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Multi-criteria Decision Making for Rural Road Project Selection

Satish Subedi [a], Prem Nath Bastola [b]

[a, b] *Department of Civil Engineering, Pashchimanchal Campus, IOE, Tribhuvan University, Nepal*
[a] subedisatish09@gmail.com, [b] pnbastola@ioe.edu.np

Abstract
This research aims to develop a Multi Criteria Decision Making (MCDM) criteria for selection of rural road projects. In identifying the suitable criteria, Analytic Hierarchy Process (AHP) formulation was used. For the identification of criteria and sub criteria for selection of rural road projects, pilot survey was done with experts working in rural road sectors. Five criteria and seventeen sub criteria identified after pilot survey were sent as questionnaire in the form of pairwise comparison to experts for main survey. Responses were analyzed using Super Decisions software to determine the weights of criteria as well as sub criteria. It was found that Employment Generation has the highest weightage of 13.4% among the seventeen sub criteria. Similarly, Access to Agricultural and Livestock pocket Areas and Tourism Destination (12.6%), Population Served per Km (9.9%), Connection to Strategic Road Network (8.3%) and Access to Growth Centers (6.8%) lie in the top five ranked categories of sub criteria. Finally, a case study was done for ranking of selected three road projects using Simple Additive Weightage method.

Keywords
MCDM, AHP, Rural Road Selection, Simple Additive Weightage

1. Introduction

1.1 Background

In the context of developing countries, rural roads are essential for the transportation of agricultural products, poverty alleviation and accessibility improvement to basic facilities such as markets, schools and health care services[1].According to economic survey report of 2020-21, total road length of Nepal is 63,577 km, of which, share of black-topped, gravel and fair weather is 7, 21 and 72 percentage respectively. Upgrading and improvement of rural roads require huge amount of budget. Proper utilization of scarce financial resource requires that the roads are prioritized during planning phase and budgeting is done accordingly. Road investments are largely made based on ad-hoc decisions and subjective judgment of local government officials.This often leads to inefficient and inequitable distribution of limited resources, and omission of local views and interests. In developing countries like Nepal, where financial resources are limited, planned allocation of resources is very important to yield desired results. Prioritizing projects based on transparent and evidence-based decision-making processes helps in proper allocation of financial resources. Therefore, a systemic methodology is required, which can be practically applied by professionals and government officials for the planning and prioritization of rural roads.

1.2 Objectives of the Study

The general objective of this study is to develop a Multi Criteria Decision Making Criteria for selection of rural road projects.
Specific objectives are:
1. To identify the criteria for selection of rural road projects.
2. To determine the weightage of identified criteria used in the selection process.
3. To apply the weightage for a case study of ranking three road projects.

2. Literature Review

2.1 Approaches for Evaluation of Road Projects

Decision making is important in various fields of transportation including identification of existing

problems; problem definition (objectives, criteria, measures, constraints, etc.); generation of alternative solutions (options/alternatives) for the problem (e.g., building new infrastructure, rehabilitating existing infrastructure, improving its management, applying policy measures, etc.); and evaluation and selection of the best solution. Methodological framework for evaluation of transport projects can be grouped into two categories: single criteria method or monetary approach and multi-criteria approach or non-monetary approach [2]. Cost Benefit analysis (CBA) belongs to first category while Multi-criteria Analysis (MCA) belongs to second. CBA has certain limitations related to difficulty in performing objective and adequate valuation of all the costs and the impacts of the alternatives in monetary terms. Multi Criteria Decision Making (MCDM) considers multiple criteria which may be qualitative or quantitative in decision making among several alternatives. MCDM is widely used in transport sector[3].

2.2 Analytic Hierarchy Process

Analytic Hierarchy Process is a mathematical method developed in the 1970's by Dr. Thomas Saaty.AHP uses a pairwise comparison of a knowledgeable person to determine the importance of a criterion in a decision[4].AHP can be used to handle both qualitative as well as quantitative criteria for ranking of the options[5].In AHP, alternatives are rated and aggregated to find the most relevant alternative. The ranking is done with respect to an overall goal which can be broken down into a set of criteria and sub criteria. Importance weight associated to each criterion is established by pairwise comparison. Experts are asked to express a graded judgment about each pair in terms of relative importance of each other with respect to the goal to be achieved.

