SPATIAL MULTIPLE CRITERIA DECISION ANALYSIS IN INTEGRATED PLANNING FOR PUBLIC TRANSPORT AND LAND USE DEVELOPMENT STUDY IN KLANG VALLEY, MALAYSIA

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ABSTRACT:

This paper describes the way spatial multiple criteria decision analysis "SMCA" has been applied to develop and evaluate of an integrated plan for public transport system and land use development in the Klang Valley, in Malaysia. The SMCA here has been used as a framework for design, and evaluation of alternative rail-network, which in combination with the other transportation systems, will meet the future socio-economic, and environmental, requirements of people in the Klang Valley region. The paper briefly introduces the applied methodology, the MCDA process, and the final results. It will also briefly presents the way Geographic Information Systems, Spatial Multicriteria Evaluation and complex transportation modelling is used to support design, impact assessment and the evaluation of alternative rail-network. Finally it will look at the problems, shortcomings and the lessons that were learned in the process of implementation.

1. INTRODUCTION

The Government of Malaysia, through Kementerian Wilayah Persekutuan had embarked on the Integrated Public Transport System and Land Use Development Plan for the Klang Valley. This study was to identify the needs and to design suitable future rail corridors to enhance the usage of public transportation facilities to serve a projected population of 7 million people by year 2020. The study puts social, institutional and environmental concerns on par with economics and engineering concerns in the design and evaluation process. The latter two concerns were traditionally given greater attention at the expense of the former in the conventional Four Step approach in transportation studies.

Historically Multiple Criteria Evaluation methods were developed to select the best alternative from a set of competing options. These included single criteria methods for example cost benefit analysis, decision tree analysis and pay-off tables, and many other methods of Multiple Criteria Decision Making methods "MCDM". Over the years, these methods have evolved into a diverse range of decision aid techniques that can be used in many different decision making processes.

In this study, MCDA has been used as a framework for design, and evaluation of alternative rail-network in order to:

1. Guide the preliminary design of potential alternative rail-networks, which matches the existing, and future socio-economic and technical requirements of the Klang Valley region.
2. Study the pros and cons of the potential networks from different perspectives, considering appropriate indicators in order to improve the designs.
3. Selection of a suitable transportation network through the evaluation of potential alternative networks from different local authorities perspectives through the consideration of relevant socio-economic, environmental and engineering criteria and indicators. The preferred network was to be subjected to further detailed design and development.

This article illustrates the application of MCDA techniques to support the planning of an integrated land use and transportation system for the Klang Valley. In this process, a new preference assessment method was developed and applied. The method, called structured pair-wise comparison, is a slight variation of the Analytic Hierarchy Process (AHP) (Saaty, 1980). The structured pair-wise comparison method applied in this study has proven its ease of use within limited time-constraints and participatory framework.

2. BACKGROUND TO THE KLANG VALLEY, MALAYSIA

The Klang Valley region comprises the entities of Federal Territory of Kuala Lumpur and seven other municipal councils of the state of Selangor. Its current population is about 4.7 million and this is projected to increase to about 7.0 million by 2020 the Another 7.0 million people are expected to be living within the immediate outer Klang Valley region. There is about 182 km of rail network within the valley operated by four different operators, i.e. the monorail, the Putraline (light rail), the StarLine (light rail), and the KTM Commuter (heavy rail).

The present modal split of public to private transportation is about 20:80. This situation is unsustainable and newer modes of transport networks need to be considered. In the past, various transportation studies have been undertaken for the region, but these have been largely focused on highway network development. and Other planning studies within the different local authorities have recommended disjointed rail networks which cater poorly for intra and inter-regional travel. The Klang Valley Secretariat (a planning and coordinating body established in 1981) recently engaged a team of local and foreign consultants to propose future rail corridors. These were designed to enhance public transportation ridership and also to improve the model split closer to 40:60.

