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Application of an Alternative Multi-Criteria Federal Road Projects Selection Using Integrated Analytic Hierarchy Process and Linear Programming Models

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Abstract

The allocation of resources in federal road projects in Ethiopia is critical multi-criteria decision challenge which requires proper analysis, ranking and selection of projects. Unfortunately, the selected projects are also facing delays and cost overruns. The project selection methods commonly used are quantitative in nature and lack to consider intangible factors which can affect the outcome of project appraisals. An integrated Analytic Hierarchy Process and Linear Programming model that considered both quantitative and qualitative factors in choosing capital project is presented. The combined model is applied in Ethiopian Roads Administration projects with Federal Planning and Development Commission and Ministry of Finance as prime stakeholders in project selections. Research surveys were conducted in those organizations and secondary documents were used for in-depth analysis. The results indicated that project characteristics, with 0.5 weight, were ranked higher than other criteria related to the firm characteristic and external factors which had weights of 0.36 and 0.14, respectively. The most important project selection sub-criteria were profit, measure of worth, project risk, financial standing, and resources with the overall weight of 0.15, 0.13, 0.12, 0.10 and 0.09, respectively. Four projects selected out of six had the best use of resources. The integrated model is recommended for future applications due to its ability to capture all potential factors and produce optimal solution and applicability in different situations with refining the selection criteria.

Key Words: Analytic Hierarchy Process, Linear Programming, Project Appraisal, Resource Constraint, Optimality

INTRODUCTION

Construction industry is an important sector in the economies of nations and plays a key role in their socio-economic growth. The Ethiopian construction industry accounts for 8.5% of the Gross Domestic Product (NPC, 2016). Construction projects produce vital physical infrastructures, industrial housings as well as dwelling needs of society.

Roads are key to Ethiopia's development. They connect rural and urban communities and drive economic growth. However, Ethiopia faces a substantial infrastructure deficit. Despite investing ETB 525.66 billion from 1997 to 2023 and expanding the road network from 26,500 km to 169,000 km, the condition of these roads remains a pressing issue (Seta 2024).

However, according to (WorldBank 2025), it is notable that the nation has faced multiple challenges such as “COVID-19, the conflict in Ukraine, the Tigray conflict, and droughts, worsened economic imbalances, leading to a debt default in late 2023”.

Despite the construction industry’s significant contribution to the economy of Ethiopia, its performance remains generally low. For instance, road construction projects are important components of the economy which have rippling effect in the production, manufacturing, and service sectors of the aggregate economy. In spite of their importance, Ethiopian road projects have been suffering from a serious drawback in delivery of projects on time and cost, which is caused in part due to the improper selection of projects under the case of national and internation bids (Kesto and Tsega 2022).

(ERA, 2021) stated that the project management skill gap is among the basic reason for projects to deviate from their intended quality, time, and cost. As project management skill is more critical at initiation stages of the project, it is evident that the existing skill gap will lead to increased difficulty in identifying and appraising project. With increased demand for public work projects, there is a need to focus on efficiency of decisions in construction project management processes. During the last decades, various methods focused on critical success factors such as adequate planning, improved decision making, proper allocation of cashflow, etc. have been utilized to improve under performance of construction projects and its effects (Berta and Tesfaye 2025). Among the potential strategies to foster the sectors development is thus selecting the proper projects through improved analysis of the project success factors.

One of the innovative approaches in this regard is to use multi-criteria decision-making method to properly prioritize and select construction projects (Broniewicz and Ogrodnik 2020). So, proper selection of road projects helps the country to invest on highly prioritized works under serious resource constraint. (Shiferaw, Klakegg, and Haavaldsen, 2012) stated that roads in Ethiopia have been built and expanded; however, it is not always a success story as constructing roads in low traffic volume areas has been observed as an example.

According to (Ali and Sayegh, 2016), the challenges in project selection is attributed to the involvement of different goals (organization’s objectives and priorities) and the large number of attributes to consider such as financial benefits, intangible benefits, availability of resources and risk level of the projects.

Over the last decades, quantitative capital budgeting techniques that provide the highest return over a given period of time have been employed to select projects.

Typically project owners use optimization techniques using a measure of worth such as the Net Present Value (NPV) and the Internal Rate of Return (IRR). However, these methods fail to take into consideration the intangible factors that can affect the results of project assessments such as the right for access, organizational culture, experience, project location, political and economic environment (Ali and Sayegh, 2016). Focus on sustainable road sector development which focuses on safety, suitability and environment (UNECA 2012). Therefore, there is a need to develop a method for project selection for client organizations that can take into consideration both tangible and intangible factors. Multi-Criteria Decision Making (MCDM) techniques, such as the Analytic Hierarchy Process (AHP), have the ability to evaluate quantitative and qualitative criteria. (Broniewicz and Ogrodnik 2020) showed that AHP results are simple, and suitable tool for project selection criteria prioritization and Linear Programming for optimizing resources. Therefore, a combined Analytic Hierarchy Process (AHP) and Linear Programming (LP) approach can be used to select and optimize projects to enhance the quality of capital budgeting.

Problem Statement

Construction industry plays a key role in socio-economic growth of Ethiopia while it is required to compete for funding from other economic sector and improving effectiveness and efficiency of project selection is critical. Studies such as (Shiferaw, Klakegg, and Haavaldsen, 2012) showed construction projects in Ethiopia are not competitive to meet project performance expectation in terms of time, cost, and quality which partly requires an examination of alternative techniques for best possible project selections.

