ANALYTIC NETWORK PROCESS MODEL FOR HIGHWAY CORRIDOR PLANNING

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Summary*: The planning of highway alignment is a complex decision making that involves many objectives and stakeholders. Previous studies applied the Analytic Hierarchy Process (AHP) to prioritize the alternatives of highway alignments. Standard AHP model could not accommodate the variety of interactions, dependencies, and feedback. The Analytic Network Process (ANP) is helpful to deal with interdependent relationship within the multi-objectives and multi-stakeholders environment. This paper demonstrates how to empirically prioritize a set of alternatives by using ANP model. The paper first reviews the planning issues related to the highway corridor planning. Then related characteristics were used to structure the ANP model and scores were computed for prioritizing the potential highway alignments. Engineering practitioners may adopt the weighted criteria for alignment selection or apply the ANP method to prioritize their own set of selection criteria.*

1. Introduction

1.1 General

Highway construction is an important decision made by a government. It plays an essential role in a regional economy, and has long-term effects on the community. Selecting the optimal route is a multi-disciplinary decision problem. Various objectives to be satisfied may be in conflict with one other by different views of related stakeholders. The problem becomes more complex because the number of alternative routes involved the geological and constructional uncertainties. Cost/Benefit Analysis (CBA) is normally conducted to verify the economic feasibility of possible alternatives. However, the inadequacy of CBA in dealing with intangible factors and strategic concerns is its main weakness (Shang et al. 2004). Moreover, many cost-benefit studies tend to underestimate the importance of the local society where the impact of the project is felt most strongly (Azis, 1990). In practice, the best alternative is chosen by considering multiple criteria such as economic, engineering, environmental, and social impact, etc.

Highway corridor planning problem is defined by the selection of the optimum corridor alignment based on multiple criteria, for example, minimization of construction problems, maximization of the operational functionality of the project, minimization of the environmental impact, and maximization of the results of the economic investment (Kalamaras et al., 2000).

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Application of multicriteria methods to the highway corridor planning could be found in literatures. For example, Kale et al. (2004) analyzed the land suitability map for expressway corridor from Mumbai and Pune cities in India. Bailey (2003) applied multicriteria method with the Geographic Information System (GIS) to corridor selection for a proposed interstate highway connector in the southeastern U.S. Azis (1990) applied multicriteria method to rationally measuring the intangible and complex impacts of the Trans-Sumatra highway built in the late 1970's. Chowdhury et al. (2002) proposed the optimization approach based on the Surrogate Worth Tradeoff (SWT) method for continuous problems, and multi-attribute utility and minimum tolerance method for discrete problems. Four case studies were illustrated based on actual project data. However, the limitation of their work is the inability to factor in the preferences of multiple decision makers. Other related application included the planning of corridor for power transmission line (Bailey et al., 2005).

Several multicriteria methodologies have been proposed and practiced in highway corridor planning. For example, AHP (Azis 1990, Kalamaras et al., 2000; Bailey, 2003; Piantanakulchai, 2005), outranking system (Rogers and Bruen, 2000), surrogate worth tradeoff, multi-attribute utility, and minimum tolerance method (Chowdhury et al., 2002) Many previous studies applied the Analytic Hierarchy Process (AHP) in selecting the best alignment. However, one of the deficiencies of AHP is that it could not include interrelationship and feedback within the elements in the model. This may result in misleading in the decision making, for example, the famous bridge selection problem (Forman and Selly, 2001). Generally, the criterion of strength is set higher than aesthetics in bridge selection. However, when all bridges are satisfied with the strength requirement, the aesthetic criterion becomes more important no matter how stronger another bridge is. This is an example of a situation when the criterion depends on an alternative. The conventional top-down decision model like AHP does not handle this situation directly and may come out with the decision to select the extremely strong but ugly bridge instead of sufficiently strong and beautiful bridge. The Analytic Network Process (ANP) could handle this sort of decision making problem effectively. This study proposes the Analytic Network Process (ANP) model to handle the multicriteria highway corridor selection problem.

2. Elements of a Standard ANP Model

The fundamentals of the Analytic Network Process (ANP) could be found in Saaty (1999). In brief, ANP model consists of the control hierarchies, clusters, elements, interrelationship between elements, and interrelationship between clusters.

