from an experienced researcher in developing the network model is highly recommended here, as the network shape is subjected to change with the additional criteria/subcriteria and dependencies. In addition, to address these issues more effectively in future work, it is recommended to include other relevant factors; for example, risks factors such as technical and contractual risks; managerial risks; external and site condition risks; environmental considerations such as noise, emissions, and vibrations; and political influences such as funding issues arising from political corruption. With a structured network model, the main dependencies between criteria are observed; however, some other minor relationships may exist between nodes, such as a dependency between geometry of the road segment criteria and traffic criteria, and vice versa. These possible network dependencies were neglected in the present work due to time limitations for interviews with experts, but should be considered in further studies for a more detailed approach to the decision problem.

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