In Ethiopia, significant finance allotted for the roads sub-sector, the 2020 Ministry of Finance (MoF) Medium Term Expenditure Framework (MTEF) showed, the capital budget for the ERA as; 38.2 billion ETB from treasury, 279 million ETB from grant and 7.86 billion ETB from loans. But Ethiopian Roads Authority 23 years Road Sector Development Program (RSDP) report stated that “most areas in the country were isolated from economic centers, market and basic social services while the existing road network is largely in deteriorated condition” indicting the increased need for efficient selection and financing road projects (ERA 2023). (Shiferaw, Klakegg, and Haavaldsen, 2012) stated “some federal roads in Ethiopia are constructed in the remote areas where the traffic volumes are far below the minimum average while some of the road projects with higher Annual Average Daily Traffic (AADT) are not given priority for investment and some of the roads are constructed with gravel surfacing. These realities show that the initiation and planning of such projects requires the consideration tangible (AADT) as well as intangible (access to road) factors. One can easily understand these projects could not generate sufficient additional revenues for the government nor could they cover their running and maintenance cost. On the other hand, the government has no financial capacity and is not allocating sufficient funds for maintenance and operation. In view of that, it is envisaged important to evaluate and research for the road projects investment prioritization methods and to study better techniques”.

(Mathewos, 2018) study showed that ERA has its own road projects investment prioritization and selection criteria. There is no weighting for each criterion to evaluate all projects in equal ground. She forwarded recommendation “as mitigation and

intervention measures, that the roads authorities should develop new selection and prioritization of road projects investment". However, in its recent report, ERA had presented its project selection and prioritization approach where a preliminary selection using Multi-Criteria approach will be made followed by feasibility study (ERA 2023).

The overall objective of this paper is to study and recommend the use of multi-criteria decision making for projects selection through the analytic hierarchical scientific decision-making system integrated with linear programming under limited resources. Specifically, it aims to apply the use of multi-criteria decision-making method through combined approaches of Analytic Hierarchy Process and Linear Programming in Ethiopian road construction industry for effective and efficient projects selection, and to recommend projects selection decision making process by providing simple hierarchical prioritizing framework.

The scope of this study is however limited to use of combined AHP and LP techniques to facilitate and offer recommendations and overcome problems of ERA roads construction projects using PDC and MoF as prime stakeholders in public road projects selection. The technique, mathematical programming, does not replace the knowledge and experience of experts, but it gives insights for the decision-making system.

LITREATURE REVIEW

A project is a temporary endeavor undertaken to create a unique product, service or result. Projects in general are policy implementation tools using limited available resources (finance, work force and materials) for accomplishing development programs and plans. According to (PMI, 2008) project management is "the application of knowledge, skills and techniques to project activities to meet the project requirements". The process of project preparation, prioritization, and selection is critical steps to be considered for using a country's resource for development (Shiferaw, Klakegg, and Haavaldsen, 2012).

In a typical organization, projects compete for limited resources and hence the challenge is to prioritize projects in accordance with the strategic goals of the organization which include economic as well as non-economic factors and then allocate optimally scare resources in a manner that will maximize the organization's wealth.

(Satty, 1980) stated the fundamental problem of decision theory is how to derive weights for a set of activities according to importance. Importance is usually judged by several criteria that may be shared by some or all of the activities. In such multi-criteria decision-making situation, the development of the relative weight or significance of the key part of the decision analysis. There are many different multi-criteria decision methods found by researchers around the world. The methods commonly used are quantitative in nature and they fail to take account for qualitative or intangible factors which are real factors that can affect the outcome of project appraisals (Ehie, Oyatoye, and Joseph, 2016). Popular traditional methods of capital budgeting that depend on quantitative measures include net present value (NPV), internal rate of return (IRR) using discounted cash flow (DCF), and payback period. These traditional allocation methods depend on quantified or tangible measures but fail to capture the intangible or qualitative measures such as risk of project, priorities between business units and subsidiaries, priorities within groups, discretionary versus required projects, statutory project (government requirement), social responsibility (community development) and other factors that lie within the strategic project portfolio. Besides, there are other projects like research and development (R&D) which are necessary for the long-term survival of companies but are simply difficult to assess or put into normal

financial return model using the traditional methods. Additionally, their lack of managerial flexibility especially in a world of very dynamic business environment results in capital budgeting failures. Experience has shown that non-financial criteria should be included in project selection decision modeling (Kabir, Sadiq and Tesfamariam 2014).

(Caballero, Chopra, and Schmidt, 2012) stated project selection is an essential process for portfolio management and plays an important role in accomplishing organizational goals. They showed simple examples, which includes formulation and solution of the problem using 0-1 integer programming (one objective portfolio) and goal programming (multiple objectives portfolio) and finally concluded mathematical programming methods can improve the quality of the decision-making process reducing subjectivity and optimizing resource allocation in the projects that add more value to the organizations. Their study also presents a literature review of the techniques used in project selection, numerical methods, and non-numeric methods.

In infrastructure management, multi-criteria decision making (MCDM) has emerged as a decision support tool to integrate various technical information and stakeholder values (Cheng and Li, 2005). Different MCDM techniques and tools have been developed. The study by (Cheng and Li 2005) presents a comprehensive review on the application of MCDM literature in the field of infrastructure management. The study results suggest that there is a significant growth in MCDM applications in infrastructure management and have been successfully used. The most commonly applied methods were AHP with 24 %, ELECTRE and PROMETHEE with 6.3 %, CP with 4.7%, TOPSIS with 5.3%, WSM with 3.3%, and VIKOR with 2 %. As the study reviewed wide range of related papers across decades, it is pertinent representative as far as MCDM methods comparison is considered.

The construction projects selection processes are well established in the literatures which clearly defines the procedures. Construction clients like Road Authorities face difficulty in selecting projects which offer attractive return on their investment. Additionally, they cannot undertake all projects concurrently due to limited resources and other constraints. Therefore, they must select the most optimum projects, which maximize positive results such as profits, reputation, etc. and minimize any negative outcomes such as technical deficiency, environmental harm, etc. This process will require the development of a set of selection criteria for prioritizing projects. As stated in (Mathewos, 2018) in the developing world, the challenges in road infrastructure investment become even more daunting as manifested by the staggering size of infrastructure funding gap. It stated that project prioritization and selection in the public sector is in general a very complex and delicate problem due to huge investments, limited budget, conflicts between relevant criteria, influences of the state of politics and government. Effective prioritization of infrastructure projects is challenged by a series of constraints including institutionalized inefficiency, inadequate data obstructing decision-making, insufficient coordination among various stakeholders, lack of public consultation, lack of technical capacity for project evaluation and prioritization, and lack of consideration of possible alternatives in the infrastructure planning.