Control hierarchies consist of the top level criteria that involves in decision making. Control hierarchy provides overriding criteria for comparing each type of interaction in the network. Saaty (1999) proposed four basic control hierarchies, Benefits, Opportunities, Costs, and Risks which are subsequently called BOCR models, for example, Shang et al. (2004). It is not required to include all four control hierarchies if some criteria are irrelevant, for example, hamburger model illustrated by Saaty (1999) and BCR model presented in Poonikom et al. (2004). The determination of relative weights in ANP is based on the pairwise comparison as in the standard AHP, see Saaty (1980). With respect to any criteria pairwise comparisons are performed in two levels, the element level comparison and the cluster level comparison.

Elements are the entities in the system that interact with each other. They could be a unit of decision makers, stakeholders, criteria or sub criteria (if exists), possible outcomes, and alternatives etc. In complex system which contains a great number of elements it would be very time consuming to measure relative importance of each element with every single element in the system. Instead, elements which share similar characteristics are usually grouped into *cluster*. The determination of relative weights mentioned above is based on pairwise comparison as in the standard AHP. The weights are then put into the supermatrix that represents the interrelationships of elements in the system. The general form of the supermatrix can be described in Fig. 1.

Where C_N denotes the Nth cluster, e_{Nn} denotes the nth element in the Nth cluster, and W_{ij} block matrix consists of the collection of the priority weight vectors (w) of the influence of the elements in the ith

cluster with respect to the jth cluster. If the ith cluster has no influence to the jth cluster then $W_{ij} = 0$. The matrix obtained in this step is called the initial supermatrix.

		C_1			C_2			$\cdots$	C_N		
		e_{11}	e_{12} $\cdots$ e_{1n_1}		e_{21}	e_{22} $\cdots$ e_{2n_2}		$\cdots$	e_{N1}	e_{N2} $\cdots$ e_{Nn_N}	
C_1	e_{11} e_{12} $\cdots$ e_{1n_1}	$\mathbf{W_{11}}$			$\mathbf{W_{12}}$			$\cdots$	$\mathbf{W_{1N}}$		
C_2	e_{21} e_{22} $\cdots$ e_{2n_2}	$\mathbf{W_{21}}$			$\mathbf{W_{22}}$			$\cdots$	$\mathbf{W_{2N}}$		
$\vdots$		$\cdots$			$\cdots$			$\cdots$	$\cdots$		
C_N	e_{N1} e_{N2} $\cdots$ e_{Nn_N}	$\mathbf{W_{N1}}$			$\mathbf{W_{N2}}$			$\cdots$	$\mathbf{W_{NN}}$		

Figure 1. The General Structure of the Supermatrix

As stated earlier, the pairwise comparison is performed in two levels. The eigenvector obtained from cluster level comparison with respect to the control criterion is applied as the cluster weights. This results in a matrix which each of its columns sums to unity. If any block in the supermatrix contains a column that every element is zero, that column of the supermatrix must be normalized after weighting by the cluster's weights to ensure the column sum to be unity. The concept is similar to Markov Chain that the sum of the probabilities of all states equal to one. This matrix is called the stochastic matrix or weighted supermatrix.

The weighted supermatrix is raised to limiting power such as Eq. (1) to get the global priority vectors.

$$\lim_{k \to \infty} W^k \tag{1}$$

If the supermatrix has the effect of cyclicity, there may be two or more N limiting supermatrices. In this case, the Cesaro sum is calculated as in Eq. (2) to get the average priority weights.

$$\lim_{k \to \infty} \left(\frac{1}{N} \right) \sum_{i=1}^{N} W_i^k \tag{2}$$

3. ANP Model for Highway Corridor Planning

The framework for multicriteria evaluation of transport projects by ANP was proposed by Shang et al. (2004). The overall decision problem was disaggregated into four control subnets, benefit, cost, opportunity, and risk. In their study, the decision makers and other stakeholders interact to each other in the network called influence network. With respect to a specific criterion, the preference weight by each alternative is obtained from the limit super matrix of the influence network. On the other side, the weight

