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Prioritizing rail infrastructure projects using analytic network process

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ABSTRACT
Transportation sector as one of the energy consumer sectors has some critical features in developing countries. From macroeconomic standpoint, transportation sector plays a vital role in determining the trend and pace of economic growth. It is especially important for vast developing countries where lack of mobility can be a major obstacle to growth.Rail transport has environmental advantages with respect to other modes due to Some rail projects may also have strategic value. From the economic point of view, a new rail infrastructure improves economic and social wealth, not only by way of gains for the former users but also by providing new opportunities of exchange, and thus new traffic. On the other hand, this new infrastructure is also going to have long-term effects, which are inadequately forecast, whilst the negative impacts should also be taken into account. Faced with a choice of different transport projects, such as different infrastructure projects, which project has the most priority for implementation? Railway project appraisal needs a methodology that is transparent, but able to respond to the current changing scenarios in the railway sector, and adaptable to the size and complexity of the project. Because there are lots of multiple factors such as project risk, corporate goals, limited availability of firm's resources, etc. These problems are Multi-Criteria Decision Making problems. Prior project selection techniques are useful. However, they have restricted application, because they generally depend on the assumption of independence among the candidate projects and criteria. In this paper, we suggest an improved project selection methodology which reflects interdependencies among evaluation criteria and alternative projects using analytic network process (ANP).The purpose of this assessment is to provide a high level framework to aid in the selection of transportation infrastructure projects that can help to enhance the existing infrastructure through strategic improvements in operations. Environmental impacts, both during construction and during the whole operation period must be properly included in the appraisal.
Keywords— Prioritizing, Transportation, Railway, Analytical Network Process

Introduction
Transportation systems are considered as one of the most important factors for growth and development of each country. They have long lasting effects on the financial, social, and political life of individuals and the community. Developing and improving transportation infrastructures is the foundation of economic growth and plays an important role in the overall development of each country. Planning and implementation of transportation infrastructures and services are also results of complex decision processes that usually involve numerous stakeholders and interest groups.

Compared with different transportation modes, rail transportation has an especial importance due to its additional characteristics including safety, cleanliness, speed, enabling better planning and utilization, etc. Railway infrastructure projects are known as the stimulus for regional development and provide an appropriate ground for the development of heavy industries, activation of mines and creation of trade boom. The large investment required for these projects is a deterrent. Transportation infrastructure management is generally conducted by governmental agencies and their implementation depends on public funds availability.

In Iran, to reach twenty-five thousand kilo meters of rail network length predicted in the long-term plan, it is required to be added an annual average of about two thousand kilo meters to the current length until 2025. But the resources needed to accomplish all of these projects are less than the annual funds allocated to the rail infrastructure projects every year. Recent experience shows that the budget allocated for the rail infrastructure construction projects is equivalent to the annual construction of three hundred kilo meters new line.

The resources needed to implement all the projects is less than the funds allocated to them and it shows the Necessity of a proper mechanism to allocate limited financial resources. A large number of significant transportation capital investment projects are currently being proposed for development of rail network of Iran by many public agencies. As a result, the city and the region must make important choices about how to prioritize these investments.

Proper selection of railway development projects is a step toward proper planning of transportation, correct orientation in country development and increasing the effectiveness of the railway development credits. Recommendation and pressure from stakeholders should not be replaced by wisdom and consensus of experts in selection of developing rail network alternatives. Incorrect decision in this process leads to blocking Material and spiritual capital in incorrect way.

The study estimated the degree of importance of the attributes through a questionnaire survey. The scale of 1–5 had been used to rate the importance such that 1 not important and 5 very important in the questionnaire. The results of the questionnaire were then analysed in spreadsheet form. An ANP model is developed to prioritize the railway projects for investment with the objective of maximizing the benefits including qualitative attributes. The ranked set of projects has been identified. Even though the objective is maximizing all the attributes, in this approach, the investment decision depends upon decision makers' considerations and whether it is mainly based on the economic benefits, revenue or qualitative goal scores.

In this study, we are going to develop a mechanism to take the actual assumptions of this problem into account after reviewing studies in recent decades in this field. In the real world, there are some correlations between different factors of decision and makes it difficult, so it must be taken account. Consequently there are always important budgeting constraints leading to a non-trivial decision making process in which the expected effectiveness is evaluated for every project to define the subset to be executed.