According to (Ali and Sayegh, 2016), the factors affecting project selection in the construction industry are grouped in three main categories: Project characteristic, owner (firm) characteristics and external factors. At some point, the categories seem to have conceptual overlaps such as project measure of worth and economic factor. However, measure of worth is directly looking for the project ability to return on its investment while the economic factor encompasses all economic factors/variables in national or regional unit undertaking that particular project. The project characteristics category is related to the project itself, the expected utility of the project and the strategic benefit of the project to the client organization. It consists

of five criteria; profit, risk, measure of worth, size and complexity and duration (Unuafe, 2018). Profit refers to the direct or indirect revenue/return to the society expected from the project as in the case of toll roads or the economic internal rate of return in other public roads. The risks are different criterions which are internal to the project which can arise from different perspectives from technical to social issues. Measure of worth is used to estimate the project feasibility based on quantifiable or tangible measures such as net present value (NPV), internal rate of return, payback period and benefit-cost ratio. The size and complexity criterion includes the need for coordination and management of the technological elements. The duration is the total time required to complete the project to meet its objectives. ERA for example uses traffic level of the proposed road; network connectivity; road condition; investment potential and import-export roads for upgrading projects and economic development potential areas; roads leading to surplus food crop and cash crop growing areas; missing links between main roads or shortcuts; new access to large population centers and roads in emerging regions for new federal road projects (ERA 2023).

The second category owner (firm) characteristics are related to the financial and non-financial strength and capability of the owner to handle projects. This category includes five criteria: organizational culture, experience, financial standing, technical ability, and available resources. The organization culture is how fit the project is for the organization goals and objectives. Experience is about the capability and past experience and the lessons gained from previous projects. The financial standing refers to the financial strength of the firm (owner) in terms of budget, and capital (Satty, 1990). The technical ability is the capability of the firm to handle the technological and innovation aspect of the project to complete successfully. The resources criterion refers to resource availability as of the project needs. The external factors category represents the interaction of the firm and its surroundings comprising five factors: environment, economic, location, political and social responsibilities. The environment factors are related to the wellbeing and overall impact of the project to the sustainability of the surrounding. The economic factors are the economic conditions, both macro and micro, in which the organization competes. The location criterion refers to the geographic location as it affects the mobilization cost, accessibility and availability of electricity and water supply (Unuafe, 2018). The political factors are related to government policies, laws and regulations, threat of power, etc. The social responsibility criterion includes the social impacts of the project. The following figure illustrates the project selection criteria used to prioritize by AHP and use them in linear optimization of limited resources for list of projects. Most of the project selection factors or variables studied in the literatures are included either in one way or the other in Figure 1.

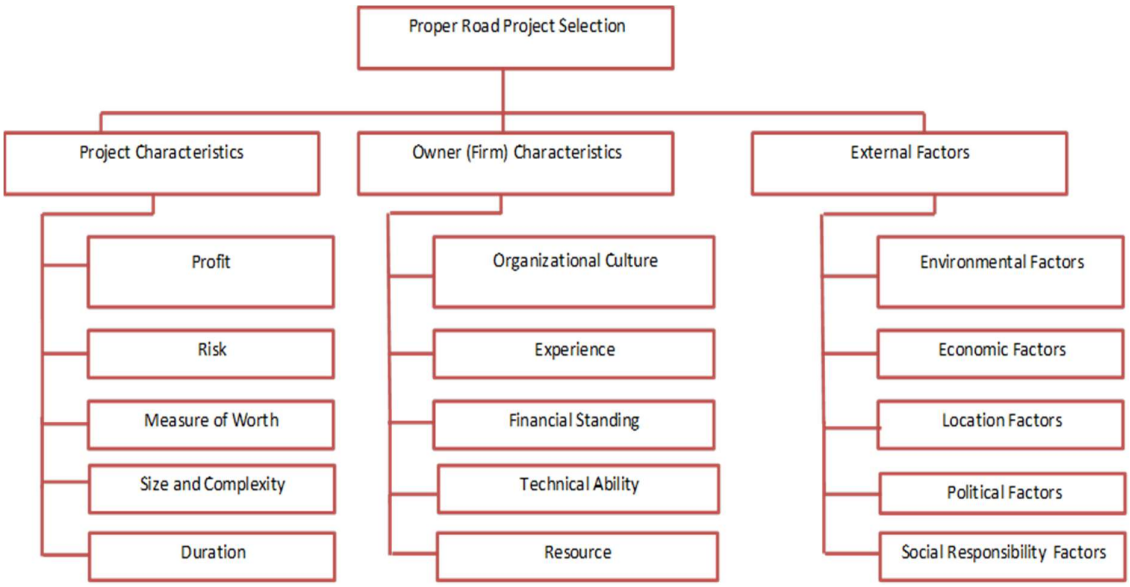


Figure 1: Factors affecting project selection

(Mathewos, 2018) studied and evaluated the Ethiopian Federal Road projects investment prioritization practice. According to the study, main road projects in Ethiopia starts with identification of potential projects, which will best contribute to government objectives and development of economic sectors (such as: agriculture, mining, tourism, industry). The basis for identification might be as a result of economic development potential of the specific area, developing import-export corridor, improve accessibility, increased traffic level, improving road condition. So, processes to meet the basic accesses and a participatory "bottom-up" and "top-down" planning approach are used.

The study of (Nandi and Paul, 2011) indicated that despite the development of various frameworks to assist in the appraisal and selection of government projects, failures are still being recorded with government projects. In developing countries, where frameworks are rarely used, the problems are encountered. In the Nigerian context where frameworks are rarely used, the problems are compounded (Nandi and Paul, 2011). Its findings revealed that with the increase in population, incidence of infrastructure shortage has continued to increase in Nigeria, causing a severe challenge, especially to the Nigerian government. The finding of the study revealed that a visible theoretical project selection framework to support public sector decision makers in making project decisions is still lacking. The significance and complications surrounding project selection within the Nigeria context, call for the development of a systematic approach that can aid decision makers in the evaluation and selection of projects. The study concludes by proposing a selection framework and guidelines/protocols that will aid decision makers to be consistent in assessing and selecting construction projects within the Nigeria public sector.

