PRIORITIZATION OF NATIONAL ROAD PROJECTS IN SAUDI ARABIA: FRAMEWORK AND IMPLEMENTATION

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ABSTRACT

Road networks play a major role in sustaining and supporting population and economic growth. They need to be constantly maintained, upgraded and expanded subject to budget constraints, hence the need for a prioritization framework which would help determine the order and timescale for implementing the proposed road schemes. This paper presents a prioritization framework which is being applied to proposed nationwide primary and secondary road projects in the Kingdom of Saudi Arabia. It comprises several stages: data collection, identification of the comprehensive set of proposed schemes, project assessment, and project prioritization. The assessment is based on a multi-criteria analysis (MCA) approach, the linear additive model, which evaluates each scheme on a set of criteria derived from the various national goals and objectives of the Saudi authorities. The relative importance of the criteria (the relative weights) is obtained using the Analytic Hierarchy Process (AHP). The whole process is supported by a Geographical Information System (GIS).

Keywords: National road project prioritization, Multi-criteria Analysis, Analytic Hierarchy Process, Geographical Information System.

1. INTRODUCTION

All transportation networks need to be constantly improved. A highway network must be maintained, upgraded to modern standards, and expanded to provide new road facilities in order to assist the growth in the population and in the economy. As in all investments, when resources are limited, improvement projects must be prioritized in order to allocate resources efficiently. It is no different in transportation. The main component of the prioritization process is to determine how well a transport scheme meets all the country's transport, socio-economic, environment, and political objectives. Given (a) the wide range of policies and objectives; (b) the conflicting priorities that could arise among the different key players (the government departments and regional authorities); and (c) the difficulty in assigning a monetary value to all the economic and non-economic factors, it is necessary to move away from conventional assessment approaches that consider a single criterion such as the cost-benefit analysis and use multi-criteria analysis instead (Tsamboulas, D.A., 2007).

The road network in Saudi Arabia has seen a remarkable expansion and upgrade in the past few years to become one of the largest and most modern road networks in the Middle East. Today, it is more than 51,000 km long and another 5,400km of roads are under construction. The primary and secondary roads constitute nearly half of the whole road network, namely 23,000 km. However, these roads are not equally distributed among the 13 regions of the Kingdom. This is due to varying demand on the network based on the differences in population densities and socio-economic activities in the regions. The demand is expected to change as new socio-economic policies are being implemented thus making the expansion and upgrade of the road network crucial to achieving these goals. The Ministry of Transport (MoT) in the Kingdom of Saudi Arabia is looking for a prioritization framework to be used to evaluate a set of proposed primary and secondary national road schemes and establish a timescale for their implementation over the next 20 years. These schemes total nearly 25,000 kilometers in length and more than $23 billion in cost. They vary widely in nature, including for example the construction of new roads, the upgrade and improvement of existing ones, maintenance and many other types of works. And they span all 13 regions of the Kingdom. This paper describes the development and the implementation of such a framework which uses a linear additive multi-criteria approach where the weights of the criteria are derived using the Analytic Hierarchy Process (AHP). The framework is known as the Saudi Arabia Road Prioritization (SARP) model.

1. KEY PLAYERS' GOALS AND OBJECTIVES

For the development of the prioritization framework, the goals and objectives of all key players had to be established. This was achieved by holding extensive consultations with all interested stakeholders.

2.1. Identification of Key Players

A key player can be defined as any person or body who would have a direct or indirect role in the decision-making process. Foremost among these, in the prioritization of the road

schemes in Saudi Arabia, are the Government and regional authorities. In addition, transport experts including academics have a part to play. The main stakeholder is the Ministry of Transport (MoT) given that it is charged with maintaining, modernizing and expanding the road network in the Kingdom which includes the primary, secondary and tertiary roads. Within the Ministry, the following Departments were involved in the consultation process: Planning and Budget; Studies and Design; Maintenance; Construction; Road Services; Information Technology; Land Transport; and Maritime Transport; as well as the regional departments for roads and transport.
In addition to the MoT, there are other actors in Saudi Arabia who play direct or indirect roles in the development of the road network. Furthermore some of these have information which affects the prioritization of the construction of future road schemes; others have data and information essential to the prioritization process. They are: the Ministries of Municipal and Rural Affairs; Commerce and Industry; Agriculture; Economy and Planning; Water and Electricity, and Petroleum and Mineral Resources; the Central Department of Statistics; Directorate General of Traffic; Saudi Commission for Tourism and Antiquities; Saudi Railways Organization; Customs Department; regional development authorities; and Saudi Arabian General Investment Authority.

2.2 The Establishment of the Goals and Objectives

The study team held a number of meetings with the key players to coordinate between them, identify their goals, objectives and concerns, and collect any information available to them relevant to the prioritization of the proposed road schemes. The team also reviewed several studies and reports, including the National Transport Strategy (NTS) report (Ministry of Transport, 2008), the Saudi Arabian National Transportation Plan III (Santraplan III – Ministry of the Economy and Planning, 2004), and the National Urban Strategy report (Ministry of Municipal and Rural Affairs, 2000). As a result of the consultation process, a list of objectives to be achieved by future road projects in KSA was identified as follows:

1. Improve transport efficiency and connectivity at a local, regional, national and international level in order to support social and economic development (for example in manufacturing, agriculture, tourism, mining, etc), and to promote international competitiveness;
2. Provide good mobility for all people and meet the increase in demand due to rapid population growth and a large and growing segment of the population consisting of well-educated young Saudis;
3. Promote and develop small cities and urban centers throughout the Kingdom in order to ease the pressure from the existing main urban centers and to achieve a better distribution of the population among the 13 regions;
4. Provide efficient and safe transportation services for Hajj and Umrah;
5. Improve safety;
6. Reduce environmental impacts; and
7. Increase accessibility and mobility for National Defense, security, social and emergency assistance services.

Given the varied nature of the objectives it was evident that some of the criteria flowing from them would be difficult to evaluate quantitatively. It would be even more problematic to assign them a monetary value. The next step in the prioritization process was to look at the different tools available to evaluate a set of proposed road schemes.

3. CHOICE OF THE PRIORITIZATION FRAMEWORK

3.1. Overview

Several approaches have been used to evaluate and prioritize road improvement schemes. The most common procedures are:

1. cost-benefit analysis; and
2. multi-criteria analysis.

The advantages and drawbacks of each approach are summarized in the following subsections.

3.2. Cost-Benefit Analysis

Most highway agencies have long used Cost-Benefit Analysis (CBA) to evaluate road projects. CBA is the assessment of all costs and benefits related to a project such as a road scheme. A monetary value is given to all economic and noneconomic factors. The option is then evaluated using an economic index such as Net Present Value (NPV), Benefit-Cost ratio (B/C), and the Internal Rate of Return (IRR) (Avineri, E. et al., 2000). It provides a very good method when financial constraints are crucial. Social benefits are included in CBA where they are expressed in monetary terms, the most important being travel time savings and accident reduction. The task of converting these parameters to monetary terms is, however, very difficult (Kulkarni, R.B. et al., 2004). The impacts on the environment are even more problematic to convert to monetary values (Department for Communities and Local Government, 2009; Kulkarni, R.B. et al., 2004; Morisugi, H., 2000; Ongprasert, S. et al., 2003).