AHP was used as a multi-criteria approach for the selection of alternative options for environmentally sustainable transport system in Delhi[5].Three alternative transport options viz. 4-stroke 2-wheelers, cars and buses were prioritized based on six different criteria—energy saving potential (energy), emission reduction potential (environment), cost of operation (cost), availability of technology (technology), adaptability of the option (adaptability) and barriers to implementation (barrier) by using pair wise comparison.

2.3 Evaluation Practices of Road Projects

Evaluation criteria for rural roads were classified into into three aspects of sustainability: economic, social and environmental[6].These three sustainability pillars were fragmented into thirteen indicators. By using AHP, highest weightage was given to economic criteria (38.16%) followed by Social criteria (34.04%) and environmental criteria (27.79%). Cost- benefit criteria was used for developed areas and agricultural potential, interaction, accessibility and environmental impact were used in the underdeveloped area for prioritization of road network[7]. Multi Attribute Utility Theory (MAUT) was used to examine how rural roads in Akwa Ibom State, Nigeria may be prioritized for upgrade to maximize access to key socio-economic facilities [8]. In the study, five criteria were used: Social, Economic, Demographic, Financial and Political.A robust, participatory and practical methodology- Rural Road Planning and Prioritization Model (RPPM) was developed for prioritizing rural roads in Bangladesh based on a set of physical, social and economic criteria[1].In MCA, traffic volume, number and type of socio-economic facilities, growth center and rural market served by a road, connectivity and local priority were the factors considered for prioritization.

3. Research Methodology

3.1 Data Collection and Sample Size

The criteria and sub criteria were identified by literature review and expert consultation. Primary data on determination of weightage of road evaluation criteria was obtained by AHP based questionnaire survey. Secondary data on design of selected road projects for case study such as engineering estimate, traffic data, design calculations, different transportation costs, etc. were obtained from DPR of the road prepared by Gandaki Province government.

AHP does not always require statistically significant sample size for its use [9, 10].Sample size of 30 or more will usually result in a sampling distribution for the mean that is very close to a normal distribution[11]. Sample size obtained was 30 for main survey. According to Fink the minimum number for a pilot study is 10[11]. Hence 10 experts were consulted for pilot survey to establish the criteria and sub criteria for the study

3.2 Data Analysis

After the rating by experts in scale of 1 to 9 and rating value a_{ij} and reciprocal values in corresponding transpose position form a pairwise comparison matrix, A.
Elements of matrix were obtained by computing geometric mean of values of the respondents.

$$G_m = \sqrt[m]{a_{j1} * a_{j2} * \ldots * a_{jm}} \quad (1)$$

Where, G_m is the geometric mean of values of m responses and a_{jm} is the element of pairwise comparison matrix for j^{th} criteria by m^{th} respondent. Pairwise comparison values obtained from the experts were analyzed using Super Decisions to obtain the final weights of all criteria and sub criteria.

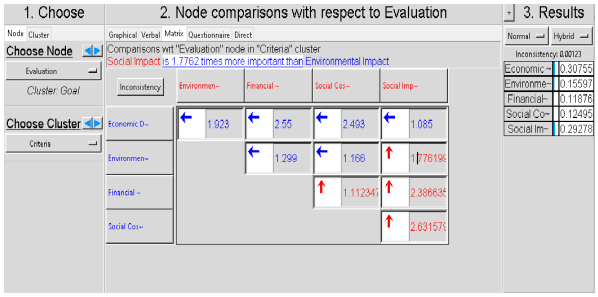

Figure 1: Sample Calculation in Super Decisions

3.3 Consistency Analysis

Consistency of responses is measured by Consistency Ratio, CR.

$$CR = \frac{\mu}{RI} \quad (2)$$

$$\mu = \frac{\lambda_{max} - n}{n - 1} \quad (3)$$

Here μ is consistency index; λ_{max} is the largest Eigen vector, RI is Randomness Index. Consistency Ratio (CR) should be less than 0.1.

3.4 Criteria and Sub Criteria for Evaluation of Rural Roads

The criteria and sub criteria identified by literature review were sent for pilot survey. After pilot survey, revision was made to the criteria and sub criteria and following factors were considered for further study. Evaluation criteria were categorized into five groups and total seventeen sub criteria were taken into consideration.