According to (Mathewos, 2018), ERA would not perform project's post-evaluation studies on government-financed projects due to different reasons; hence, there is no means to verify the constructed project's effectiveness and whether they are giving the desired benefits. In addition, feedback assessment would not be carried out from the public and its own road asset management department on the constructed roads. So, ex-post evaluations are not done in detail (since the establishment of prioritization criteria within ERA), evaluation and or revision of such criteria have not been performed. So, the main purpose of ex-post evaluation of project is to learn lessons for future prioritization and selection of projects, if not

done, it will be among the challenges to be addressed in the future. In general, the challenges of ERA's Road prioritization and selection process are, budget limitations, rapid rate of traffic growth, regional competition, excessive public demand, local consultants and contractor's capacity problem, lack of integration with other infrastructure development institutions, decision makers' interest, poor maintenance practice and lack of sufficient data (Mathewos, 2018). Even though such challenges, the study puts the overall performance as good for the last two decades in improving the country's road networks and road conditions even if it indicate the necessity of better systematic tool for project prioritization and selection (Mathewos, 2018).

The same study further puts the following recommendations to improve the current ERA's road projects selection and prioritization practice; institutions should have qualified experts and leaders to enhance their project implementation, monitoring and evaluation capacity, improve their maintenance management practices, the road project selection and the routes selection should consider the environmental sustainability, safety, compensation, and ensure to have sufficient data on the assets to use them on systematic project selection methodologies. Finally, the study recommends ERA to establish multi-criteria decision model/s for infrastructure development in which this paper partly tries to study on it. The review of the current practice of ERA shows that for upgrading projects, traffic level of the proposed road with 30%; network connectivity with 20%; road condition with 20%; investment potential with 10% and import-export roads with 20% weight are used while for new federal projects economic development potential areas with 20%; roads leading to surplus food crop and cash crop growing areas with 20%; missing links between main roads or shortcuts with 20%; new access to large population centers with 30% and roads in emerging regions with 10% are used (ERA 2023).

Research Methodology

The research involves the use of primary and secondary data. Through desk study, pertinent literature in the area of project selection was identified. The currently used project selection methods, the allotted budgets, the projects profile information were gathered from Planning and Development Commission (PDC) of Ethiopia, Ministry of Finance (MoF), and Ethiopian Roads Administration (ERA). Primary data were collected through questionnaires in those three organizations.

A modeling approach based on integrated Analytic Hierarchy process (AHP) and Linear Programming (LP) was applied. AHP is a tool and technique for the mathematical treatment of decision problems, and it is recommended for stakeholder's decision-makers requiring a development of weighting-based aggregation approach. LP is a mathematical tool and technique; ways to formulate real-world problems in mathematical terms (models), techniques for solving the models, and engines for executing the steps of algorithms. The technique can be used for optimum allocation of scarce resources subject to a set of limitations or restrictions on the use of available resources.

The questionnaire of the survey on the data collection tool seek to compare project selection factors for AHP analysis. The results of AHP process are augmented with LP to optimize and select projects with the available resources.

RESULTS AND DATA ANALYSIS

There were 100 questionnaires included in the survey and a response rate of 88 % was achieved even though the questionnaire requires high level of expertise and commitment. Among them 10 were rejected due to failure to fill the questionnaire completely. Hence, 78 surveys are used for the analysis where 35.9% were from PDC, 33.3% were from ERA, and 30.8% were from MOF and

almost 70% of the respondents had more than five years' experience.

The Cronbach's alpha (α) for the survey was calculated and was found to be 0.95. Cronbach's alpha typically ranges from 0 to 1. According to Nunnally, (1967) as stated in (D. L. Streiner 2003), recommended 0.50 to 0.60 for the early stages of research, 0.8 for basic research tools, and 0.9 and above for minimally tolerable estimates. To this end, the alpha of this study is found to be acceptable since it is above the cutoff.

In this study, a decision hierarchy structured and AHP was applied in order to examine the relationship between road construction projects selection criteria and their importance to meet objectives. The model used has a three-tier analytical hierarchical structure whose goal is providing alternative technique for the effective and efficient selection of road projects in the public sector arena, the case of Ethiopian Roads Authority.

Evaluating the pair-wise comparison questions judged by the project management professionals' experience was done. According to (PMI, 2008) "the fundamental scale of the AHP is a scale of absolute numbers used to answer the basic question in all pair-wise comparisons: how many times more dominant is one element than the other?" Based on this principle, to obtain the set of overall priorities for a decision problem, synthesizing the judgment was made in the pair-wise comparison (refer to Table 1). The data is weighted and added in order to give a single number to indicate the priority of each element on a scale of 1 to 9. To evaluate the pair-wise comparison, a comparison matrix was created for all criterions. Figure 2 shows the result matrix of criterions from all respondents.

According to (Saaty 1980), AHP measures the overall consistency of judgments by means of Consistency Ratio and value of the consistency ratio should be 0.1 or less and for practical purpose, even a CR which is above 0.1 percent with few figures is considered. Thus, the Consistency ratio of this study was evaluated (CR = 0.048) and was found acceptable.