In general, CBA is a good method to evaluate a small number of alternatives at a fixed location (for example in determining the best alignment for a single corridor). However, it has its limitations when dealing with nationwide / region-wide improvement projects (Kulkarni, R.B. et al., 2004; Ongprasert, S. et al., 2003; Tsamboulas, D.A., 2007) for the following reasons:

1. These projects are usually diverse in nature (new road, road widening, geometric improvement, capacity improvement, etc...) and CBA cannot include all the potential benefits resulting from such schemes as some of the impacts are too difficult to measure in monetary terms; and
2. Some of these projects are proposed because they would improve access to remote and badly served areas. CBA cannot take into account the needs of these areas and might reject such projects because of their higher costs.

It is therefore necessary to move away from CBA and apply an approach that can take into account the different impacts and needs of a project without having to assign a monetary value to each impact. The multi-criteria analysis approach meets these requirements.

3.3. Multi-Criteria Analysis

Multi-criteria analysis (MCA) consists of the evaluation of a number of strategic criteria derived from the goals and objectives of the key players. These criteria can either be subjectively analyzed or technically quantified, which is the main advantage of this approach, and hence all impacts can be evaluated including those that can only be analyzed subjectively (Kulkarni, R.B. et al., 2004). In short, MCA can deal with the difficulties facing decision-makers in handling a large amount of complex information, including quantitative and qualitative data, in a consistent way (Department for Communities and Local Government, 2009).

MCA models are used in various situations where different decisions are to be made: identification of the most preferred option among several alternatives; ranking and prioritizing options; identification of a number of options for a more detailed appraisal; or sorting between acceptable and unacceptable options. They bring a degree of structure, analysis and openness to different types of decisions that lie beyond the practical reach of CBA (Department for Communities and Local Government, 2009).

A wide range of approaches is used in multi-criteria analysis. What they have in common is that they consider the scheme performances on the different criteria explicitly and require the use of judgment. Where they differ is the way in which they combine the data. The formal technique is usually to use a relative weighting system for the different criteria (Department for Communities and Local Government, 2009).

In deciding which type of MCA technique to use, key players consider the type of decision to be made, the time available to carry out the analysis, the available data, and the analytical skills of the users of the model and their requirements (Department for Communities and Local Government, 2009). Decision-makers also take into account the number of schemes to be evaluated.

The heart of the MCA approach is the assessment table. It displays the performance values, quantitative or qualitative, of each scheme on each criterion. How the basic information in this table is analyzed differs from one MCA approach to the other (Department for Communities and Local Government, 2009).

The study team reviewed several MCA methodologies including the simple approach, the Linear Additive Model (Department for Communities and Local Government, 2009), the Goal Achievement Matrix approach (Berechman, J. et al, 2005; Shefer, D. et al.,1990), the Need-based approach (Kulkarni, R. et al., 2004), the Multi-Attribute Utility theory (Ballestero, E. et al., 2003), the fuzzy sets theory (Avineri, E. et al., 2004; Department for Communities and Local Government, 2009), and others.

3.4 The Chosen Approach

The various approaches used in the evaluation of a number of schemes can be classified into two broad categories which involve: monetary or non-monetary evaluation; and one or multi-criteria. Given the wide range of objectives that were established from the various concerns of the key players, the diversity in nature and in geographical terms of the schemes to be assessed, and the difficulty in assigning a monetary value to all economic and non-economic factors, the chosen approach had to involve a non-monetary, multi-criteria evaluation. In addition, it had to:

1. Give a precise score for each scheme in order to facilitate the prioritization of all the schemes;
2. Be simple enough for non-experts to use in order to evaluate any set of schemes in the future, but not so simple as to lose precision;
3. Be transparent, again for ease of use and ability to prioritize the set of schemes;
4. Require data that is relatively easy to collect; and
5. Be able to deal with a large number of schemes.

The main MCA approaches that do not require the conversion of all factors to monetary values were then compared for precision, simplicity, transparency, type of data requirements, and the ability to assess a large number of schemes. The Linear Additive approach fulfilled all these requirements and was thus chosen as the main tool for the assessment and prioritization of the different road schemes in the Kingdom. The other approaches were deemed either too simple, unable to deal with a large number of schemes in a systematic way or unsuitable for use by non-experts in the future.
The Linear Additive model consists of calculating the overall value score of a proposed road scheme by adding its weighted score on a set of criteria:

$$S_i = \sum_{j=1}^{n} w_j s_{ij} = w_1 s_{i1} + w_2 s_{i2} + \dots + w_n s_{in} \qquad (1)$$

where S_i is the total value score of scheme i; w_j is the relative weight of criterion j; s_{ij} is the value score of scheme i on criterion j; and n is the total number of criteria. It should be noted that the relative weights of the criteria should add up to unity:

$$\sum_{j=1}^{n} w_j = 1 \qquad (2)$$

It is a full compensatory model i.e. a low score of the scheme on one criterion may be offset by a high score on another. The degree of compensation between the criteria is determined by their relative weights. Some of the weighting methods available to derive relative weights are discussed in the following section. It should be noted that although this approach is transparent and can cope with different problems in different circumstances, it has its limitations, namely that criteria weights and scores can rely heavily on expert judgment. However, the methodology was verified independently by different members of the study team in order to reduce the effect of subjectivity. In addition sensitivity analysis has been carried out to test the reliability of the results.

3.5 Weighting Methodology

As the assignment of weights relies heavily on the judgment of the different key players (stakeholders and experts), methods have been developed to deal with the problem of subjectivity and to move away from open-biases towards certain criteria. The most widely used methods are Saaty's AHP/Eigenvector, Trade-Off and Swing Weighting. The following is a summary of the advantages and drawbacks of each method.

2.5.1 Saaty's AHP / Eigenvector

Saaty's AHP/Eigenvector is a widely accepted method which is based on the hierarchical representation of the criteria and on the comparison of these criteria in pairs ("pairwise comparison") (Department for Communities and Local Government, 2009; Hochbaum, D.S. et al., 2006; Saaty, T.L., 1980; Hiroyuki, T., 2000; Tsamboulas, D.A., 2007). The hierarchical representation can be thought of in terms of a value tree hierarchy. It is systematic, simple to implement, and transparent. However, it may have some shortcomings, namely inconsistency and 'rank reversal'.

2.5.2 The Trade-Off Method

The Trade-Off method (Diakoulaki, D. et al., 2004; European Commission, 1998; Ongprasert, S., et al., 2003) also consists on pairwise comparisons of criteria. However, for each pair, two hypothetical schemes are considered, a scheme which performs best on one criterion but worst on the other and vice-versa for another scheme. The relative weight is then derived based on how much the key player is willing to trade-off from one criterion to improve the other to its best level. This method has a significant advantage, namely its high sensitivity to the performance range of each criterion thus making it the best method to use when choosing the best alternative among a set of alternatives along a same route. However, it has some disadvantages: (a) it is not very transparent, (b) inconsistency is a problem and (c) it is difficult to elicit key players' preferences especially where there is a large number of criteria (the pairwise comparisons have to be carried out at the lowest level in the hierarchy i.e. for sub-criteria of all the criteria together, not divided into segments as in the case of AHP).

2.5.3 The Swing Method

Swing weighting (Diakoulaki, D. et al., 2004; European Commission, 1998) is based on two extreme hypothetical schemes W and B. Scheme W represents the worst performance on all criteria (using the worst score of all the schemes being examined on each criterion) and scheme B represents the best performance. When using this method, the performance of all the schemes to be assessed on each criterion must be established before the weights can be derived. Therefore, one drawback of this method is that the weights have to be derived every time a new scheme is to be examined which falls outside the initial performance range of the criteria. It is however a simple and transparent way of eliciting key players' preferences, it normally avoids inconsistencies and can handle a large number of criteria.