Problem Definition

The resources available in any country for transport infrastructure improvement rarely meet the needs. Major transport projects require large capital spending, and they invariably have a wide range of tangible and intangible impacts. To facilitate an efficient, equitable and environment-friendly allocation of limited resources, the impacts of a project should be weighed against those of other projects to determine funding priorities. This is a difficult task because of the lack of a single and objective measure that can be used to determine the net worth of each competing project to the society. In a democracy, this problem is compounded by the presence of many stakeholders whose vested interests often make the funding of a major transport project contentious.

We are going to prioritize the identified projects for investment while maximizing the objectives and considering the budget limit for capital investment. The objectives of the model include quantitative and qualitative attributes. The model is applied to prioritize the new railway projects. Optimization models are constructed for decision-making especially in selecting an optional subset of projects that are identified for investment. These models vary widely in their degree of objectivity and reliance on data and in the format of their outputs. The estimated benefits are both quantitative and qualitative. We provide an analytical foundation to combine both tangible and intangible impacts into numerical scores for ranking alternatives. It requires evaluators to perform pair-wise comparisons of the relative importance of criteria and objectives, as well as the relative desirability of competing projects.

From a normative standpoint, the process of project evaluation should be part of an overall process of regional transportation planning and design. A major component of this process is the project generation phase, where projects are first proposed and subsequently become part of the set of alternatives to be evaluated. In theory, we can distinguish between several approaches to project generation and evaluation, based on the underlying transportation planning perspective or perception of what transportation planning is about. It is beyond our scope here to examine this issue with any degree of rigor. Suffice it to say that in this study the set of projects put forward for analysis represents a mixed bag of planning criteria and projects. Whereas some were proposed to solve transportation problems, others are meant to mainly boost real-estate development and economic growth in specific locations. Still others have resulted primarily from political aims. Recall that the main objective of this study is to rank and prioritize a set of investment projects.

In the transportation sector ANP is not as widespread as AHP, however there are studies that provide interesting methodological and operational insights (Meade and Sarkis, 1998; Shang, Tjader, and Ding, 2004; Piantanakulchai, 2005; Wey and Wu, 2007). The approach needs to be tested in different kind of situations that show systemic relations between elements that cannot be tackled by other methods. The quantity and quality of the information processed for building and exploiting the model should also be analyzed to assess the usefulness in real world applications. In general, ANP is an alternative solution to solve the limitations of the Analytic Hierarchy Process (AHP) method, developed first by Thomas L. Saaty, in dealing with the complexities of real world problems because of its strictly hierarchical structure. Similar to AHP, in ANP the priorities are determined by a comparison scale which provides numbers that allows various basic arithmetic operations. The scale is obtained from conducting pairwise dominance comparison based on informed user judgment.

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Methodology

Various transportation project evaluation and comparison techniques have been developed by researchers and practitioners. The existing methodologies range from single-criteria cost/benefit analysis (CBA) to multiple criteria models and mathematical programming approaches. Among the current decision making methodologies for transportation projects we can mention the cost-benefit analysis (CBA) and multi criteria approaches. These concerns are more important in regions where disagreement about dimensions in political, socioeconomic and technological factors exists. In contrast, multi criteria approaches allow simultaneous modeling of several criteria, making it a good alternative to address this decision problem. Multiple criteria decision analysis approaches are widely used because they can consider issues that cannot be easily expressed with economic (monetary) measures.

CBA is a microeconomic approach that establishes the benefits and costs of projects in dollar values by taking into account positive and negative impacts, and compares the benefits/costs ratio. In many countries cost–benefit analysis (CBA) is used for evaluating all possible impacts of infrastructure investments. The disputes on CBA can be summarized into five main points of criticism. First, some scientists argue that, fundamentally, CBA represents a flawed appraisal method, based as it is on utilitarianism, which the authors consider as an unsatisfactory moral system. One of the basic principles of CBA is that all impacts of a project on individuals are valued on the basis of the impact issue. Does it satisfy or dissatisfy individual preferences? This concept of ‘utilitarianism’ as the base for decision-making has been widely attacked. The second criticism of CBA is that the market analogy valuation methods for non-priced goods, required in most CBAs for infrastructure projects, are inherently flawed. A third criticism of CBA is that it ignores equity issues. A fourth point in the debate is that some people worry that CBAs will easily result in incomplete or incorrect information to the decision-makers. Finally, CBA is criticized violently because the highly complex, resource intensive and expert-driven nature of the CBA appraisal method makes it extremely difficult for the public to understand and participate in the process.