Table 1: Pair-wise comparison scale by (Satty, 1990)

Weight	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent scale values	When compromise is needed
Reciprocals	For Inverse comparisons	A reasonable assumption

Pairwise Comparision Matrix															
Parameter	Profit	Risk	Measure of Worth	Financial Standing	Resource	Economic Factors	Experience	Technical Ability	Size and Complexity	Duration	Organizational Culture	Environmental Factors	Location Factors	Social Responsibility	Political Factors
Profit	1.00	3.58	2.47	3.04	3.91	4.68	4.45	3.45	3.74	4.73	5.79	6.24	5.68	5.85	6.65
Risk	0.28	1.00	2.40	2.84	2.82	4.36	3.98	3.46	3.85	4.41	5.47	6.21	5.74	5.49	6.45
Measure of Worth	0.41	0.42	1.00	3.10	4.18	4.86	4.49	3.30	3.73	4.91	5.76	6.22	5.67	5.95	6.68
Financial Standing	0.33	0.35	0.32	1.00	3.41	4.29	3.91	3.09	3.59	4.58	5.72	6.40	5.67	5.60	6.40
Resource	0.26	0.36	0.24	0.29	1.00	3.90	3.34	3.02	3.27	4.26	5.51	6.27	5.97	5.64	6.45
Economic Factors	0.21	0.23	0.21	0.23	0.26	1.00	2.99	2.62	2.93	3.77	5.51	5.72	5.51	5.31	5.97
Experience	0.22	0.25	0.22	0.26	0.30	0.33	1.00	2.98	3.02	3.65	5.16	5.60	4.92	5.42	5.90
Technical Ability	0.29	0.29	0.30	0.32	0.33	0.38	0.34	1.00	3.53	4.40	5.51	5.90	5.41	5.38	6.12
Size and Complexity	0.27	0.26	0.27	0.28	0.31	0.34	0.33	0.28	1.00	3.71	5.27	5.41	4.81	5.25	5.86
Duration	0.21	0.23	0.20	0.22	0.23	0.27	0.27	0.23	0.27	1.00	4.60	5.29	5.23	5.05	6.17
Organizational Culture	0.17	0.18	0.17	0.17	0.18	0.18	0.19	0.18	0.19	0.22	1.00	3.78	3.46	3.65	5.00
Environmental Factors	0.16	0.16	0.16	0.16	0.16	0.17	0.18	0.17	0.18	0.19	0.26	1.00	3.48	3.09	4.17
Location Factors	0.18	0.17	0.18	0.18	0.17	0.18	0.20	0.18	0.21	0.19	0.29	0.29	1.00	3.11	3.78
Social Responsibility	0.17	0.18	0.17	0.18	0.18	0.19	0.18	0.19	0.19	0.20	0.27	0.32	0.32	1.00	3.79
Political Factors	0.15	0.16	0.15	0.16	0.16	0.17	0.17	0.16	0.17	0.16	0.20	0.24	0.26	0.26	1.00
Total	4.31	7.81	8.47	12.42	17.58	25.32	26.03	24.31	29.86	40.37	56.34	64.89	63.15	66.05	80.39

Figure 2: Comparison Matrix

Percent Ratio of Priorities and Results

The following steps were used for calculating the priorities.

Step 1: Develop a model

The basic project selection decision factors are categorized into three where different features are included within each category.

Step 2: Derive priorities (weights) for the criteria

To compute the priorities, scores were normalized first. This step is to normalize the matrix by taking the total of the numbers in each column. Each entry in the column is then divided by the column sum to yield its normalized score. The sum of each column is one. Then the sum of the values of each column were computed and then each element in the matrix was divided with its column total to generate a normalized pair-wise matrix. Finally, by dividing the sum of the normalized column of the matrix with the number of criteria used, the weighted matrix is developed. The matrix below shows the relative priorities of each decision factors.

Hence, among the three basic categorical factors related to project characteristics are weighted 0.50 with profit (0.15), risk (0.12), measure of worth (0.13), size and complexity (0.06), and duration (0.04); related to owner (firm) characteristics are 0.36 with organizational culture (0.03), experience (0.07), financial standing (0.10), technical ability (0.07), and resource(0.09), and related to external factors are weighted only 0.14 with environmental factors (0.02), economic factors (0.07), location factors (0.02), political factors (0.01), and social responsibility (0.02). Figure 3 illustrates the priority weights of the three broad categories and the fifteen criterions.

Project Profit……..	0.15
Project Risk……	0.12
Measure of Worth……..	0.13
Financial Standing…….	0.10
Resource……..	0.09
Economic Factors……..	0.07
Experience……..	0.07
Technical Ability……	0.07
Size and Complexity……..	0.06
Duration……..	0.04
Organizational Culture…...	0.03
Environmental Factors……	0.02
Location Factors…….	0.02
Social Responsibility…….	0.02
Political Factors……	0.01

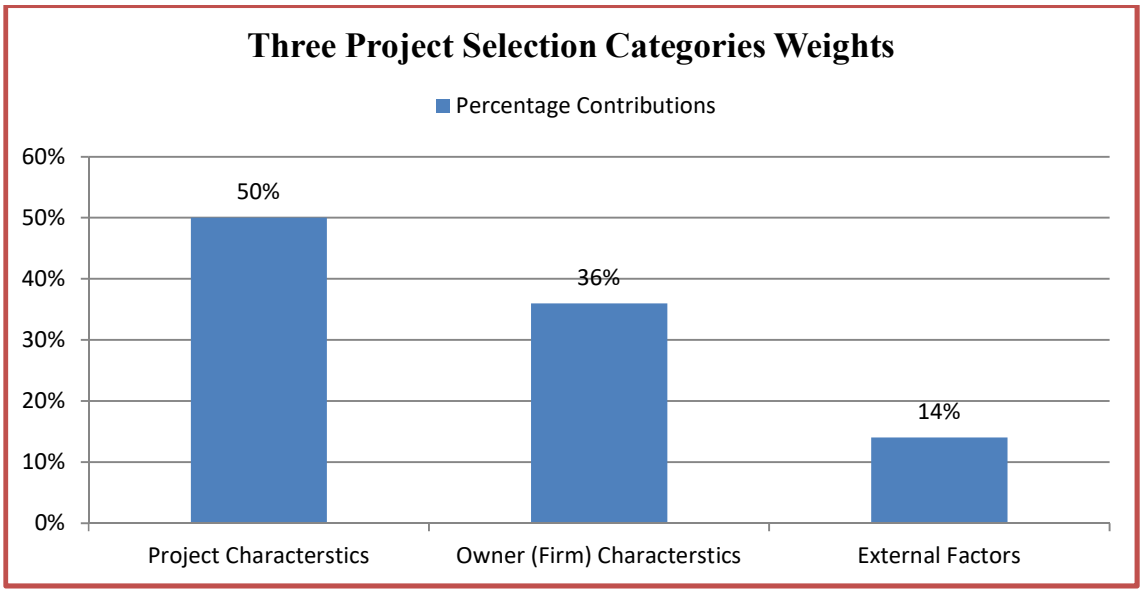


Figure 3: Three broad categorical project selection factors percentage contributions