2.5.4 The Preferred Method

After examining the most widely used weighting methods, the Saaty's AHP/Eigenvector method was found to be the most appropriate in the current context for the following reasons:-

1. it is simple, straightforward and transparent;
2. the weights do not have to be derived again if a new scheme is to be examined (as is the case with the Swing weighting method);
3. the processing of a large number of criteria can be overcome by dividing the task into a series of small sets of pairwise comparisons to be carried out within each segment of the hierarchy (which cannot be done in the Trade-Off method);
4. the aim of the study is to prioritize a number of nationwide/region-wide proposed road schemes that differ in nature, and to assist in the determination of a timescale for their implementation. It is not to determine the best alternative among a certain number of alternatives on a specific route (where the Trade-Off and Swing Weighting methods would have been preferred).

However, as discussed above, Saaty's AHP/Eigenvector method may have some drawbacks, namely inconsistency and 'rank reversal'. First, inconsistency becomes a problem when the number of criteria being compared exceeds 4. However, this shortcoming can be mitigated by: (a) limiting the number of criteria on each segment of the value tree to a minimum and carrying out several series of pairwise comparisons at each segment; and (b) explaining each criterion and how the proposed schemes are expected to perform on each one of them before the key players cast their judgments about the relative importance of the criteria, thus making the key players' task easier and less prone to inconsistency. Second, the 'rank reversal' phenomenon may occur when adding or deleting a scheme / criterion. It is due to the change in the key players' priorities before and after the addition or deletion is made (Wang, Y-M. et al., 2003). Experience shows that this phenomenon is most likely to occur in complex hierarchies with more than 3 levels (Perez, J. et al., 2002). In addition, it may occur when an irrelevant scheme is added or an inconsequential criterion (on which all schemes have similar performances) is added. That is why the 'rank reversal' phenomenon arises when the scale of the scores of the schemes on the different criteria are not related consistently to the associated weight. Therefore, the mitigation measures on inconsistency, (a) and (b) above, should greatly minimize the occurrence of the 'rank reversal' phenomenon. In addition, the hierarchy of the proposed model to be used in the study does not have more than 3 levels, and AHP is not used to determine the overall ranking of the schemes (the latter is done using a linear additive model) thus making 'rank reversal' an unlikely problem.

4. IMPLEMENTATION OF THE PRIORITIZATION FRAMEWORK

4.1 Overview

The Ministry of Transport in the Kingdom of Saudi Arabia is responsible for the improvement and expansion of the national road network necessary for accommodating and supporting population and economic growth. Until now, decisions regarding proposed road schemes have been dealt with on a case by case basis. Some schemes have been judged on transport and/or economic assessments, while others have been proposed without a systematic analysis. The MoT therefore requires a prioritization framework which can be applied to all its proposed primary and secondary road schemes. The framework follows the Linear Additive model to evaluate the schemes with the relative weights being derived using Saaty's AHP/Eigenvector method. It is called the Saudi Arabian Road Prioritization (SARP) model. Its implementation involved several building blocks: (i) data collection; (ii) review of the road schemes proposed by the MoT and establishment of a comprehensive set that would accommodate and support all the objectives of the Kingdom; (iii) definition of the criteria based on the objectives of the key players; (iv) derivation of the relative weights of the criteria; and (v) scoring of the schemes on all the criteria.

Once the building blocks were in place, a weighted score was obtained for each primary road scheme, and was used to rank them according to priority. Sensitivity analysis on the relative weights was then performed before a set of schemes was chosen to be implemented during the first phase of the 20 year road network development programme. At the time of writing, the secondary road schemes are being ranked by region, after which a set will be allocated to the first five-year phase. The whole process will then be repeated based on the assumption that the selected schemes are already in place. This will result in another set of schemes being chosen to be implemented in the second phase. The process will continue until the schemes are prioritized and slotted into the different implementation phases. Given the large number of schemes to be prioritized, the study team devised a semi-automated algorithmic approach to carry out the prioritization process automatically. This process is illustrated in Figure 1. These steps remain work in progress.

4.2 Data Collection

An extensive collection of data was undertaken involving the various key players. Some of the data was readily available; other data was calculated or derived. It consisted of:

1. transport demand and supply data of the transport networks including types of roads, existing and future annual average daily traffic on a big section of the road network, existing and future traffic arising from Hajj and Umrah, current and expected level of service (LOS), percentage of freight traffic, bus passenger levels as well as existing and proposed railway lines and their connectivity to the road network;
2. socio-economic data that have a direct and indirect effect on the traffic along the road network including data on population and economic sectors such as agriculture, manufacturing, tourism, Economic Cities, and mining; and

3. information from the national urban strategy plan on the regions, corridors and urban centers to be developed.

The objective of the exercise was: (a) to assess the existing situation of the primary and secondary road network; (b) to identify the existing traffic levels on a large part of the road network; (c) to estimate the future traffic levels; (d) to examine how well the existing road network serves the population and the different economic sectors and how it would do so in the future; and (e) to determine how well the existing road network supports the current and future urban development trends. This exercise was paramount to establish the comprehensive set of road schemes which were to be prioritized.

4.3 Identification of the Proposed Roadway Schemes

The Kingdom of Saudi Arabia has an existing primary and secondary road network consisting of 23,000 km of roads which covers all 13 regions and serves a big proportion of the transport demand between population and urban centers. However, there are wide differences between the regions in terms of the distribution of the roads due to vast variations in population densities and traffic demand. In general, the condition of the existing roads in KSA is very good and most have a high level of service which shows that there is capacity within the road network to deal with an increase in demand over the next 20 years. In addition to the existing primary and secondary roads, there are around 18,000 km of roads that are under construction or being upgraded. These schemes also include road proposals that have been approved by the MoT and that will be implemented in the near future.

In order to further develop the network, the MoT has proposed a number of schemes totaling more than 25,000 km of primary and secondary roads with an estimated cost of $23 billion. These include a wide variety of works: (a) the construction of new roads (single carriageways, dual carriageways and expressways), (b) the upgrade of existing ones (from single carriageway to dual carriageway, or to expressways), (c) the improvement and widening of existing roads, and (d) other minor works such as lighting, pedestrian and animal crossings, fencing, resurfacing, etc.

The objective of this phase of the study was to examine and prioritize all the proposed schemes and to assess whether they would cover all the future needs and objectives of the Kingdom. The assessment consisted of several screening levels. These determined how well the proposed schemes would:

1. cope with the increase in traffic demand resulting from population and economic growth;
2. improve the connectivity of the road network as a whole (making sure that all primary and secondary roads would interconnect and form an integrated whole, thus adding any missing link in the primary and secondary road network; and ensuring that the road network would serve all regions and connect to the neighboring countries' road networks);