3. APPLIED MCDA METHODOLOGY TO THE KLANG VALLEY

Decision-making is a process, involving a sequence of activities that starts with recognition of a decision problem and ends with recommendation for a decision. The quality of the decision depends on the sequence and quality of activities that are carried out. Depending on the situation, there are a number of ways that the sequence of activities can be organized. According to Keeney (1992), two major approaches can be distinguished, the alternative-focused, and the value-focused approach. The alternative-focused approach starts with development of alternative options, specification of values and criteria, then evaluation and recommendation of an option. The value-focused approach on the other hand, considers the values as the fundamental element in the decision analysis. Therefore it first focuses on the specification of values (value structure), then considering the values feasible options are developed and evaluated based on the predefined value and criteria structure. This implies that decision alternatives should be generated in such a way that values specified for a decision situation are best achieved. In other words, the order of thinking is focused on what is desired, rather than evaluation of alternatives. In fact alternatives are considered as means to achieve the more fundamental values, rather than being an end. Naturally, in decision problems which alternative options have to be developed and then evaluated the value-focus approach can be much more effective, however if the decision problem starts with choice of option, the alternative-focused is more relevant.

The objective of the Klang Valley Integrated Land use and Transportation Study was to design and recommend the most appropriate rail-network, which together with the other existing and planned transportation infrastructure would meets, the socio-economic, environmental and technical requirements of the residents of the people in Klang Valley region up to the year 2020. Considering the objectives, the decision-making paradigms and approaches, procedural rationality, the value-focused approach was selected to be used in the study. This considers values as the fundamental element in the decision analysis and focuses on the specification of values (value structure), followed by developing values feasible options and evaluated based on the predefined value and criteria structure.

In this context after careful study of the case and discussion with various members of the consortium of local consultants involved in the study, a process as specified in Figure 1 was developed and implemented.

3.1 Basic Principle and Design of Rail Network

To implement the selected value-focused MCDA approach, a top down method was used to define the goal, objectives, and their related indicators of the required transportation network. After several rounds of discussions involving the consulting team, Technical Committee members and local authority officials, a criteria structure as presented in Figure 2 was accepted and used as the basis for development and evaluation of the rail-network. The various elements of this structure are briefly defined as follows:

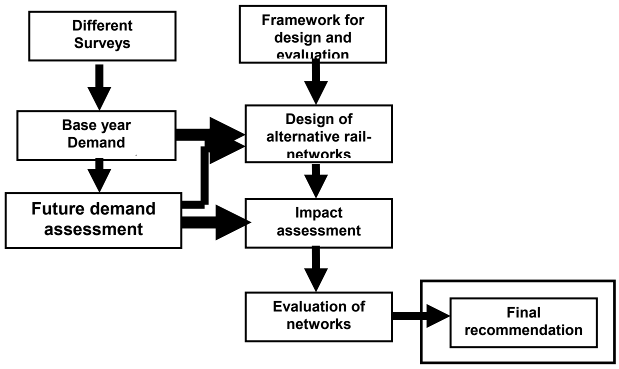

Figure 1. Conceptual approach to the decision making process

Goal and Objectives: The goal of this study is to identify an efficient public transport system for Klang Valley region integrated with a land use in such a way that it meets the future and long-term (2020) socio-economic and environmental requirements of the people in the region. This goal can be achieved if the following objectives are met:

Economic objective: Economic objective seeks to maximize feasible economic return in investment from the network. A number of criterion were used to measure how well an alternative performs on each indicators, e.g., benefit/cost ratio, first year return, internal rate of return, net present value, construction cost and operation cost.

Engineering Objective: This objective looks at three main concerns i.e. efficiency of the network, construction issues, and effective use of the network for work and non-work trips. The criteria used to measure the extent of such achievements by the respective networks are as follows:

- Efficiency is measured by examining the minimum number of transfer, (whereby an alternative with excessive transfer will score low for this criteria), a network which contributes to a reduction in travel time compared to time spent on the roads will score high or be beneficial; and the greater distance covered by rail was considered to be a plus in comparison to a smaller area of coverage;

- From the construction perspective, alternatives that have rail routes passing through problematic areas like utility lines, high-density built-up areas, commercial, industrial and institutional areas, would score low for this criteria.