of each sub criterion is obtained by the limit super matrix of the overall decision problem. The preference weight of each alternative is then multiplied with the importance weight of each sub criterion to the total system. Summation of weighted score gives the priority of an alternative. It could be seen that their formulation requires the decision makers to compare the alternatives based criteria at the most upper level criteria (more abstract). Therefore, their model is most useful to compare fairly different projects. In their study, interactions among decision makers and stakeholders were modeled by including all feedbacks within the influence network. While strong emphasis was put on the influence network, however, the interactions among elements in the super matrix of the overall decision problem were less specified. This could be illustrated by many zero elements in their super matrix, for example, the benefit control matrix (see Shang et al. (2004), Table III). It should be noted that how the super matrix is formulated depends on the scale and nature of the decision making problem being considered. For the highway corridor selection problem, the alternatives may not be much different when considered at upper level criteria. This would make the decision more difficult. The judgment would be easier at lower level criteria or at indicator level. In this study, in order to capture the interactions in lower level criteria the super matrix is designed to include the clusters of stakeholders, main objectives, sub objectives, indicators, and alternatives respectively. The decomposition of the decision making problem into lower levels would benefit in two folds. Firstly, the judgment is done easier at the lower level than at the upper level. Secondly, experts in various fields, stakeholders, and decision makers could participate in the decision making process in a well structured environment. For example, experts in each field would make the lower level judgment about the importance of subcriteria in their field while the different stakeholders may be able to put their preference on the criteria differently in the upper level.
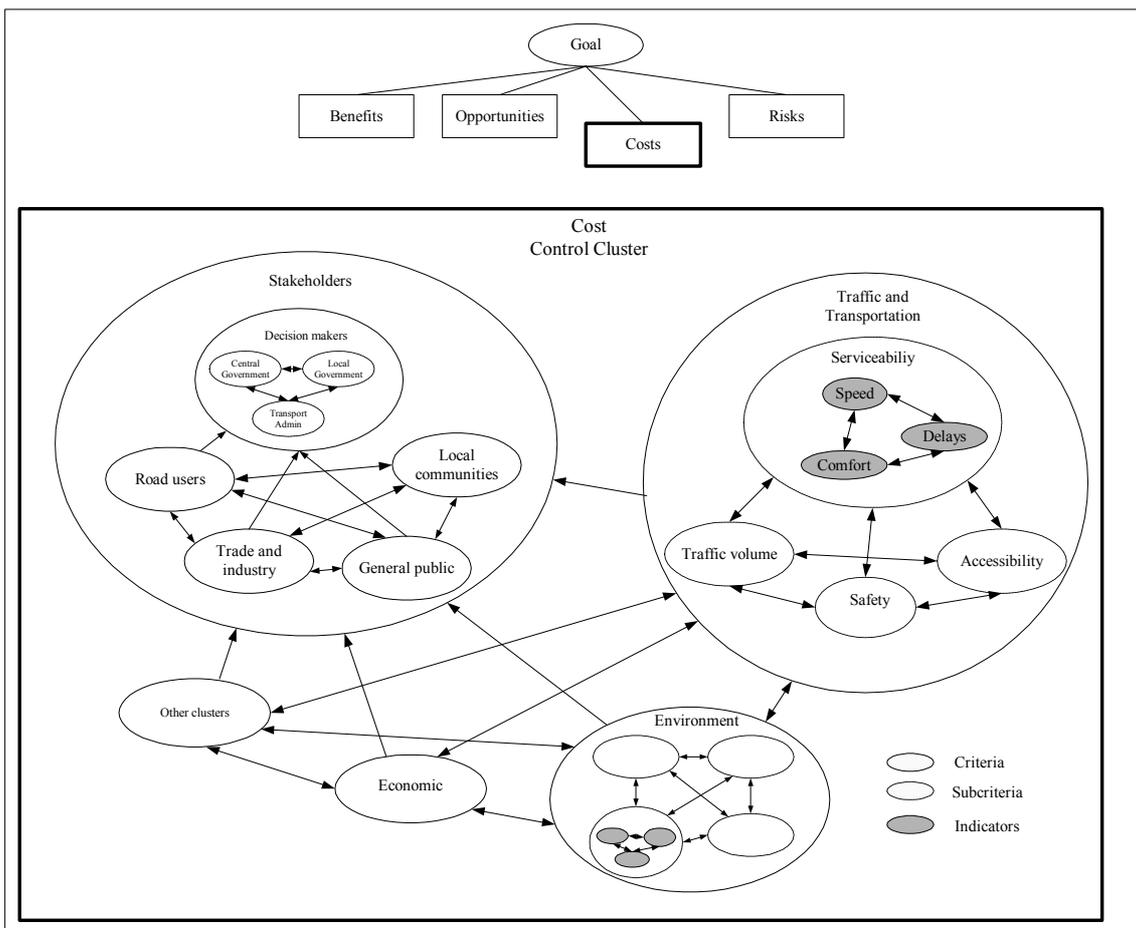
Figure 2. An Example of the Structure of ANP for Highway Corridor Planning