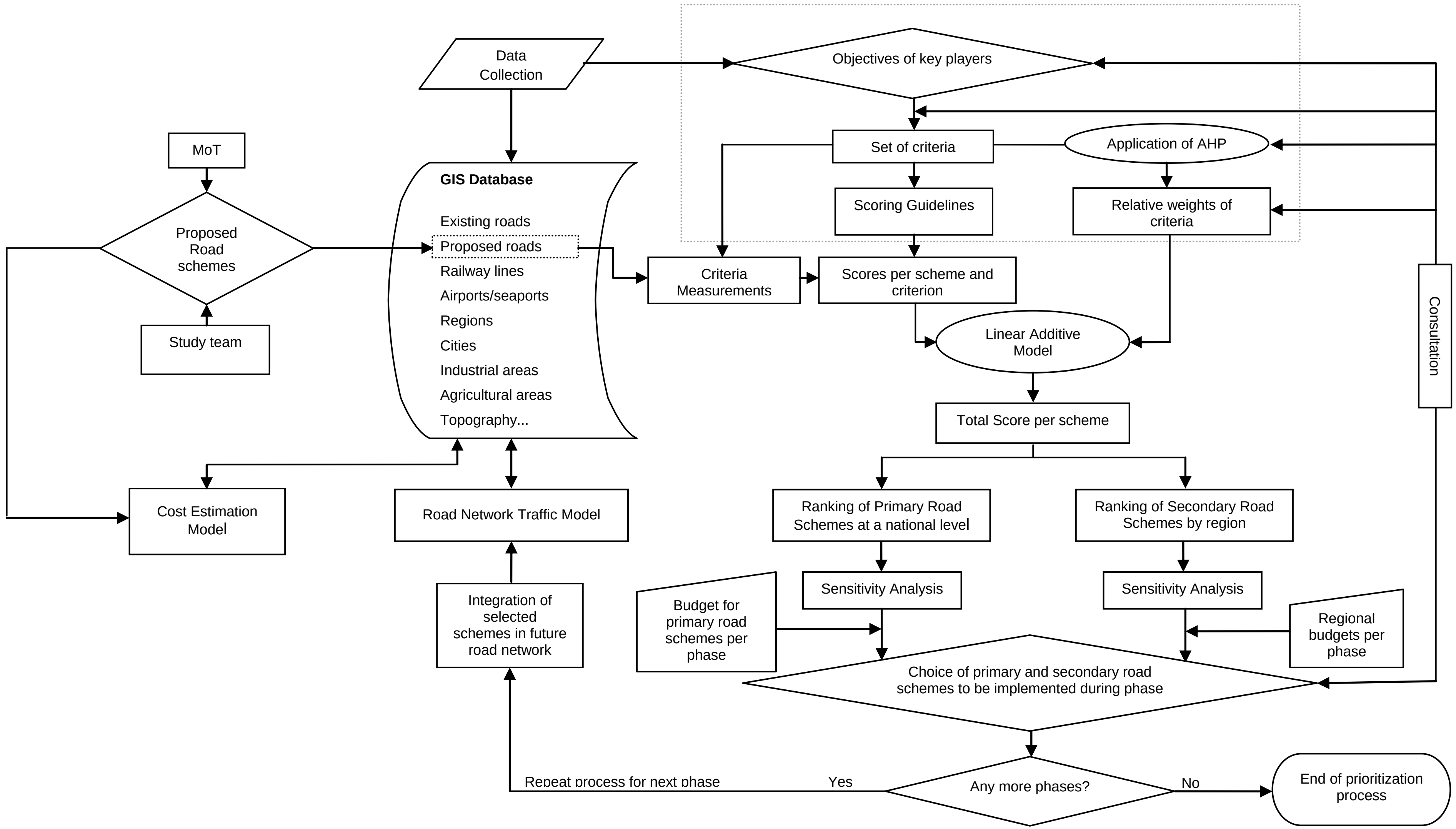

Figure 1 – The Prioritization Process

3. improve the connectivity with other modes of transport, namely, airports, seaports and the railway network;
4. serve existing and future economic activities (in agriculture, manufacturing tourism, Economic Cities, mining and other activities);
5. support the objectives of the Urban Development Strategy plan, the military strategies and other national security strategies;
6. serve Umrah and Hajj traffic; and
7. help to improve safety levels on the roads.

The screening resulted in a number of the proposed schemes being modified and new schemes being added to form a comprehensive set. This includes 36,394 km of roads to be built or upgraded of which 18,103 km (approximately 50%) are primary roads, 14,875km (41%) are secondary roads, and 3,416 (10%) are military and border roads. The geographical distribution of the proposed schemes shows the highest percentage in the region of Riyadh (20%) where the capital is located. It is followed by the Eastern region (13%), a major industrial area and the Makkah region (10%), the cradle of Islam, which is subject to additional traffic arising from Hajj and Umrah.

The schemes, excluding minor works, comprise 30,500 km of roads. Their distribution among the various types of works is illustrated in Figure 2. This figure shows that 36% of the schemes involve upgrades to dual carriageways, 22% upgrades to expressways, 15% new single carriageways, 11% new dual carriageways, 8% new expressways, 4% new ring roads, and 4% widening and general improvement of the existing roads. What this paper covers is the prioritization of these major works schemes which total approximately 530 in number.

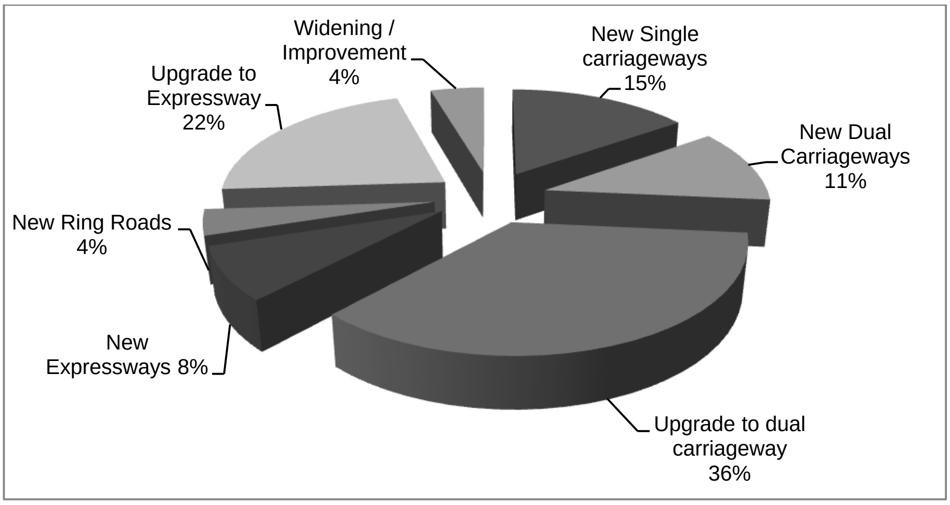

Figure 2 – Distribution by total length of the proposed schemes according to type of works

4.4 Definition of the criteria

This stage consisted of defining an exhaustive set of criteria that would reflect all the objectives of the key players established at the beginning of the study. The criteria were represented in hierarchical form and care was taken to limit their number to a minimum on each segment of the hierarchy tree. Attention was also given to avoid any overlapping, and to ensure (a) that each criterion was defined clearly enough to be assessed, and (b) that all the criteria were mutually preference independent. A criterion is considered preference independent from another when the score of a scheme on that criterion can be assigned without knowing what the score of that scheme is on any other criterion. If all criteria are preference independent from all other criteria then they are said to be mutually preference independent. A preliminary set was defined which was then put forward to the key players during a first round of consultations. This resulted in some criteria being added and the hierarchy slightly modified to include all the changes. During another round of consultations, a final set of criteria was agreed by all the relevant stakeholders. The selected criteria were grouped into 5 main criteria (Group Criteria) reflecting the broad objectives of the key players: A- Road Network Development; B- Socio-Economic Development; C- Economic Efficiency; D- Serving Hajj and Umrah; and D- Other Criteria including Security, Safety, and Environment relating to three key goals of the MoT. Each main criterion was then divided into primary criteria, some of which were divided further into secondary criteria, thus resulting in a three level hierarchy (see Figure 3).