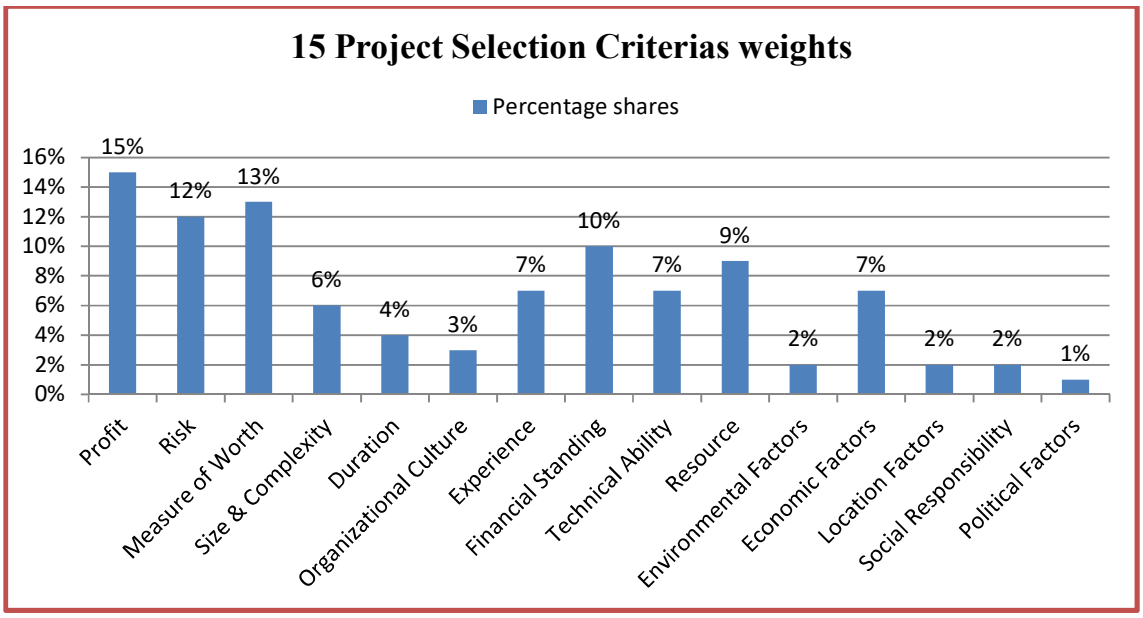


Figure 4: The fifteen project selection criteria percentage contributions

Model Testing

For this study, the available investing options for the organization are considered as six road projects started in 2020/21 G.C. To simplify calculations, reduce the time for pair-wise comparisons of alternatives against each selection factor and to accelerate work, the top five factors are selected for pair-wise comparison purposes. These five criteria are profit, measure of worth, project risk, financial standings, and resource. The project profile of the six anonymous projects is presented which are alternatives in AHP priority and linear optimization calculations. As some of the projects for this study might have conflict of interests, it was decided not to mention the names of the projects and hence, projects are identified with sequential numbers. However, all the

required data has been gathered and included in the study.

Project 1 (P1): The project is in central Ethiopia with 100 km length with the total cost of 1,306,509, 000 ETB. The project document indicates, the project road, an existing gravel road connects three woreda in the regional state. It has a variable carriage width ranging from 6m to 8m, with very poor to medium riding quality, and was built with (Design Standard) DS5. In general, it has rough gravel wearing course surfacing (with complete gravel loss at some sections), can be rated as road in fair to poor condition. The existing average travel speed on the road is about 40km/h with sections having running speed as low as 35km/h and it passes through mainly rolling to mountainous terrain. The project road will be designed for DS-5 standard with improvement to asphalt concrete. The project was started at 2020/21 GC budget year. Its length is 100km with road functional classification of main access road. The project area climate classification is temperate with minimum and maximum elevation of 1570-2170m respectively. The forecasted traffic volume is 1,420 at 2038. The transport demand in the immediate influence area includes the proximity to major towns. The EIRR is 25.5 %, the NPV is 4,003.23 million ETB and B/C of 3.7.

Project 2 (P2): The project road is located in the southeast part of Ethiopia. The total project length is 140km with functional classifications of link road. It was started in 2020/21 GC budget year with expected future traffic of 679 forecasted in 2038. The climate classification of the project area is hot-arid climate zone with the mean annual rainfall less than 450mm. The project cost is 2,878,405,998.33 ETB. The road improvement project to asphalt concrete has NPV of 2,438 million ETB, 1.98 benefit-cost ratio, and 19.33 % EIRR.

Project 3 (P3): The project was started at 2020/21 G.C budget year. Its cost is 9.240 billion ETB with the total length of 308 km running from the center of the country to the south. It was started in 2020/21 GC budget year. The project feasibility undertaken by consultants of ERA shows, the project corridor width is 7.3m carriageway standards and 3.0 m shoulders in rural areas and additional 3.5m parking lanes and 2.5 m sidewalks in urban areas. The project's functional classification is link road with climatic classification of cold and temperate at an elevation from 1,800-3000m. The road traffic volume classification, AADT is from 3,000-10,000. The project AADT forecasted to be 13,693 at 2038. The project has EIRR is 43.8 %, benefit –cost ratio of 5.02, and the NPV calculated at 10.23 % is 25,425.11 million ETB.

Project 4 (P4): The project length is 90 km to be built in northern Ethiopia 580km from Addis Ababa with total project cost of 3.5284 billion ETB. The project construction period is 4 years aimed at upgrading to the paved road standard. It is started at 2020/2021 G.C budget year. The project AADT is 152 in 2020 and it is projected to be 875 in 2038. The economic indicators done at 10.23 % discount rate are EIRR of 11.9 % and NPV of 196 million ETB.