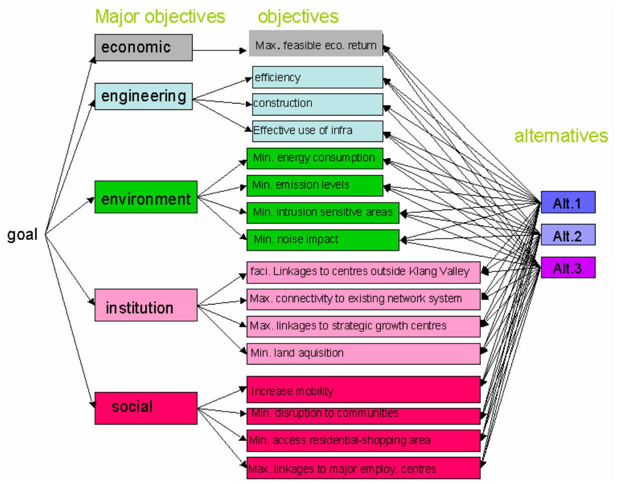

Figure 2. Graphic Presentation of hierarchical structure of goals, objectives, criteria and indicators

Environmental Objective: The designed network should minimize intrusion and damage to the environment. This is accomplished through a reduction in energy consumption, minimal emission levels, minimal intrusion into environmentally sensitive areas, minimal noise impact to sensitive land use (such as hospital, residential and schools).

Institutional Objective: This objective measures the match between the networks and spatial policies of the federal and state governments, e.g. to maximizes connectivity to existing public transport systems; maximize linkages to strategic growth centers (as designated/proposed in structure and local plans), to provide good linkages between Klang Valley urban centers and those outside the Klang Valley and minimizes land acquisition.

Social Objective: The network should increase social mobility by way of easy access to existing and future settlements. This is measured by forecasting passenger/km reduction for residential to employment area, and residential to educational institution. Based on ideas of future settlements, employment and educational institutions, efficiency of land use objective should be achieved by; maximizing access between residential areas and shopping, service and recreational centers. Such systems; would serve highly populated areas; and particularly disadvantaged areas (low cost settlements); increase access to tourism attraction areas; minimize disruption to neighbourhood communities; and maximize linkages to major employment areas/centers.

Criteria and Indicators: To further support the design and evaluation of the rail-network, the objectives had to be further broken down into criteria and their corresponding indicators. The indicators were further used to measure the performance of each alternative rail network on each objective.

3.2 Design of Alternative Rail Networks

Considering the set goal, objectives, related criteria and indicators, three (3) alternative competitive rail networks with three different design approaches were developed. The network design was an iterative process, guided by the set criteria structure. It took a number of iterations to come up with the three distinct networks that are potentially good networks, although, with its own pros and cons. The three networks are presented in Figures 3b to 3d and are briefly described as follows:

Branch Network "Branch-option": This network pattern is designed to meet the overall development pattern proposed by the various structure plans in Klang valley. The rail corridors in Kuala Lumpur are radial and its key features are the use of the current KTM rail corridor from Klang to Kuala Lumpur as the main spine, with branches into Subang Jaya, Shah Alam and Klang. However this preliminary design has no spur to Petaling Jaya.

Radial Network "Radial-option": This option is designed to meet the overall development pattern in its current form. The rail corridors in Kuala Lumpur are radial and its key feature is the continuation of the radials in the western direction towards Klang. Kuala Lumpur continues to be the major commuting direction bypassing town centers of Shah Alam and Petaling Jaya.

Loop Network "Loop-option": This option is a combination of all the different rail proposals that have been proposed in the past. This includes the Kuala Lumpur Structure Plan, the Selangor Structure Plan and local plans. Generally it has elements of a wider coverage beyond the Klang Valley but not directed at connecting Shah Alam and Petaling Jaya town centers.