4.5 Derivation of the weights

The next stage of the study was to derive the relative weights of each criterion in each segment of the hierarchy tree. The first step was to develop a questionnaire in which the key players would provide their pairwise comparisons. It was divided into 7 main sections:

1. the purpose of the questionnaire explaining the objective of the exercise;
2. an overview depiction of the schemes that were identified for prioritization;
3. a detailed description of each criterion and how the schemes were expected to perform on it;
4. the steps to be taken in order to fill out the questionnaire;
5. the preliminary ranking of the criteria to be filled out by the key players which would help them keep their judgments consistent during the pairwise comparisons exercise; and
6. the pairwise comparisons to be provided by the key players. An example is given in Figure 4. The two criteria to be compared are located on either side of the scale. The middle position corresponds to the situation where both criteria are considered equally important. The closer we move towards one criterion along the scale, the more important that criterion is considered over the other.

A panel of MoT managers, transport professionals and academics, 16 in total, gathered for a workshop during which they were invited to give their judgments on the relative importance of the different criteria. Each key player provided pairwise comparisons for each segment of the hierarchy tree. These were then refined and synthesized using Matlab and Excel. Once the weight set was calculated for each decision maker, the one for the entire group was derived using: (i) the conventional AHP method and the Aggregation of Individual Priorities (AIP) (Saaty, T.L. et al., 1985, Saaty T.L. et al., 2001) for most of the criteria; and (ii) the Vector Space Formulation of AHP (VAHP) method (Zahir, S., 1999) for the criteria on one segment of the tree because the data was unstable. During a second round of consultations, the resulting set of weights was circulated to the panel of MoT managers and transport experts for comments and finalization. Figure 3 illustrates the final set of weights. It shows two weights for each criterion, at the group, primary, and secondary levels. The one to the left is the absolute weight within the segment to which the criterion belongs. Note that the weights for the criteria within the same segment should add up to unity. The one to the right is the relative weight which will be used to derive the overall score for each scheme. Note that the total weights of all the criteria that will be scored should add up to unity. These are to be found at the secondary level, or at the primary level where there is no secondary level.

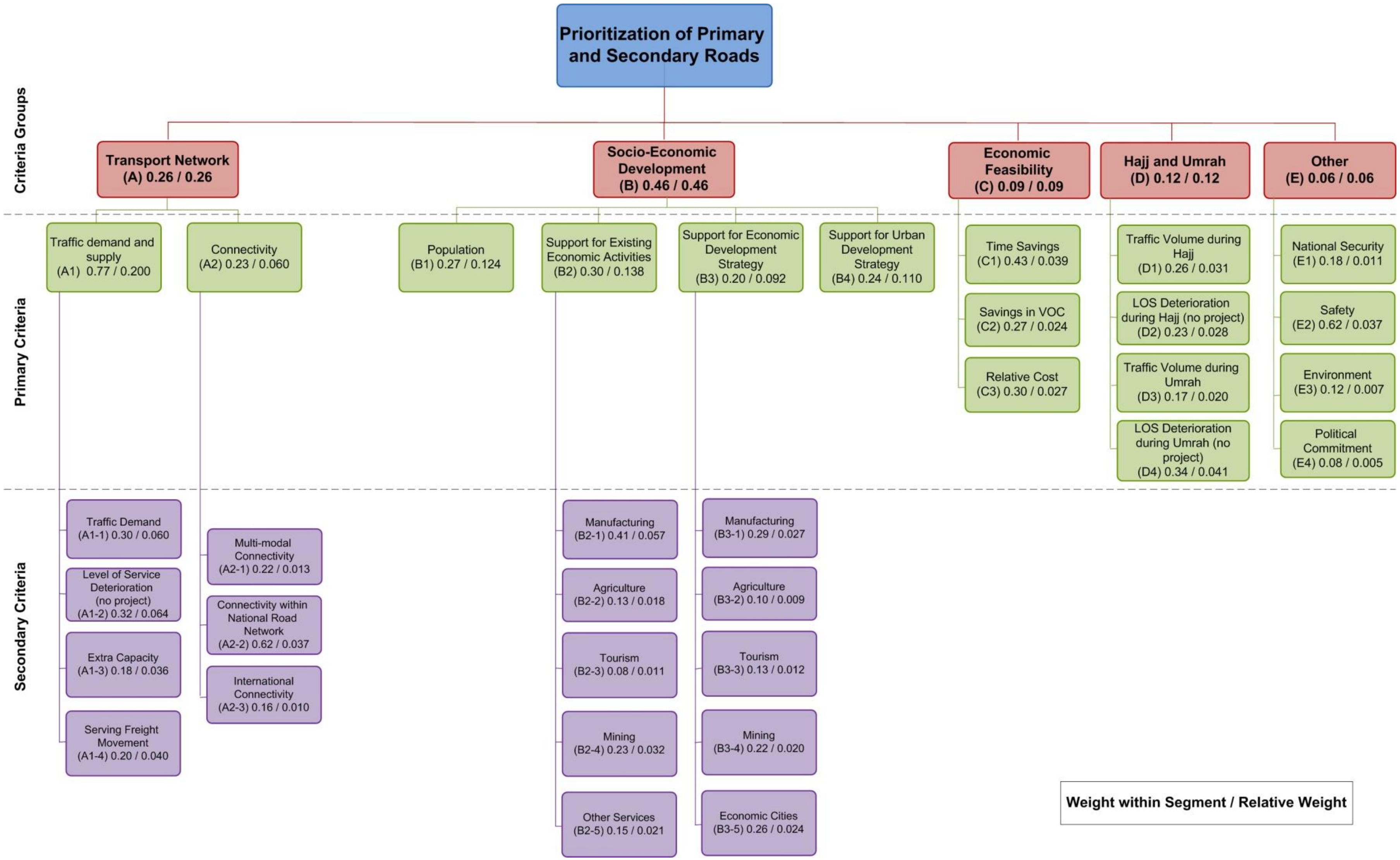

Figure 3 – The hierarchy of the set of criteria

In developing the weights associated with the various criteria, it was interesting to identify any differences in judgments between the groups of individuals who filled out the questionnaire and completed the pairwise comparisons. For that purpose, the weights resulting from the judgments provided by the following two groups were identified: (a) MoT managers, and (b) experts on the study team. Appreciable differences in weights were mainly found at the primary and secondary levels of the criteria; and were insignificant at the group level. These differences could be a basis for future sensitivity analysis.

Pairwise Comparisons										
Secondary Criteria										
Traffic Demand (Future Traffic Volume on the road - AADT)	Extremely more important	Very strongly more important	Strongly more important	Moderately more important	Equally important	Moderately more important	Strongly more important	Very strongly more important	Extremely more important	Level of Service deterioration in case project is not implemented (LOS & V/C)
Multi-modal Connectivity	Extremely more important	Very strongly more important	Strongly more important	Moderately more important	Equally important	Moderately more important	Strongly more important	Very strongly more important	Extremely more important	Connectivity with National Road Network
	Extremely more important	Very strongly more important	Strongly more important	Moderately more important	Equally important	Moderately more important	Strongly more important	Very strongly more important	Extremely more important	Connectivity with International Road Network
Connectivity with National Road Network	Extremely more important	Very strongly more important	Strongly more important	Moderately more important	Equally important	Moderately more important	Strongly more important	Very strongly more important	Extremely more important	

Figure 4 – Extract showing pairwise comparisons from the questionnaire

4.6 Scoring of the Schemes

4.6.1 Overview

One of the advantages of the MCA methods is that the criteria can be measured either quantitatively or qualitatively. In this study, some of the criteria were measured directly using either available data or derived data (through simple calculations and/or from models such

as the National Road Network model and the cost estimation model); others were given qualitative attributes using expert judgment. The measured performances on each criterion were then converted to scores using a numerical scale ranging from 0 to 5 where 0 was assigned to reflect the least preferred possible performance on a criterion and 5, the most preferred possible performance. Any performance outside this range, whether below or above, would score 0 and 5 respectively. The intermediate scores were then established using two different methods. The first used value functions. They were applied to some of the criteria which were assessed quantitatively. The second method involved assigning discrete scores between 0 and 5. It was used on some of the criteria which were assessed quantitatively and on all the criteria that were evaluated qualitatively.
On the whole, the value functions consisted of piecewise linear functions where linearity was assumed between two discrete scores. Several functions were developed for each criterion under assessment. The preferred function was chosen with a view to achieving: (i) a greater discrimination in the scores; (ii) a limited number of schemes falling above the most preferred possible performance (which corresponded to a score of 5), and (iii) a good distribution of the schemes between 0 and 5.