3.4.1 Financial Aspects

Financial aspect of a transport project includes agency costs such as construction cost and maintenance cost and also vehicle operation cost. Construction cost of a road includes cost of advance planning, preliminary engineering, final design, land acquisition and all construction works. Maintenance cost of a road includes routine, recurrent and periodic maintenance costs. VOC include fuel cost, repair and maintenance of vehicle, tire replacement cost and depreciation of vehicle.These costs of roads for case study were taken from prepared DPRs.

3.4.2 Social Cost

Social costs are external costs, which are not borne by the project but are generally borne by the society. For the purpose of this thesis work, three sub criteria of social cost are studied.

Accident cost:

Accidents in roads can be of three types: fatal crash, injury crash and property damage-only crash. The most important accident costs in road transport are dependent on, vehicle kilometers, vehicle speed, type of road, drivers' characteristics (such as driving behavior, experience, speeding), traffic speed and volume, time of day (day/night) and interaction with weather conditions. Following formula can be used to calculate marginal accident cost[12]:

Marginal External Accident Cost = Traffic Volume* Risk elasticity* Unit cost per accident* external part.

Following costs are used for casualties due to road crashes in Low and Middle Income Countries[13].

Table 1: Unit Cost of Casualties due to Road Crashes

S. No.	Description	Cost per Casualty (000, US$)	
1	Average cost per Injury (000, US$)	135.7	19.38
2	Average cost per Fatality (000, NRs.)	17281.4	2468.77

Air Pollution Cost:

Air pollution costs of transportation includes human health costs, damage to buildings and materials, losses in agricultural crops and other ecosystem, impact on biodiversity and ecosystem, etc. Air pollution costs can be calculated by following formula.

External Air pollution Costs= Specific Emission*

Cost per Pollutant.

Specific emission was taken from Nepal Vehicle Mass Emission Standard, 2069.The health cost of pollutants in Kolkatta were calculated as shown in following table, which was applied for this study as well[14].

Table 2: Health Cost of Pollutant

Pollutant	CO	HC	Nox
Cost (NRs./Kg)	0.00208	3.072	49.472

Value of Travel Time Savings:
Value of travel time is actually the value of some goods, services or utilities that can be produced in a time frame[15]. Value of Travel Time Savings of roads for case study was taken from the DPR.

3.4.3 Economic Development Impacts

Economic development impact represents the effects on economic activities of the region. Transportation facilities contribute to the economic development of the region as well as the country. Economic development is reflected by consumption of goods and services, revenue generation, employment opportunities and so on. Three sub criteria were considered under economic development impacts for this study: Employment Generation was calculated as manpower required during road construction. Property appreciation was measured by probable change in land value after road construction. Access to Agricultural and Livestock pocket Areas and Tourism Destination was measured by number of such places in the influence area.

3.4.4 Social Impacts

Social impact by any transportation facility is the impact to the population of an area, that changes the way in which people live, work, play or organize. Under the social impact, four performance measures were considered. Population served per km was taken from census data. Access to educational services was measured by the number of students benefited by the road. Access to Growth Centers (market, health services, and administrative services) was measured by the number of such places in the influence area.

3.4.5 Environmental Impacts

Three parameters were considered under environmental impact. Number of trees to be cut along the road alignment was taken from the IEE report. Encroachment on cultural and historical aspects was measured by the number of encroachment of historical/ cultural areas and precious ecology (e.g. sensitive or protected areas). Land sliding /erosion or flooding was measured by the length of road passing through landslide or flooding area.

3.5 Case Study

After the sub criteria weights were established using AHP, a systematic case study was done for three road projects of Gandaki Province. The measured values for the performance measure were normalized using Z-score method.

$$Z_{jn} = \frac{X_{jn} - \sigma_j}{\mu_j} \tag{4}$$

Where, Z_{jn} is the Z score of j^{th} indicator of n^{th} alternative, X_{jn} is the performance value of j^{th} indicator of n^{th} alternative, σ_j is the mean value of j^{th} indicator of all alternative and μ_j is the standard deviation of mean value of j^{th} indicator of all alternative.
Final score of each alternative was obtained by summing the weighted score of each criterion as shown in following formula.

$$S_n = \sum_{j=1}^{n} W_j * Z_{jn} \tag{5}$$

Where, W_j is the Weight of criteria j, n is the number of alternatives, Z_{jn} is the Z- score of criterion j under alternative n and S_n is final score of alternative n.