Different corridor has a different impact to the economy and society. The impact is a result of the interaction among various components of the system, for example, engineering, economic, and social

impacts, etc. In fact, there is no optimum alignment because different stakeholders are interested in different objectives. For instance, the government may be interested in regional economic development while the environmentalists may prefer to preserve the nature. In addition, some objectives are positively related, but others may be negatively related. As a result, based on specific indicator selected, the evaluation of alternatives will be different. Which objective should be considered and the importance of each objective are essential in the analysis. Based on ANP method, experts from different fields should be interviewed to decide the major criteria and sub criteria in their field for evaluating different alignments. The stakeholder level composed of several parties exerting influence into the decision process. These parties could be, for example, the transportation administrators, municipal government, and the local communities. These parties play different roles in viewing the project criteria. For example, the local community may be more interested in the environmental and social effects. The transportation administers may have objectives to increase the mobility of people and goods within the study area while the municipal government may have to consider most of the project criteria. The decision of a stakeholder may be influenced by the decision of other groups. This decision process could be included in the analysis under the framework of ANP by introducing the interdependence or feedback. The objectives of each stakeholder could be decomposed into major criteria categories, for instance, engineering, economic, environmental, and social criteria. It is noted that the stakeholders may have different expectations on these criteria categories. Hence, ANP facilitates integration of their expectation to form the composite objective weights after taking into account their various interest and interactions. Fig. 2 shows an example of ANP framework for highway corridor planning. To exemplify the selected cost control hierarchy is illustrated in detail. The structure of the supermatrix applied in this study is shown in Fig. 3.

Goal: Best Corridor		Stakeholders			Criteria			Subcriteria			Indicators			Alternatives		
		G_1	...	Gq	C_1	...	C_r	S_1	...	S_m	I_1	...	I_n	A_1	...	A_k
Stakeholders (G)	G_1 ... Gq		$\mathbf{W_{GG}}$			$\mathbf{W_{GC}}$			$\mathbf{W_{GS}}$			**0**			**0**	
Criteria (C)	C_1 ... C_r		$\mathbf{W_{CG}}$			$\mathbf{W_{CC}}$			$\mathbf{W_{CS}}$			**0**			**0**	
Subcriteria (S)	S_1 ... S_m		$\mathbf{W_{SG}}$			$\mathbf{W_{SC}}$			$\mathbf{W_{SS}}$			$\mathbf{W_{SI}}$			**0**	
Indicators (I)	I_1 ... I_n		**0**			**0**			$\mathbf{W_{IS}}$			$\mathbf{W_{II}}$			$\mathbf{W_{IA}}$	
Alternatives (A)	A_1 ... A_k		**0**			**0**			**0**			$\mathbf{W_{AI}}$			**0**	

Forward dependence   ⌐ ¬ Required experts
Inner dependence   in multi-disciplinary fields
(diagonal blocks)   Required experts
Feedback dependence   in specific field

Figure 3. The Basic Structure of the Supermatrix for Highway Corridor Planning

From Fig. 3 it should be noted that all feedback dependences require the expert in multi-disciplinary fields that could judge the relative importance of upper level criteria with respect to a single lower criterion or indicator. For example, each stakeholder may specify their preference of criteria. The decision is therefore based on their own preferences and pressure from other stakeholders (inner

dependence). Other blocks without shading are possible submatrices that could be included to enhance the model's information, for example, W_{SI}. The feedback dependence block, W_{IA}, indicates the relative importance of each indicator based on each alternative. For example, corridors being considered may create significant impact in different impact categories. Therefore, the relative importance of each impact created by different corridor may be different. Table 2 shows typical ANP elements considered in highway corridor planning.