4.6.2 GIS Database

Given the huge amount of data required, collected and derived for the study, the study team used a GIS database to house all this information. This database was developed and employed throughout the different stages of the study. For example, it was drawn on to establish the comprehensive set of schemes to be prioritized and greatly facilitated the task of gathering all the input required to score the proposed schemes on each criterion. The data contained in the GIS database was stored in different layers and included:

1. name and code of the proposed road scheme;
2. administrative region in which the scheme is located;
3. road category (primary, secondary, tertiary);
4. type of road (single carriageway, dual carriageway, expressway)
5. type of proposed works (new construction, upgrade, widening, minor works etc...);
6. number of lanes;
7. overall length of road and length of parts of the road in terrain with different topographic attributes (flat, rolling, mountainous);
8. estimated cost of the scheme;
9. cities, towns and villages served by the road;
10. predicted annual average daily traffic (AADT) along the road;
11. location of transport facilities for different modes such as seaports, domestic and international airports, existing and proposed railway lines;
12. who proposed the scheme; and
13. general comments on the proposed scheme.

4.6.3 National Road Network Model

A road network model was developed to include the whole primary and secondary road network of the Kingdom of Saudi Arabia. It was used to derive base, seasonal (Hajj and Umrah), as well as future traffic and to establish the traffic levels on (and benefits of) each proposed road scheme. In other words, it provided the data required to calculate the performances of the schemes on many of the criteria. The base-year model was developed based on available national road network base maps, origin-destination data (Santraplan III), and recent traffic counts on national roads (MoT). The future road network reflected the implementation of proposed road projects; future travel demand levels were estimated based to a large extent on data available from Santraplan III.

4.6.4 Cost Estimation Model

A cost estimation model was developed to predict the construction cost of each proposed scheme. The estimation was based on the road type, on the kind of works to be carried out, and on the topography of the area through which the road scheme would pass. A cost per kilometer of road was estimated for each road type/works category: new single carriageway; new dual carriageway; new expressway; new ring road; upgrade to dual carriageway; and upgrade to expressway. The cost was divided into several components: (i) pavement cost which differed for single carriageways, dual carriageways and expressways because the thickness of the pavement varied according to the AADT levels expected on the road (following the MoT's code for pavement construction); (ii) cut and fill cost which depended on the topography of the area through which the scheme would pass (a relatively flat area of no more than 1% in slope, an area with a slope varying between 10 and 30%, and a mountainous area with a slope greater than 30%); (iii) cost of works related to safety such as barriers, medians, markings, signs; (iv) drainage and lighting costs; and (v) cost of pedestrian and animal crossings for expressways and ring roads.

4.6.5 Examples of Scoring on Some Criteria

The text below provides examples illustrating the scoring of four criteria, namely, A1.2 *Level of Service*, B1 *Population*, C3 *Relative Cost Indicator*, and E4 *Political Commitment* using different approaches. A1.2 was scored quantitatively using discrete scores, B1 and C3 were scored quantitatively using a value function, and E4 was scored qualitatively using discrete scores.

A1.2 *Level of Service* criterion reflects the deterioration in the level of service (LOS) on the alternative road if the proposed road scheme was not implemented. The LOS was derived from the Volume/Capacity ratio (V/C). Two values of LOS were calculated: (i) if the scheme were to be implemented; and (ii) if the scheme were <u>not</u> to be implemented. Figure 5 shows an example of an alternative route considered in the study. The calculation of the volume was based on the future directional AADT (drawn from the National Road Network Model). The capacity depended on the number and capacity of the lanes. Table I shows the corresponding LOS for each V/C range. The scoring for criterion A1.2 is given in Table II.

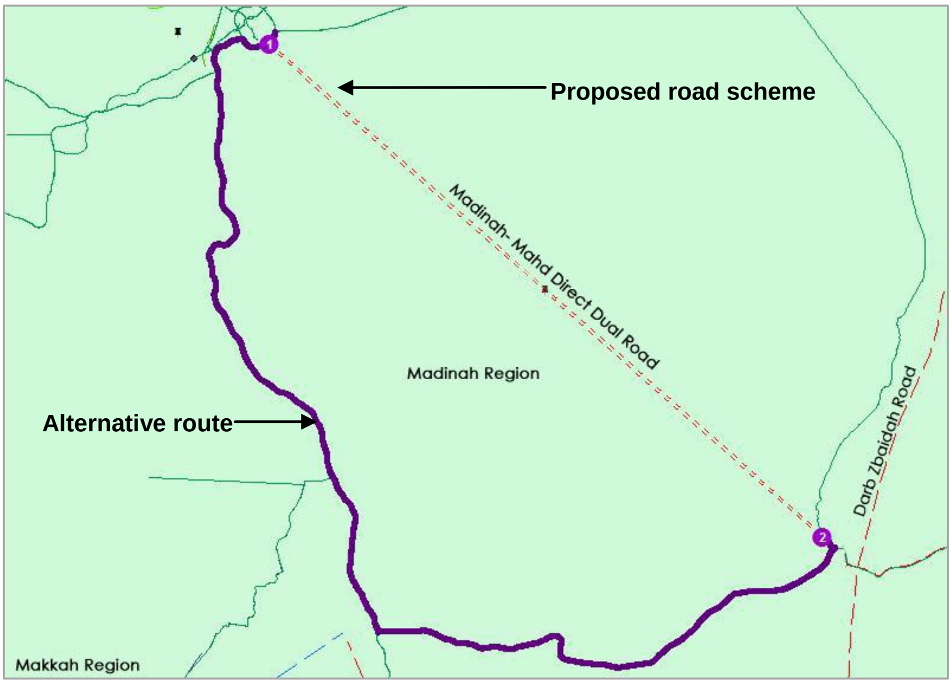

Figure 5 – Example of an alternative route

Table I – Derivation of LOS from V/C

LOS	V/C
A	Less than 0.3
B	Between 0.3 and 0.55
C	Between 0.55 and 0.75
D	Between 0.75 and 0.9
E	Between 0.9 and 1
F	Greater than 1

Source: HCM, TRB, 2000

Table II – Scoring of criterion A1.2 *Level of Service*

<table>
<tr><th>LOS on the alternative route if proposed road scheme was not implemented</th><th>LOS on the alternative road if proposed road scheme was implemented</th><th>Score</th></tr>
<tr><td>A</td><td>A</td><td>0</td></tr>
<tr><td>B</td><td>A</td><td>1</td></tr>
<tr><td>C</td><td>A or B</td><td>2</td></tr>
<tr><td rowspan="2">D</td><td>C</td><td>3</td></tr>
<tr><td>B or A</td><td>4</td></tr>
<tr><td rowspan="3">E</td><td>D</td><td>3</td></tr>
<tr><td>C</td><td>4</td></tr>
<tr><td>B or A</td><td>5</td></tr>
<tr><td rowspan="3">F</td><td>E</td><td>3</td></tr>
<tr><td>D</td><td>4</td></tr>
<tr><td>C, B or A</td><td>5</td></tr>
</table>

B1 *Population* indicates the number of inhabitants that could be served by the new/upgraded road if the scheme were to be implemented. This is measured by considering the total number of inhabitants living within a buffer zone of 20 km from the road for primary roads and 10 km for secondary roads, calculated using population densities. Figure 6 shows the value function used to convert the number of inhabitants served by the scheme to a score between 0 and 5. A Score of 0 corresponds to 0 inhabitants and a score of 5 corresponds to 350,000 inhabitants or more. This function was derived by ranking the schemes according to the number of inhabitants being served by the scheme and then allocating the bottom 20 percentile to the 0-1 score range, the second 20 percentile to 1-2, and so on. It should be noted that the corresponding ranges of the number of inhabitants were slightly modified in order to provide greater variation of the scores within each range and to limit the number of schemes falling above the range 5 threshold (350,000 inhabitants). As explained above, linearity was assumed within each range which resulted in a piecewise linear function.