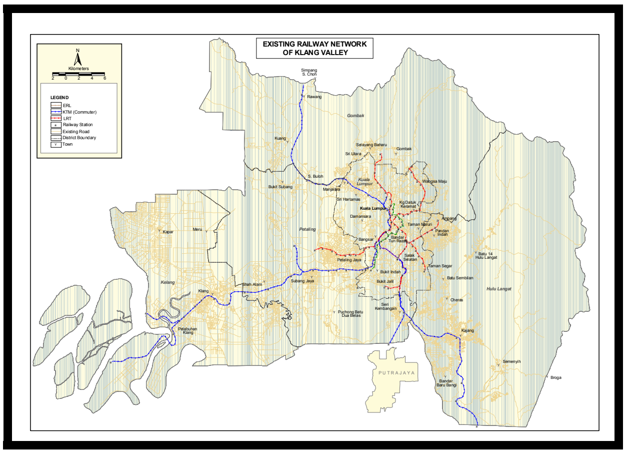

Figure 3a. Existing Rail Transit Network

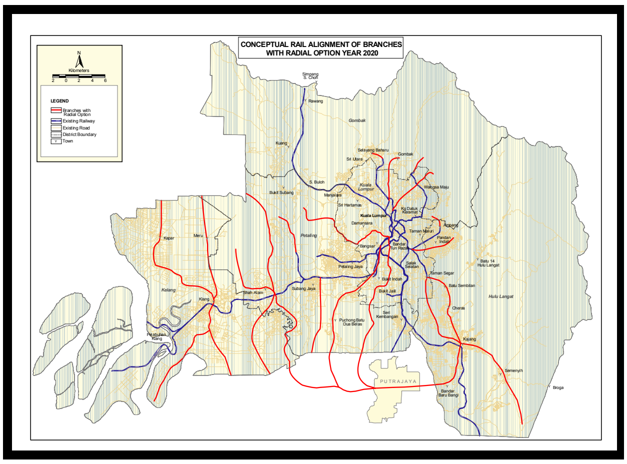

Figure 3b. Option 1: radial with branches

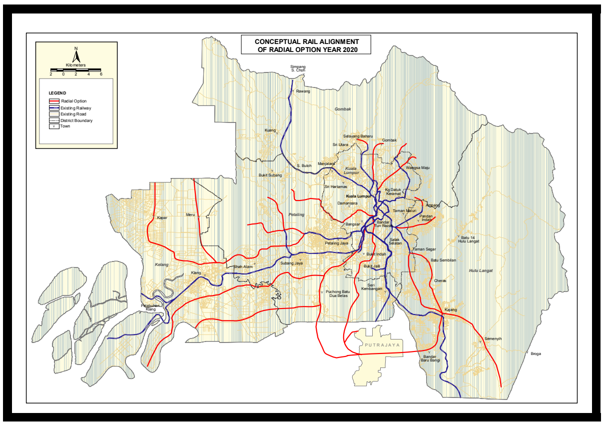

Figure 3c. Option 2: radial

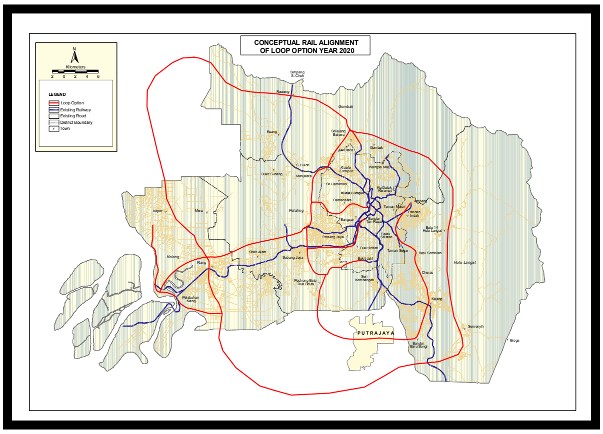

Figure 3d. Option 3: loop

No.	Objectives	Option		
		1	**2**	**3**
1.0	Economic Objective			
1.1	Maximize Feasible Economic Returns			
	Benefit / Cost Ratio	3.4	3.2	3.3
	First Year Rate of Return	17.9	19.7	19.2
	Internal Rate of Return	15.2	13.6	14.0
	Net Present Value (RM Million)	600	300	300
1.2	Total Cost			
	Construction Cost (RM Million)	19,292	19,128	17,902
	Operation and Maintenance Costs (RM Million)	274.7	265.1	283.4
2.0	Engineering Objective			
	Length in km	261.6	252.4	269.9
2.1	Efficiency			
	Minimize number of transfer stations	11	13	17
	Faster (Less passenger hours-million)	3,897	3,697	3,904
	Less distance travelled (Less passenger km-million)	25,815	23,524	24,016
2.2	Distance through Problematic Areas			
	High density built up areas (km)	154.3	156.9	127.9
	Commercial areas (km)	11.3	11.8	7.6
	Industrial areas (km)	25.0	25.5	20.2
	Institutional areas (km)	15.5	13.7	8.9

Table 1. Economic and Engineering Objectives

4. EVALUATION OF THE NETWORKS (MCDA PROCESS)

The multiple criteria evaluation of the networks was carried out based on the performances of each network on various defined indicator "objective data" and the relative importance of each indicator, criterion and objectives in relation to the other indicators, criterion and objectives "subjective data". The objective data was estimated using GIS, transportation modelling and where necessary through surveys. The result of this process is given in the "so called effect table" which is only partially presented in Table 1. This table contains, the objective data (the last columns) representing the performances of each network on each indicator (efficiency, effectiveness) and impact indicators of the three (3) networks in 2020.

The objective data is derived through the following activities:

a. Translation of the conceptual network designs onto the actual GIS maps (Figure 3).
b. Assessment of the land use and environmental impacts of each network using GIS and surveys.
c. Transportation modelling to assess the effectiveness, efficiency and impacts of the designed networks on in year 2020 using Transcad software.
d. Assessment of the land use and environmental impacts of each network using GIS analysis techniques.