Table 2. Typical ANP Elements Considered In Highway Corridor Planning

0. Stakeholders	0-A	Government and public administrators
	0-B	Road users
	0-C	Trade and industry
	0-D	Local Community
	0-E	General public

Criteria		Subcriteria		Indicators
1. Economic	1-A	Initial investment	1	Investment costs
	1-B	Operating and maintenance costs	1	O&M costs
	1-C	Economic returns	1	B/C
			2	Return period
	1-D	Tourism development	1	Qualitative
	1-E	Trade and industial development	1	Qualitative
2. Engineering and construction	2-A	Physical suitability of land	1	Qualitative
	2-B	Geometric of road	1	Horizontal curves (No. of curves and curve radius)
			2	Vertical curves (% grade changes)
	2-C	Ease or difficulties in construction	1	Tunnel length
			2	Bridges (No. of bridges and span length)
			3	Cut&fill volume
	2-D	Future expansion and improvement	1	Qualitative
3. Traffic and Transportation	3-A	Traffic volume	2	Traffic volume
	3-B	Serviceability	1	Average speed
			2	Average delay
			3	Comfort (qualitative)
	3-C	Accessibility	1	No. of accessible communities
	3-D	Safety	1	Horizontal curves (No. of curves and curve radius)
			2	Vertical curves (% grade changes)
	3-E	Efficiency of network	1	PCU-km
			2	PCU-hr
			3	Average speed
			4	V/C
	3-F	Connection to other modes	1	Qualitative
4. Environment	4-A	Change in land topography	1	Cut&fill volume
	4-B	Soil erosion	1	Affected area by soil type
	4-C	Air	1	Number of receptors (communities)
			2	Number of receptors (schools)
			3	Number of receptors (temples, mosques)
	4-D	Noise	1	Number of receptors (communities)
			2	Number of receptors (schools)
			3	Number of receptors (temples, mosques)
			4	Tunnel's length (during construction only)
	4-F	Vibration		Same indicators as air and noise impact
	4-G	Water	1	Tunnel's length (underground water)
			2	Number of crossed streams and type of structure
	4-H	Energy	1	Energy used/saved
	4-I	Watershed areas	1	Area affected by type of watershed area
	4-J	Forrest	1	Area affected by type of forest
	4-K	Wildlife	1	Area affected by type of reserved land for wildlife
5. Land use	5-A	Land development or land use change	1	Qualitative
	5-B	Harmony of land use and road usage	1	Qualitative
	5-C	Consistency with city development plan	1	Qualitative
	5-D	Sustainability development of city	1	Qualitative
6. Social	6-A	Relocation of residences	1	No. of relocated residences
	6-B	Education	1	Qualitative
	6-C	Public health	1	Qualitative
	6-D	Community acitivities (cultural, religion)	1	Qualitative (related with noise impact)
	6-E	Aesthetics and visual impact	1	Qualitative

4. A Numerical Example: A Case Study of Highway Corridor Planning: in the South of Thailand
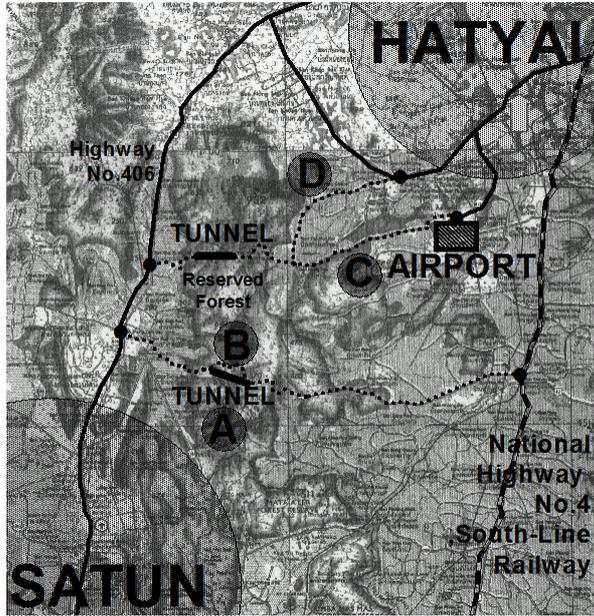