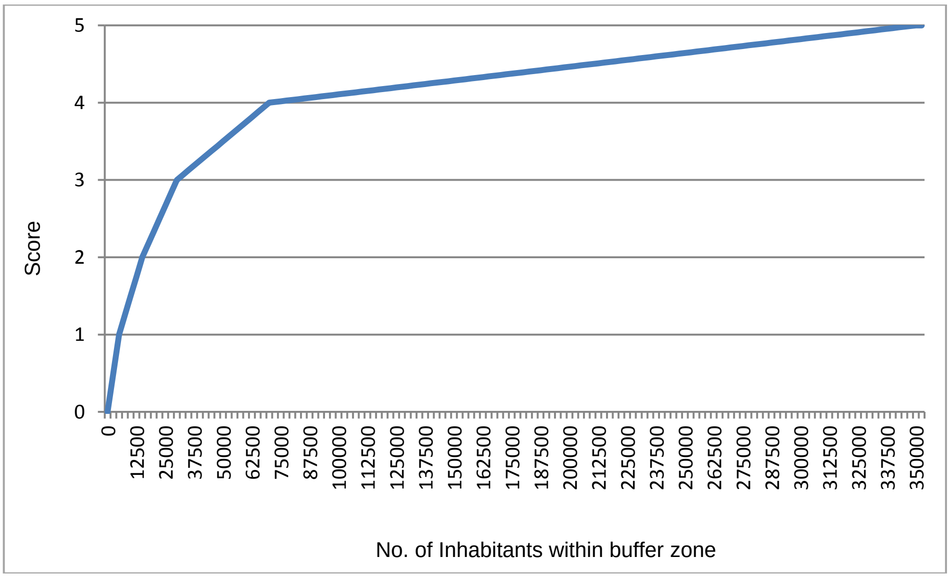

Figure 6 – Value function for criterion B1 *Population*

C3 *Relative Cost Indicator* is the cost of implementing the road scheme per projected annual vehicle-kilometers travelled along the road:

$$\mathrm{RC} = \frac{\mathrm{Cost}}{\mathrm{AADT} \times 365 \times \mathrm{Length}} \quad (3)$$

where RC is the relative cost indicator; Cost is the total cost of implementing the road scheme obtained from the Construction Estimation Model; AADT is the predicted annual average daily traffic on the road if the scheme is implemented drawn from the National Road Network Model; and Length is the total length of the scheme.

The Relative Cost Indicator is higher, the higher the cost of implementing the scheme and/or the lower the amount of traffic predicted on the road. The value function used to convert the cost per annual vehicle-kilometers travelled to a score between 0 and 5 is shown in Figure 7. A Score of 0 corresponds to 60 Saudi Riyals per annual vehicle-kilometers travelled and a score of 5 corresponds to 0.5 Saudi Riyals per annual vehicle-kilometers travelled. Note that the value function has negative slopes. This is explained by the fact that the higher the cost per annual vehicle-kilometers travelled, the less attractive the scheme would be.

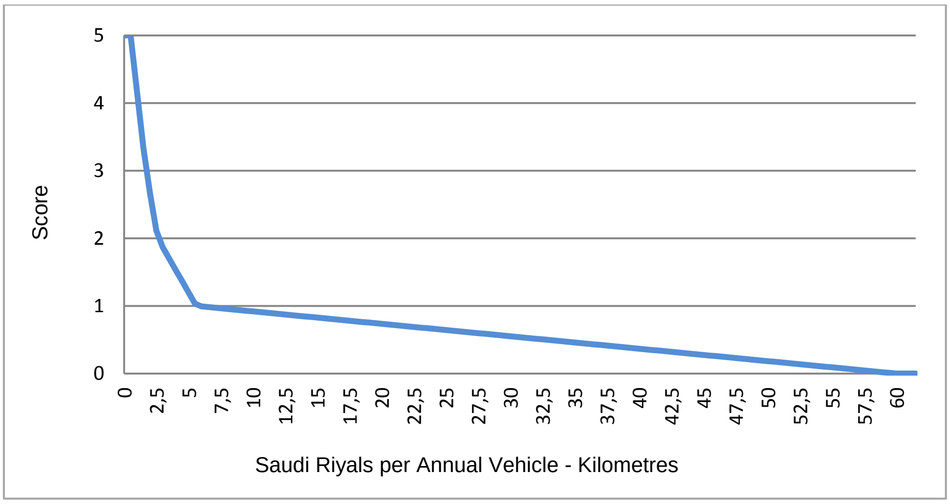

Figure 7 – Value function for criterion C3 *Relative Cost Indicator*

E4 *Political Commitment* indicates how supportive the authorities are of implementing the road scheme. It deals with “political” issues which should not be overlooked when selecting transport schemes. The scoring on this criterion is an example of a qualitative measurement. Responsibility for making this judgment lay with the MoT. The scoring of E4 is given in Table III.

Table III – Scoring of criterion E4 *Political Commitment*

Political Commitment	**Score**
Very high	5
High	4
Medium	3
Low	2
Very low	1
No commitment	0

4.7 Prioritization of the Schemes

4.7.1 Ranking of the schemes based on total scores

Once the scores of each road scheme on all the criteria were derived, the total score was calculated for each scheme using equation (1). The schemes were then divided into two groups based on the road category: primary and secondary roads. Primary roads are defined by the MoT as those that:

1. serve national and international traffic with a high percentage of the trips being long distance;
2. serve all major urban areas of the Kingdom and link important traffic destinations; and
3. form a linked network without major gaps.

Secondary roads are defined as those that:

1. serve traffic between the regions consisting mainly of trips shorter than those on primary roads;
2. serve large towns which are not on the primary road network; and
3. receive traffic from the tertiary road network directly.

As the primary road schemes spanned several regions and the secondary road schemes were more contained within the regions, the study team decided to prioritize the former at a national level and the latter at a regional level. At the time of writing, the primary road schemes have already been ranked based on the calculated total scores. A list of the top 20 schemes with the highest total scores was then derived.

4.7.2 Sensitivity Analysis

Sensitivity tests were carried out to evaluate the robustness of the SARP model. The study team looked at the criteria which contributed the most to the total score for each of the schemes in the top 20 list. An identification of the three criteria that contributed the most to the weighted score for each of the top 20 schemes demonstrated that criteria B1 and B4 were, in most cases, the highest contributing factors. The subsequent sensitivity analysis consisted of reducing the weights of these two criteria by half in two separate exercises. The balance of the weight was then distributed proportionally to the weights of the other criteria so that equation (2) would still be met. The results were relatively stable in the face of these tests. Although the order of the schemes changed to a certain extent, the list of the top performing schemes remained relatively unchanged and the initial results were therefore deemed reliable. At the time of writing, more sensitivity analysis was being envisaged and it remains work in progress.