4. Results and Discussion

4.1 Response to Main Survey

Of the 30 responses obtained, 9 were found consistent. Of the remaining 21 responses, 6 were found to be highly inconsistent and hence, were discarded. For remaining 15 slightly inconsistent responses, respondents were contacted through telephone and asked to revise the pairwise comparison. Hence 24 responses were considered for further analysis.

4.1.1 Criteria and Sub Criteria Weights

The criteria weights obtained from AHP survey is represented in the following figure.

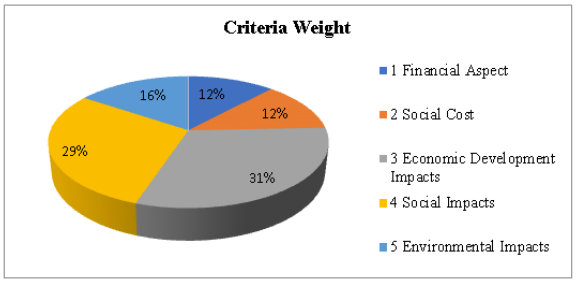

Figure 2: Criteria Weights after AHP Survey

Above figure suggests that among the five criteria selected for the study, Economic Development Impact (31%) has the highest priority followed by Social Impact, which has 29% weightage. Similarly Financial Aspect and Social Cost were given the lowest weightage of 12% each by the respondents. Environmental Impact was given 16% weightage. Weights obtained for sub criteria under the five criteria are shown in the following bar chart.

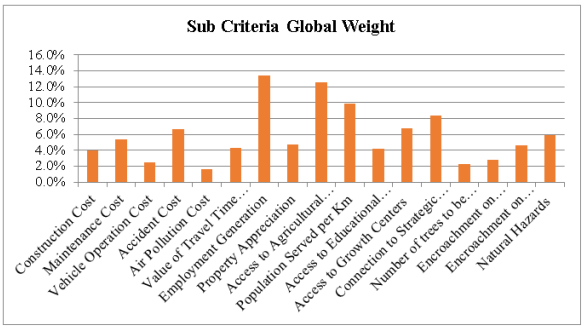

Figure 3: Sub Criteria Weight after AHP Survey

Above figure shows that Employment Generation has the highest weightage of 13.4% among the seventeen sub criteria. Similarly, Access to Agricultural and Livestock pocket Areas and Tourism Destination (12.6%), Population Served per Km (9.9%), Connection to Strategic Road Network (8.3%) and Access to Growth Centers (6.8%) lie in the top five ranked categories of sub criteria. Except the top five sub criteria, Accident Cost (6.7%) and Maintenance Cost (5.4%) have weightage more than 5%. Other ten sub criteria have weightage less than 5%. The lowest weightage is given to Air Pollution (1.6%) followed by Number of Trees to be Cleared (2.2%) and Vehicle Operation Cost (2.5%). Since the traffic volume is low in rural roads, air pollution is also low and hence the sub criteria Air Pollution Cost has obtained lowest weightage.

4.1.2 Case Study Results:

The data obtained for five criteria and seventeen sub criteria of following three selected roads are tabulated below.

- Gatthe Khola-Dhampus-Khanigau Road, Kaski (Road A)
- Patichaur-Bajung-Kyang-Nagi Road, Parbat (Road B)
- Adalatchautari- Tityang- Saalbot- Daha- Bhakunde-Rayadanda- Damek- Bayang Road, Baglung (Road C):

Table 3: Summary of Scores of Performance Indicators

S. No	Sub Criteria	Road A	Road B	Road C
1	Construction Cost (000, NRs.)	419633	733315	627635
2	Maintenance Cost (000, NRs. Per year)	26710	36350	47708
3	Vehicle Operation Cost Savings (000, NRs. Per Year)	6518.28	9606.71	12112.40
4	Accident Cost (000,NRs./year)	5279.20	6632.84	5008.47
5	Air Pollution Cost (NRs./Year)	7927.26	13159.60	13339.10
6	Value of Travel Time Saving (000, NRs. Per Year)	3364.97	4861.57	6090.26
7	Employment Generation (Man-days)	131478	231573	196136
8	Property Appreciation (000, NRs. Per Ropani)	300	3715	625
9	Access to Agricultural and Livestock pocket Areas and Tourism Destination, (Nos.)	2	4	3
10	Population Served per Km (Nos./Km)	391	340	410
11	Access to Educational Services (Nos.)	340	827	916
12	Access to Growth Centers (Market Centers, Health Services, Administrative Centers) (Nos.)	5	4	4
13	Connection to Strategic Road Network (Highway, Feeder Road, District Road)	3	3	3
14	Number of trees to be cleared (Nos.)	31	32	39
15	Encroachment on Agricultural Land (000, Sq.m)	72	68	132
16	Encroachment on Cultural and Historical Areas (Nos.)	0	0	0
17	Natural Hazards (Land Sliding, Erosion, Flooding) (m)	65	65	35