Figure 4. The Study Area

The goal of the project is to construct a two lane highway connecting Hatyai and Satoon province located in the southern part of Thailand. The proposed highway extends about 90 km. length connecting the provinces in the South of Thailand. The main benefits of the project include savings of travel time and distance between southern provinces on the side of the Andaman Sea and the Gulf of Thailand. Other benefits include stimulating the trade in the southern part of the country, complement with the strategic policy regarding the national security in the southern part of the country, enhancing the potential for tourism development within the area. The project is responsible by the Department of Highway. The study area covers, mountains (in North-South direction), national reserved forest, watershed areas, and agricultural land, see Fig.4.

There are four alternatives considered in this study. Table 3 provides some detail of the alternative highway corridors. The weights in the initial supermatrix were adapted from the feasibility study of the project (with agreed weights from experts). All cluster's inner dependences are set to 0.2. For demonstration, the initial supermatrix, weighted supermatrix, weighted supermatrix, and the limiting supermatrix for the benefit control criterion are illustrated in Table 4-6 respectively. The converged values of the elements in each row represent the global priority weights to the system. For example, from Table 6 the global priorities for each alternative with respect to benefit control hierarchy are (0.086, 0.088, 0.083, 0.080). The global weights may be normalized to get the relative weight of each alternative sum to one, e.g. (0.257, 0.261, 0.247, 0.236). For instance, with respect to benefit control hierarchy the corridor B is the best alternative with priority weight 0.261. The priority of each indicator to the overall system could be obtained similarly by reading the stabilized column values. As stated earlier, the alternatives may be evaluated based on control hierarchies of benefits, opportunities, costs, and risks. The evaluation of alternatives with respect to other control hierarchies could be conducted in the same way as illustrated here. Finally, if each control hierarchy is weighted equally the overall evaluation of each alternative is synthesized by using Eq. (6), (Saaty, 1999).

$$Multiplicative\ Score = \frac{(Benefits) \times (Opportunities)}{(Costs) \times (Risks)} \tag{6}$$

Table 7 shows an example of synthesized scores using the above expression. The result obtained by ANP could be compared to the result of the feasibility study obtained from real experts.

5. Conclusion

This study proposed ANP as a novel approach to tackle the multicriteria highway corridor selection problem. The general structure of ANP and essential roles of stakeholders and experts were discussed in the paper. A simple numerical example was shown to illustrate the application of the model presented. It is generally believed that feeding more information to the model (or experts) would lead to better decision. The author suggests further study to interpret and investigate the effect of including more possible feedback blocks as added information to the proposed ANP model.

Table 3. Detail of Alternative Highway Corridors

Item	Indicators	Sub category	Alternatives			
			Corridor A	Corridor B	Corridor C	Corridor D
Land Compensation and Relocation Costs ($)	Costs ($)		557,210	557,210	1,616,026	2,696,314
Construction Costs ($)	Costs ($)		55,040,000	303,085,000	104,490,000	102,747,500
Industiral and Tourism Development	Qualitative		Good	Good	Fair	Fair
Integrated Road Network Strategy	Qualitative		Good	Good	Fair	Fair
Overall Length (km)	Length (km)		95	97	83	82
Horizontal Curves	Number of Curves (Classified by Curve Radius, m)	R <100	0	0	0	1
		100 <R<300	45	46	26	17
		300<R<500	3	6	3	6
		R>500	24	20	43	48
Vertical Curves	Number of Grade Changes (ΔG, %)	ΔG<4%	37	33	46	46
		4%<ΔG<8%	12	8	4	4
		8%<ΔG<12%	6	13	5	5
		ΔG>12%	0	1	0	0
Difficulties in Construction	Tunneling (km)		2	0	6	6
	Bridges (total length, m)		1,350	1,350	160	160
	Cut&Fill (million cu.m)		3	4	2	2
Potential for Future Improvement and Extension	Tunneling		Yes	No	Yes	No
	Right of Way (m)		40	40	30	30
Expected Traffic Volume (vehicle/day)	Traffic Volume (vehicle/day)		4,596	4,596	6,805	5,817
Road Network Efficiency	Change in PCU-km		-124,181	-124,181	-121,339	-105,352
	Change in PCU-hr		-148	-148	382	533
	Change in Average Speed		0	0	0	0
	Change in V/C		0	0	0	0
Soil Erosion	Qualitative		Medium	High	Least	Medium
Surface water	Number of Crossings over Natural Streams (Classified by Width of Stream)	W>10 m	1	1	0	0
		6>W>10 m	5	5	3	5
		1<W> 6 m	3	3	0	1
Underground Water	Length of Tunnel (m)		2	0	6	6
Air, Noise, Vibration	Design Traffic		3,000	3,000	4,000	4,000
	%Truck		15	15	15	15
	Number of Temples		5	5	3	2
	Number of Villages		7	7	5	9
	Number of Schools		0	0	1	1
Watershed Ecosystem	Qualitative		2nd Class	2nd Class	1st Class	1st Class
Forrest	Qualitative		Natural Park+Tunnel	Natural Park Without Tunnel	National Reserved Forrest	National Reserved Forrest
Wildlife	Qualitative		Non-Wildlife Sanctuary+Tunnel	Non-Wildlife Sanctuary Without Tunnel	Wildlife Sanctuary	Wildlife Sanctuary
Residential Relocation	No. of Relocated Houses		42	42	117	308