4.7.3 Implementation Timescale of Road Schemes

The MoT has set the implementation timescale at 20 years, divided into four five-year blocks. The aim of the study is to prioritize the proposed road schemes into the four implementation phases:

1. Phase I – Immediate implementation of the schemes (within the next 5 years);
2. Phase II – Implementation of the schemes in the short term (in 5 to 10 years);
3. Phase III – Implementation of the schemes in the medium term (in 10 to 15 years); and
4. Phase IV – Implementation of the schemes in the long term (in 15 to 20 years).

The MoT has a budget for each implementation phase. Part of the total budget for each phase is allocated for the implementation of the primary road schemes, and the balance is allocated for the implementation of the secondary road schemes. Since the primary road schemes are prioritized at a national level, the top ranking schemes whose costs add up to that budget would then be assigned to that phase. At the time of writing, the first set of primary road schemes has been assigned to Phase I. The next step is to assign the secondary road schemes for implementation during that same phase. To do so, the secondary road budget will be divided by region. This will be done based on current regional spending trends. The secondary road schemes will then be ranked by region and prioritized based on the regional budget.

This process will be repeated for every implementation phase as illustrated in Figure 1. It should be noted that after each phase, the road network in the National Road Network Model will be updated to include the schemes chosen for that phase before deriving the data required for the following stages of the prioritization process. If after phase IV, there are still schemes that have not been assigned to any implementation phase, then those schemes will be considered as having a lower priority and would need to be revised. It is important to note that the prioritization framework is intended to facilitate a decision regarding the order in which road schemes should be implemented. However, it is for the decision makers to use their judgment in interpreting the results.

5. CONCLUSIONS

This paper describes the development and implementation of the multi-criteria analysis (MCA) framework adopted to prioritize a set of primary and secondary road schemes in the Kingdom of Saudi Arabia over the next 20 years.

A road network is paramount in supporting and assisting population and economic growth. It needs to be maintained, improved and expanded, but the resources to achieve this are almost always finite. This makes prioritization of road schemes essential in order to assess which schemes should be implemented and in what timescale. The cost-benefit analysis method (CBA) has commonly been used to achieve this. However, it is evident from an extensive literature review that CBA has limitations in dealing with a nationwide set of schemes, of varying types, spanning many regions and involving different key players with various concerns and objectives. In this study, it was therefore necessary to move towards a MCA approach which could evaluate the different impacts and needs of a road scheme.

This prioritization framework relies on a linear additive approach called the Saudi Arabia Road Prioritization (SARP) model and a comprehensive GIS database in developing the schemes' priorities. In the SARP model, the performances of each road scheme on the different criteria are converted to weighted scores which are then added to calculate the overall performance of the scheme. The weights reflect the relative importance of the different criteria as expressed by the judgments of the key players and they are derived using Saaty's Analytic Hierarchy Process (AHP).

The prioritization framework is a well-structured, comprehensive, even-handed, and transparent approach. It is well-structured in its systematic evaluation of each proposed scheme involving the GIS database, the Road Network Traffic Model, the Cost Estimation Model and the linear additive model. It is comprehensive as it is anchored in the national goals and objectives of the different Government ministries, departments, and regional authorities, and includes monetary as well as non-monetary factors such as socio-economic, environmental and political/defense concerns. It is even-handed, for example, because it does not exclude a scheme purely on the basis of its high construction cost or low traffic levels. And finally, it is transparent since the performance of each road scheme on each of the criteria is clearly set out, making it very easy to understand why one scheme is favored over another. This in turn facilitates sensitivity analysis which is important in assessing how reliable the results are.

It is essential to note that the prioritization framework is intended to facilitate a decision regarding the order in which road schemes should be implemented. However, it is for the decision makers to use their judgment in interpreting the results. It is also important to recall that the implementation of the framework to the primary and secondary road network of the Kingdom of Saudi Arabia is work in progress and some of the results may still be modified.

REFERENCES

Avineri, E., J. Prashker and A. Ceder (2000). Transportation projects selection process using fuzzy sets theory. Fuzzy Sets and Systems, 116, 35-47.

Ballestero, E., JM. Anton and C. Bielza (2003). Compromise-based approach to road project selection in Madrid Metropolitan Area. J. Operations Research Society of Japan, 46, No.1, 99-122.

Berechman, J. and R.E. Paaswell (2005). Evaluation, prioritization and selection of transportation investment projects in New York City. Transportation, 32, 223-249.

Department of Communities and Local Governments, UK (2009).Multi-criteria analysis: a manual. Available online at www.communities.gov.uk/documents/corporate/pdf/1132618.pdf.

Diakoulaki, D. and S. Grafakos (2004). Multicriteria Analysis. ExternE-Pol, Externalities of Energy: Extension of Accounting Framework and Policy Applications (Contract N° ENG1-CT-2002-00609), Final Report on Work Package 4. Available online at www.externe.info/expolwp4.pdf.

European Commission (1998). A methodology for policy analysis and spatial conflicts in transport policies. Edited by Euro Beinat, Report No. R98/08 of 31/07/98, available online at www.kent.ac.uk/economics/documents/research/DTCS-final-report.pdf.

Hiroyuki, T. (2000). Decision Analysis. In: Handbook of Industrial Automation (R.L. Shell and E.L. Hall, ed.), pp. 369-376. Marcel Dekker, Inc., New York.

Hochbaum, D.S. and A Levin (2006). Methodologies and algorithms for group rankings decision. Management Science, 52, Issue 9, 1394-1408.

Kulkarni, R.B., D. Miller, R.M. Ingram, C-W. Wong and J. Lorenz (2004). Need-based project prioritization: alternative to cost-benefit analysis. J. Transportation Engineering, 130, No 2, 150-158.

Morisugi, H. (2000). Evaluation methodologies of transportation projects in Japan. Transport Policy, 7, 35-40.

Ongprasert, S., and T. Todoroki (2003). Recommendations of multi criteria analysis under multi actor decision condition in transport project evaluation. Proceedings of the Eastern Asia Society for Transportation Studies, Vol.4, available online at www.kochi-tech.ac.jp/library/ron/2002/g5/M/1055137.pdf.

Perez, J., J.L. Jimeno and E. Mokotoff (2002). Another potential strong shortcoming of AHP. Available online at www2.uah.es/docecon/documentos/DT8.pdf.

Saaty, T.L. (1980). The Analytic Hierarchy Process. McGraw-Hill, U.S.A.

Saaty, T.L. and K.P. Kearns (1985). Analytical planning: The organisation of systems. Pergamon Press Inc., Tarrytown, NY, USA, pp34.

Saaty, T.L. and L.G. Vargas (2001). Models, method, concepts and applications of the Analytic Hierarchy Process. Kluwer Academic Publishers, Dordrecht, The Netherlands, Chapter 2.

Shefer,D. and V. Tsubari (1990). Tribute plan evaluation method: An essay in memory of Morris (Moshe) Hill. J. Planning Education and Research, 10, No.1, 5-14.

Tsamboulas, D. A. (2007). A tool for prioritizing multinational transport infrastructure investments. Transport Policy, 14, 11-26.

Wang, Y-M. and T.M.S. Elhag (2006). An approach to avoiding rank reversal in AHP. Decision Support Systems, 42, Issue 3, 1474-1480.

Zahir, S. (1999). Geometry of decision making and the vector space formulation of the Analytic Hierarchy Process. European Journal of Operation Research, 112, 373-396.