Project 5 (P5): The project is 103.9km running in western Ethiopia with project cost of 2.072 billion ETB started in 2020/21 GC budget year. The road functional classification is link road with minimum and maximum elevation of 492.06m and 1002.4m above sea level with arid climate. It is classified as DC-5 as per ERA geometric design manual. The project traffic is 460 at 2023 and forecasted to be 1592 in 2038. ERA's consultant had done the economic analysis and the NPV is

987.07 million ETB, the B/C ratio is 2.129 with EIRR of 17.3%.

Project 6 (P6): The project is located in the northern Ethiopia 650 km from Addis Ababa. The project length is 72 km started in 2020/21 G.C budget year. The project road functional classification is DC-5 with temperate climate classification. The traffic on the project road is estimated at about 330 AADT in the year of opening (2024). The project traffic road in 2038 is projected to be 1107. The project EIRR is 18.2 % and NPV of 2,372,000.9 ETB calculated at 10.23 % discount rate. The project cost is 1.79 billion ETB. Construction period has been scheduled for four years, and it started in 2020/21 GC budget year.

The project profile of the six anonymous projects is summarized in Table 2 below and is used as alternatives in AHP priority and linear optimization calculations. As some of the projects for this study might have conflict of interests, it was decided not to mention the names of the projects and hence, projects are identified with sequential numbers. However, all the required data has been gathered and included in the study. The results of each project, which is extracted from the projects profile, for those five criteria are presented in the Tables 3 and 4. The global weights (priorities) calculated by AHP process as the results are shown above, then, local priorities (preference) of the alternative projects were obtained by comparing each other with respect to selected top five criterions. The alternative projects were compared using the objective features of the projects i.e., by maximizing or minimizing with respective of best features in that particular criterion. Finally, the score (weight) of each project is then calculated. The Economic Internal Rate of Return (EIRR) is considered as profit indicator, Benefit-Cost ratio (B/C) as measure of worth indicator, and the project cost as resource indicator. Profit in this case is the direct (as in the case of toll roads) or indirect revenue/return the society and the government benefits in investing in public road infrastructures. The financial standing which is the firm characteristics is considered equal for all projects since they are executed by the same firm in the public sector arena. Had it been in private sector, it may vary depending on the type of the project. To simplify the process, the project risks are categorized based on the discounted cash flow rate of return (DCFROR) considering high risks are taken expecting high returns naturally (Ehie, Oyatoye, and Joseph, 2016). So, low risk (DCFROR; 10%to 20 %), medium risk (DCFROR; 21% to 35 %), and high-risk (DCFROR; above 35 %). Hence, corresponding with the EIRR of each project as in the above threshold, on the scale of 1-5; low risk is assigned as 1, medium risk as 3, and high-risk as 5. In order to found out the overall priority, the score (weight) for each project is calculated by multiplying the score of each project for each criterion by its global weight and then adding them to find out the overall score of each project. Then, the overall priorities of each project and the ranks are presented.

Linear Programming Analysis

Linear Programming is a mathematical tool; ways to formulate real-world problems in mathematical terms (models), techniques for solving the models, and engines for executing the steps of algorithms. Linear programming (0 & 1 integer programming) is used for budget constraints after selecting six road projects from database and analyzing using the topmost prioritized five criterions from AHP analysis.

Many road projects were up under the Ethiopian federal government for 2020/21 G.C budget year. According to Ministry of Finance (MoF) 2020/21 federal government capital budget, the annual budget available for the road sector was around 58 billion ETB. This capital budget

is including ongoing projects, road rehabilitation, upgrading, maintenance works, bridge constructions, projects feasibility studies as well as new road construction projects. The number of new road projects already committed budget were 151 with more than 18 billion ETB budget. The calculations shown in this section are done by considering the 2020/21 allotted capital budget for Ethiopian Roads Authority as the budget constraint.

Six anonymous projects which started in 2020/21 budget year were selected, considering those sample projects financed by the government, availability of enough data about the project, and functional classification similarity of the roads. Then the average annual allotted expenditure was divided into the number of newly entered road projects to find the expenditure of one project at specified year. Hence, the average budget ceiling for six projects is 750,783,000, then those six projects were constrained against this available financial resource.

The following calculations show the use of binary integer linear programming in project selection. This study uses ERA's six candidate projects and investigated which projects increase the overall benefits. Maximizing the AHP priority weights actually shows the contribution of each project towards meeting the organization objective of selecting proper projects. The available budget, the first-year expenditure of projects, and the AHP priority weights associated for each project are shown in Table 5 below

.

Table 2: Projects Profile

	B/C	EIRR	Project Cost (ETB)	Length (Km)	AADT @ 2038 G.C	Functional Classifications
P(1)	3.7	25.5%	2.29 billion	100	1420	Main access road
P(2)	1.98	19.33%	2.89 billion	140	679	Link Road
P(3)	5.02	43.8%	9.240 billion	308	16,693	Link Road
P(4)	4.9	11.9%	3.53 billion	90	875	Link Road
P(5)	1.858	17.3%	2.072 billion	103.9	1592	Link Road
P(6)	2.517	18.2%	1.79 billion	72	1107	Link Road

Table 3: The global and local priority weights of each project

Global weights	Profit (0.254)	Measure of Worth (0.221)	Project Risk (0.203)	Financial Standing (0.169)	Resource (0.153)	
Project 1	**0.19**	**0.19**	**0.07**	**0.17**	**0.20**	**0.163**
Project 2	**0.14**	**0.10**	**0.22**	**0.17**	**0.16**	**0.155**
Project 3	**0.32**	**0.25**	**0.04**	**0.17**	**0.05**	**0.18**
Project 4	**0.09**	**0.25**	**0.22**	**0.17**	**0.13**	**0.17**
Project 5	**0.13**	**0.09**	**0.22**	**0.17**	**0.22**	**0.159**
Project 6	**0.13**	**0.13**	**0.22**	**0.17**	**0.25**	**0.173**