Ranking of Alternatives

Ranking of selected three road projects were done using Simple Additive Weightage method. Following table shows the normalized weighted values of all seventeen performance indicators for all the alternatives.

Table 4: Weighted Score of Alternatives

S.N.	Sub Criteria	Weighted Z-Score		
		Road A	Road B	Road C
1	Construction Cost (000, NRs.)	4.366	-3.510	-0.856
2	Maintenance Cost (000, NRs. Per year)	5.226	0.293	-5.519
3	Vehicle Operation Cost Savings (000, NRs. Per Year)	-2.572	0.173	2.400
4	Accident Cost (000,NRs./year)	2.762	-7.594	4.833
5	Air Pollution Cost (NRs./Year)	1.827	-0.867	-0.960
6	Value of Travel Time Saving (000, NRs. Per Year)	-4.387	0.278	4.108
7	Employment Generation (Man-days)	-14.525	11.949	2.576
8	Property Appreciation (000, NRs. Per Ropani)	-3.139	5.459	-2.320
9	Access to Agricultural and Livestock pocket Areas and Tourism Destination, (Nos.)	-12.586	12.586	0
10	Population Served per Km (Nos./Km)	2.965	-11.062	8.097
11	Access to Educational Services (Nos.)	-4.834	1.810	3.024
12	Access to Growth Centers (Market Centers, Health Services, Administrative Centers) (Nos.)	7.867	-3.933	-3.933
13	Connection to Strategic Road Network (Highway, Feeder Road, District Road)	0	0	0
14	Number of trees to be cleared (Nos.)	1.545	1.030	-2.575
15	Encroachment on Agricultural Land (000,Sq.m)	1.484	1.802	-3.286
16	Encroachment on Cultural and Historical Areas (Nos.)	0	0	0
17	Natural Hazards (Land Sliding, Erosion, Flooding) (m)	-3.411	-3.411	6.822
	Sum of Sub Criteria Scores	-17.413	5.003	12.410
	Rank	III	II	I

5. Conclusions and Recommendations

5.1 Conclusions:

Following conclusions can be drawn from the study:

Identification of main criteria and sub criteria was done from past research and expert opinion. Five main criteria viz. Financial Aspect, Social Cost, Economic Development Impact, Social Impact and Environmental Impacts were found to be important for selection of rural road projects.

Similarly, seventeen sub criteria found prominent for the study are: Construction Cost, Maintenance Cost, Vehicle Operation Cost Saving, Accident Cost, Air Pollution Cost, Value of Travel Time Saving, Employment Generation, Property Appreciation, Access to Agricultural and Livestock pocket Areas and Tourism Destination, Population Served per Km, Access to Educational Services, Access to Growth Centers, Connection to Strategic Road Network, Number of trees to be cleared, Encroachment on Agricultural Land, Encroachment on Cultural and Historical Areas and Natural Hazards.

The weights of the main criteria obtained by using AHP based survey reveal that Economic Development Impact is the most important factor with 31% weightage followed by Social Impact which bears 29% weightage. Similarly Financial Aspect and Social Cost bear the lowest weightage of 12% each. Environmental Impact was given 16% weightage. Among the seventeen sub criteria, Employment Generation has the highest weightage of 13.4% followed by Access to Agricultural and Livestock pocket Areas and Tourism Destination (12.6%) and Population Served per Km (9.9%). Air Pollution bears the lowest weightage of 1.6%.

From a case study of three alternatives using the derived weights and Simple Additive Weightage approach, Adalat Chaupari- Tityang- Rayedanda-Bayeng Road with score of 12.410 was selected as highest ranked alternative.

5.2 Recommendations:

Based on the findings of the research work, a recommendation is made to the Local and Provincial Governments, who are working in rural road sector, to use the multi criteria decision making approach for selection of road projects so that selection is made based on a well-defined criteria.

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