The need to account for social, technical, political, economic, and environmental factors makes the transportation projects evaluation field well suited to multi criteria decision-making (MCDM). Several procedures have been adopted for MCDM, including the factor rating method, multi objective mathematical programming, and the analytic hierarchy process. (AHP)

To ensure a fair and transparent decision-making process, management has asked us to develop a systematic evaluation approach that is impartial and independent of the level of an individual decision maker's political influence. In order to accommodate these requirements, to provide a complete array of evaluation factors, to account for their interactions, and to ensure the openness of the process, we recommend the analytical network process (ANP) model. Both AHP and ANP are capable of evaluating a wide range of criteria, including tangible and intangible factors that have bearing on the outcome. However, AHP uses a unidirectional hierarchical relationship to model decision levels, while ANP allows for complex interactions among subnets and among criteria inside a cluster. ANP is a relatively new methodology that is still not well-known to the operations research community and practitioners.

ANP differs from traditional hierarchical analysis tools in that it allows feedback and interdependence among various decision levels and criteria. Compared with the conventional transportation evaluation methods, our model has incorporated a much wider range of long-term and short-term factors. Tactical and operational issues are taken into consideration. The evaluation framework is comprehensive and flexible, and shows great potential for helping decision-makers and others concerned with the transportation decision-making process.

We propose a comprehensive approach to evaluate various transportation projects. The proposed framework effectively uses available data and management judgments to systematically and consistently assess and prioritize alternatives. The ANP facilitates decision-making by organizing perceptions, experiences, knowledge and judgments, the forces that influence the decision, into a network framework with a goal, criteria and alternatives of choice.

This methodology makes it possible to model a decision problem taking into account the influences that may exist among its different aspects. In particular, it allows to take into account an aspect that has been frequently observed in real situations: the dependence of the priorities derived for the upper level elements (criteria) from the characteristics of the lower level elements (alternatives). Therefore ANP represents the general model of which AHP is a particular case.

The network structure of ANP makes it possible to model various aspects at stake without concern about what comes first and what comes next. This way of representing the problem, with less constrains than the structure imposed by the AHP, is more similar to real situations where the elements act in a non-hierarchical way.

ANP models a decision making problem as a network of criteria and alternatives (which are all called elements), grouped into clusters. All the elements in the network can be related in any possible way, which means that a network can incorporate feedback and interdependent relationships within and between clusters. This provides a more natural approach for modeling complex environment, such that ANP leads to a more objective concept, for example, "what is the most influential" to the goals. Thus, in the context of this study, ANP offers a high flexibility for modeling and prioritizing risk. ANP can break down more clearly the risk attributes, not limited to the probabilities, but also all possible potential consequences, in more specific criteria. The influence of elements in the network on other elements in that network can be represented in a supermatrix. This is a two-dimensional matrix of elements by elements which adjusts the relative importance weights in individual pairwise comparison matrices to form a new overall supermatrix with the eigenvectors of the adjusted relative importance weights. The ANP comprises four main steps:

1. Conducting pairwise comparisons between the elements.
2. Placing the resulting relative importance weights (eigenvectors) in pairwise comparison matrices within the supermatrix. (unweighted supermatrix)
3. Adjusting the values in the unweighted supermatrix so that it can achieve column stochastic. (weighted supermatrix)
4. Raising the weighted super-matrix to limiting powers until the weights have converged and remain stable. (limit supermatrix)

Case Study

It seems to be necessary Construction of new lines and development of current lines to achieve an efficient rail network in Iran. The human error in the evaluating process will be increasing while there are too many alternatives and large variety of variables and criteria. Thus, studies related to the five executing railroad projects in Iran were reviewed and information needed to compare with each other has been provided by pairwise comparisons. There are many different criteria involved in the process of rail project assessment and effect on their Preferences. It is not possible consideration all of those criteria simultaneously. In a general classification, these criteria can be divided into three main categories of financial, socio-economic and transport.