Table 4. The Initial Supermatrix for Benefit Control Criterion

		Stakeholders			Criteria				Subcriteria								Indicators										Alternatives			
		0-A	0-B	0-C	1	2	3	4	1-C	1-D	2-D	3-A	3-B	3-C	3-E	4-H	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	A	B	C	D
Government and public administrators	0-A	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Road users	0-B	0.65	0.80	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Local Community	0-C	0.20	0.20	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Economic	1	0.25	0.00	0.50	0.20	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Engineering	2	0.25	0.00	0.00	0.30	0.40	0.40	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Traffic	3	0.25	1.00	0.00	0.40	0.60	0.30	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Environment	4	0.25	0.00	0.50	0.10	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Economic returns	1-C	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tourism development (criteria)	1-D	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.10	0.50	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Future expansion and improvement	2-D	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.10	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Traffic volume (criteria)	3-A	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.70	0.00	0.50	0.70	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Serviceability	3-B	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accessibility	3-C	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.30	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Efficiency of network	3-E	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.50	0.00	0.00	0.00	0.50	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy saving	4-H	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Travel benefits (travel time saving, etc)	I1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.20	0.20
Tourism development (indicator)	I2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.60	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.10	0.10
Future expansion and improvement	I3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.10	0.20	0.20
Traffic volume (indicator)	I4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.10	0.30	0.00	0.00	0.10	0.20	0.20	0.01	1.00	1.00	0.25	0.25	0.20	0.05	0.05
Average speed	I5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.10	0.00	0.20	0.20	0.50	0.20	0.00	0.00	0.00	0.00	0.00	0.25	0.10	0.10	0.10	0.10
Average delay	I6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.10	0.00	0.20	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.25	0.10	0.10	0.10	0.10
No. of accessible communities	I7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.10	0.20	0.00	0.20	0.00	0.00	0.90	0.00	0.00	0.25	0.10	0.10	0.10	0.10
PCU-km	I8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.10	0.10	0.05	0.05
V/C	I9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.80	0.80	0.00	0.00	0.00	0.00	0.10	0.10	0.05	0.05
Energy saved	I10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.05	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.05	0.10
Corridor A	A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.28	0.28	0.21	0.23	0.30	0.25	0.26	0.23	0.25	0.00	0.00	0.00	0.00
Corridor B	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.28	0.36	0.21	0.23	0.30	0.25	0.26	0.23	0.20	0.00	0.00	0.00	0.00
Corridor C	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.22	0.18	0.31	0.28	0.20	0.17	0.25	0.34	0.35	0.00	0.00	0.00	0.00
Corridor D	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.22	0.18	0.27	0.26	0.20	0.33	0.23	0.20	0.20	0.00	0.00	0.00	0.00