The analysis of the performances of the different networks for the different criteria indicates that there is no option that dominates absolutely over the other options. In fact this was expected, as the designed networks were compatible, comparable and buildable options in their own right. Therefore each of the alternatives had their own positive and negative attributes. As an example the Loop-option performs better than the others options in terms of lower construction costs, linking with centres in outer Klang Valley, minimal disturbance to neighbourhoods, minimal noise disturbance to residents, schools and hospitals and minimum passage through problematic areas. Similarly the Radial-option is performs best in terms of minimal intrusion into historical, forest and conservation areas. In addition it performs very well in terms of access to disadvantaged areas, energy consumption, and speed. For all other indicators the Branch-option performs best.

In assessing all of these criteria, if only the relative importance of the technical criteria and indicators are considered (relative importance of the criteria and indicators in contributing to the objectives of the study), meaning that all objectives are assumed to be of equal importance, and then the Branch-option is the best performer (Figure 3).

Priority Assessment: The subjective information however relates to the view and perception of various stakeholders on the related issues. This includes the relative importance of various objectives, criteria and indicators presented in the criteria structure (Figure 2), and Table 1 as viewed by different stakeholders. To achieve ranking and performance of the subjective information, two groups of stakeholders were identified to provide critical inputs. These were as follows:

- The first group consisted of those involved in planning, decision-making and the political side of the process. These stakeholders were asked to make judgments on the relative importance of the main objectives, i.e economic, engineering, environmental, institutional and social objectives. The stakeholders included the municipal councils in the Klang Valley and members of the Technical and Steering Committees.

- The second group consisted of those involved in the technical side of the process. These were mainly experts in the various fields, who were able to make expert judgment on the relative importance of the technical indicators e.g., the relative damages to the environment due to the various emissions. This also included the relative importance of all indicators (from the lowest level of the criteria structure) and the relative importance of the criteria (second level of the criteria structure).