The algorithm presented in Section 3 is applied to determine the importance ratings within each level by pairwise comparisons. The application is stated in stepwise form below:

To compare the criteria, one responds to this question: "Which criteria should be emphasized more when evaluating these five projects of the Iranian Railway network, and how much more?" Using a pairwise comparison of all pairs with respect to the three criteria, we will obtain the following data using the AHP method, assuming no interdependence between them. These data provide only relative weight without considering independence between the criteria.

Again, by assuming that there is no interdependence between the five projects (P1–P5), they are compared with respect to each criterion and yield a normalized weight with respect to each criterion. (Table 1)

Table 1: Data of five projects to three criteria

	C1	C2	C3
P1	0.058738	0.053155	0.091859
P2	0.263412	0.529462	0.268342
P3	0.109223	0.27756	0.019079
P4	0.21223	0.088141	0.025618
P5	0.356396	0.051682	0.028512

Then, by assuming that there is no interdependence between the three criteria (C1–C3), they are compared with respect to each project and yielding a normalized weight with respect to each project. (Table 2)

Table 2: Data of three criteria to five projects

	P1	P2	P3	P4	P5
C1	0.6657	0.6688	0.7008	0.1087	0.5709
C2	0.2261	0.2059	0.1914	0.4104	0.3241
C3	0.1080	0.1252	0.0705	0.1187	0.1285

Next, we consider the interdependence between the criteria. When we select the revitalization strategies, we cannot concentrate on only one criterion but must consider the other criteria with it. Therefore, we need to examine the impact of all the criteria on each by using pairwise comparisons. We obtain the four sets of weights through expert-group interviews. (Table 3) These data tell us the relative impact of each criterion.

Table 3: Data for the three criteria

	C1	C2	C3
C1	0.6346	0.4482	0
C2	0.3653	0.5517	0
C3	0	0	1

Next, we dealt with interdependence between the alternatives with respect to each criterion and defined the weight matrices. An illustration of the question to which one must respond is ‘‘With respect to satisfying criterion 1, which project contributes more to the effect of project 1 on criterion 1, and how much more?”. (Table 4)

Table 4: Data for five alternatives

	P1	P2	P3	P4	P5
P1	0.3697	0.3237	0.2488	0	0
P2	0.3236	0.5079	0.2527	0	0
P3	0	0	0.2889	0	0
P4	0.0601	0.0260	0.0399	0.5384	0
P5	0.2465	0.1422	0.1695	0.4615	1

Finally, to evaluate the weights of the elements, we used the limiting process method of the powers of the supermatrix. The cluster matrix is then applied to the unweighted supermatrix as a cluster weight and the result is the weighted supermatrix. The weighted supermatrix is raised to a limiting power in order to converge and to obtain a long-term stable set of weights that represents the final priority vector.

Mention should be made to the fact that the model has been developed by means of a specific focus group where experts in the different subjects worked together in the compilation of the pairwise comparison matrices. Particularly, the focus group considers different experts in the fields of transport infrastructures, environmental assessment, urban planning, economic evaluation and social sciences.

Table 5: Limiting Supermatrix

		Criteria			Projects				
		C1	C2	C3	P1	P2	P3	P4	P5
Financial	C1	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Socio-economic	C2	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
Transport	C3	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Isfahan-Arak	P1	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
. Mashhad-Gorgan	P2	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Zanjan-Hamedan	P3	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Isfahan-Ahvaz	P4	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Zabol-Yoonosi	P5	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12

Conclusion

An effective project assessment method helps to ensure optimal resource utilization and greater contribution of projects toward company’s missions and goals. It should be noted that five projects reviewed in this paper and evaluated and ranked: 1. Isfahan-Ahvaz, 2. Isfahan-Arak, 3. Mashhad-Gorgan 4. Zanjan-Hamedan, 5. Zabol-Yoonosi.

The decision-making process is lucid, and allows for feedback and interdependency among various decision levels, criteria, and clusters.

Traditional efficiency measures such as benefit/cost ratio appear analytically objective. It may be misleading to believe that all aspects of a project can be evaluated on a monetary scale. Management nowadays recognizes that the efficiency (monetary) measure should only be part of the evaluation criteria.

A possible drawback of this approach is that when the model becomes large, it could be time-consuming. Yet, when millions/billions of investment dollars are at stake, a structured analysis like the proposed one is deemed necessary to reduce the chance of poor decisions and risks.

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