Table 5. The Weighted Supermatrix for Benefit Control Criterion

		Stakeholders			Criteria				Subcriteria								Indicators										Alternatives			
		0-A	0-B	0-C	1	2	3	4	1-C	1-D	2-D	3-A	3-B	3-C	3-E	4-H	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	A	B	C	D
Government and public administrators	0-A	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Road users	0-B	0.13	0.16	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Local Community	0-C	0.04	0.04	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Economic	1	0.20	0.00	0.40	0.04	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Engineering	2	0.20	0.00	0.00	0.06	0.08	0.08	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Traffic	3	0.20	0.80	0.00	0.08	0.12	0.06	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Environment	4	0.20	0.00	0.40	0.02	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Economic returns	1-C	0.00	0.00	0.00	0.64	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tourism development (criteria)	1-D	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.01	0.05	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Future expansion and improvement	2-D	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Traffic volume (criteria)	3-A	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.07	0.00	0.05	0.07	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Serviceability	3-B	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accessibility	3-C	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Efficiency of network	3-E	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.05	0.00	0.00	0.00	0.05	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy saving	4-H	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Travel benefits (travel time saving, etc)	I1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.20	0.20
Tourism development (indicator)	I2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.30	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.10	0.10
Future expansion and improvement	I3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.10	0.20	0.20
Traffic volume (indicator)	I4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.09	0.15	0.00	0.00	0.05	0.10	0.10	0.00	0.50	0.50	0.13	0.25	0.20	0.05	0.05
Average speed	I5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.09	0.00	0.10	0.10	0.25	0.10	0.00	0.00	0.00	0.00	0.00	0.13	0.10	0.10	0.10	0.10
Average delay	I6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.09	0.00	0.10	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.13	0.10	0.10	0.10	0.10
No. of accessible communities	I7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.05	0.10	0.00	0.10	0.00	0.00	0.45	0.00	0.00	0.13	0.10	0.10	0.10	0.10
PCU-km	I8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.10	0.10	0.05	0.05
V/C	I9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.40	0.40	0.00	0.00	0.00	0.00	0.10	0.10	0.05	0.05
Energy saved	I10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.90	0.03	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.05	0.10
Corridor A	A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.14	0.14	0.11	0.12	0.15	0.13	0.13	0.12	0.13	0.00	0.00	0.00	0.00
Corridor B	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.14	0.18	0.11	0.12	0.15	0.13	0.13	0.12	0.10	0.00	0.00	0.00	0.00
Corridor C	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.11	0.09	0.16	0.14	0.10	0.09	0.13	0.17	0.18	0.00	0.00	0.00	0.00
Corridor D	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.11	0.09	0.14	0.13	0.10	0.17	0.12	0.10	0.10	0.00	0.00	0.00	0.00

Table 6. The Limiting Supermatrix for Benefit Control Criterion

		Stakeholders			Criteria				Subcriteria								Indicators										Alternatives			
		0-A	0-B	0-C	1	2	3	4	1-C	1-D	2-D	3-A	3-B	3-C	3-E	4-H	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	A	B	C	D
Government and public administrators	0-A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Road users	0-B	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Local Community	0-C	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Economic	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Engineering	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Traffic	3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Environment	4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Economic returns	1-C	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tourism development (criteria)	1-D	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Future expansion and improvement	2-D	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Traffic volume (criteria)	3-A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Serviceability	3-B	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Accessibility	3-C	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Efficiency of network	3-E	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Energy saving	4-H	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Travel benefits (travel time saving, etc)	I1	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054
Tourism development (indicator)	I2	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048
Future expansion and improvement	I3	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
Traffic volume (indicator)	I4	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130
Average speed	I5	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076
Average delay	I6	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
No. of accessible communities	I7	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105
PCU-km	I8	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
V/C	I9	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074
Energy saved	I10	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037
Corridor A	A	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086
Corridor B	B	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088
Corridor C	C	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083
Corridor D	D	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080

Table 7. The Calculation of Overall Evaluation Scores

	B	O	C	R	Score	Normalized Score
Corridor A	0.257	0.264	0.265	0.212	1.205	0.291
Corridor B	0.261	0.255	0.275	0.196	1.232	0.297
Corridor C	0.247	0.245	0.244	0.284	0.872	0.210
Corridor D	0.236	0.236	0.216	0.308	0.838	0.202

(Note: Set by the author, for the numerical example purpose only)

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