Table 4: Alternative projects weighting and ranking

Alternatives	Overall Priority Weights	Ranks
Project 1	0.163	4th
Project 2	0.155	6th
Project 3	0.18	1st
Project 4	0.17	3rd
Project 5	0.159	5th
Project 6	0.173	2nd

Table 5: Linear Optimization Table

Project Information	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Constraint (ETB)
Priority Weights	0.163	0.155	0.18	0.17	0.159	0.173	
Annual Budget (in Million ETB)	52.5	205	335	88.5	176.5	90	750,783,000

The notations are defined as follows:

X_1=1 if project 1 is selected, 0 otherwise

X_2=1 if project 2 is selected, 0 otherwise

Or

X_j: Binary decision variable for project *j*, j=1 (if project j is selected, 0 otherwise)

n: Number of projects

J: Project number, j=1 to n

Z=Total Benefits

C_j: Overall benefit on the ranking of project *j* from the score of AHP analysis

a_{ij}: Amount of capital *i* required by project *j*

D_i: Total capital available

The weights of projects actually show the contribution of each project towards meeting the organization objectives. Thus, maximizing these weights can be translated to maximizing benefit for the owner in terms of selection factors. So, the objective function of the resulting LP model is to maximize the benefit of the organization is stated as follows.

$$Z_{max} = \sum_{j=1}^{n} C_j X_j \ \forall_j$$

$$Z_{max} = 0.163X_1 + 0.155X_2 + 0.18X_3 + 0.17X_4 + 0.159X_5 + 0.173X_6$$

The decision variables, represented as X_j are the selection of project *j* for *j*= 1, 2…. n. The value of X_j is one if the project is accepted and zero if it is rejected.

Subject to the following constraint:

a. Availability of capital

$$\sum a_{ij} X_j \leq D_i \ \forall_{i,j}$$

$$52.5X_1 + 205X_2 + 335X_3 + 88.5X_4 + 176X_5 + 90X_6 \leq 750.783$$

b. If a case when there are two projects that are disjointed, since the two projects are in the same geographic regions, that is, if for example project *j* is selected, then project *i* cannot be selected. The case is described by the following constraint:
$X_4 + X_6 \leq 1$

c. At most five out of six projects constraints; maximum of only five out of six projects can be executed due to the implementation capability of the organization; with available capital base on individual project requirements, hence we have:
$X_1 + X_2 + \cdots + X_6 \leq 5$

d. $X_j \geq 0 \ \forall_{i,j}$ or X_j=0-1 (binary decision variable)

Then following optimization model developed (Table 6) and solved using excel-solver, the result showed which projects are selected with quantification of the coefficient of decision variables.

Table 6: MS-Excel solver linear optimization table

Linear Optimization Using Excel-Solver				
Variables				
Project 1(X1)	1			
Project 2(X2)	0			
Project 3(X3)	1			
Project 4(X4)	1			
Project 5(X5)	1			
Project (6X6)	0			
Objective Function				
Maximize	0.68			
Constraints	LHS	Inequality	RHS	
Constraint 1	652	<=	751	
Constraint 2	1	<=	1	LHS Left Hand Side
Constraint 3	4	<=	5	RHS Right Hand Side
Constraint 4	X1	Binary		
Constraint 5	X2	Binary		
Constraint 6	X3	Binary		
Constraint 7	X4	Binary		
Constraint 8	X5	Binary		
Constraint 9	X6	Binary		
Maximum value for the objective function is 0.679 with X1=1, X2=0, X3=1, X4=1, X5=1, and X6=0				

The optimal solution is found to be Projects 1, 3, 4, and 5 with a combined benefit of 0.679. This shows that ERA should invest in project 1, 3, 4, and 5 in order to further maximize their benefit by taking into account budget as the main constraint. Based on the integrated AHP-LP model, Projects *P*1, *P*3, *P*4 and *P*5 were selected while *P*2 and *P*6 were dropped. It also means that by investing in those projects,

the organization gets 67.9 percent of benefit in terms of the five decision factors. Hence, if the organization invests in all projects, it may get loaded during the implementation period either due to finance or implementation capability which hampers the successful completion of projects within time and cost. Of the 750,783,000 ETB budgeted, 652 million ETB will be finally allocated to the four projects selected.

CONCLUSIONS

Resources are limited for pursuing and funding new projects. An effective project selection and prioritization method ensures optimal resource utilization. As a result, they need to be prioritized using criteria that reflect the objectives of project undertaking organizations. Optimization methods for project selection mostly focused on quantitative factors, thus failing to consider intangible and qualitative measures such as organizational culture, the external environment the project operates. On the other hand, MCDM techniques lack the ability to determine the optimum solution when resource is constrained. The integrated AHP-LP provides a useful tool to assist decision maker, especially for those projects with many risks, since it takes out the deficiency of traditional methods and adds the advantage of assigning resources in a most favorable manner.

The results indicate that criteria related to project characteristics, with 0.5 weight, were ranked higher than other criteria related to the firm characteristic and external factors with weights of 0.36 and 0.14 respectively. The most important project selection sub-criteria are profit, measure of worth, project risk, financial standing, and resources with the overall weight of 0.15, 0.13, 0.12, 0.10 and 0.09 respectively. Four projects among six projects were selected to have the most use of resources under constraints. Others are economic factors, experience, technical ability, size & complexity, duration, organization culture, environmental, location factors, social responsibility, and political factors with weights of 0.07, 0.07, 0.07, 0.06, 0.04, 0.03, 0.02, 0.02, 0.02, and 0.01 respectively.

The proposed model considers all the different criteria simultaneously. It has the ability to capture both qualitative and quantitative factors in determining the most suitable project portfolio. The use of AHP ensures the full involvement and participation of key decision makers and ensures the consistency of the decision. The model also ensures alignment of the selection decision with the owner's objectives and gives an advantage to owners to allocate the limited resources in an optimal manner in order to maximize benefit. The study offers an application of the model to solve the selection problem and helps validate AHP-LP as an alternative effective decision- making tool. The model can be applied in real life scenarios as is or modified according to the situation or need of owner. organizations can even develop their own comprehensive individual sets of selection criteria and researchers can refine the criteria that are applicable in different situations.

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