The evaluation of subjective information, related to the relative importance of objectives, criteria and indicators were then elucidated in a series of meetings of with consultants and stakeholder group using the structured pairwise comparison1 method (Sharifi et al., 2004). In this process, relevant stake-holders were asked to make judgments on the relative importance of the main objectives, e.g., economic, engineering, environmental, institutional and social objectives. Stakeholders includes the Department of Town and Country Planning of the State of Selangor, Kuala Lumpur City Hall, Shah Alam City Council, and the municipal councils of Selayang, Petaling Jaya, Ampang Jaya, Subang Jaya, and Klang. In almost all cases the appointed councilors and representatives of local authorities were involved in the preference assessment exercises.

4.1 Ranking of Alternatives according to different perspectives

After completing the evaluation of objective and subjective information, the three networks were evaluated using an additive utility function. For each stakeholder, the objective and subjective information related to all three options were aggregated using a weighed linear utility function in the process of a Multi criteria evaluation. In this process the utility of each option on each indicator was combined with its relative priority and aggregated to derive the overall utility of each option. The three (3) options were then evaluated from the perspectives of each group of stakeholders. The results of this evaluation exercise are graphically represented in Figure 4. Due to the varying priorities on the main objectives for the various stakeholders, the scores in Figure 4 differ between the stakeholders. It can then be concluded that the preferred option is the Branch-option.

All stakeholders concur that the Branch Option dominates in all the objectives except for the environmental objective. Similarly, the Radial-option dominates in achieving the best results in the environmental objective.

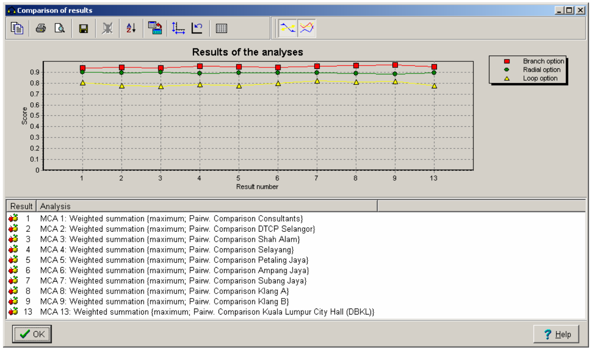

Figure 4. Comparisons of the overall performance of all alternative from different perspectives.

In the graph MCA 1: Evaluation based on equal weight for the main objectives; MCA 2 Evaluation based on the perspective of DTCP Selangor; MCA 3 Evaluation based on the perspective of Shah Alam; MCA 4 Evaluation based on the perspective of Selayang; MCA 5 Evaluation based on the perspective of Petaling Jaya ; MCA 6, Evaluation based on the perspective of Ampang Jaya; MCA 7 Evaluation based on the perspective of Subang Jaya; MCA 8 Evaluation based on the perspective of Klang A; MCA 9, Evaluation based on the perspective of Klang B, Evaluation based on the perspective of Kuala Lumpur City Hall .

The Radial-option performance is very close to that of the Branch-option, and it ranks number two (2) in the opinion of all stakeholders with rather high overall utility. The Loop-option, although performing quite well in terms of economic and engineering objectives, however ranks last.

It could also be seen that, each stakeholder would choose the branch option as the first option based however for their own reasons. In terms of the different municipalities, the objectives were weighted quite differently. However, the Branch-option appeared to be most attractive as ranked by all the municipalities.

The loop option performs somewhat better than the other options on most of the economic criteria. However, economic criteria were not considered of major importance in the evaluation by stakeholders. Apparently RM1.4 billion (close to 8%) in investment money, and the RM18 million differences in annual operational costs (close to 7% of requirement) is not considered important by a number of decision makers (Table 1). With the exception of the noise criteria, the loop option under-performs on environmental objectives. In terms of social objectives, which are considered important by most stakeholders, the loop option once again under-performs compared to the other objectives. This is one of the main reasons for the poor performance of the loop option.

4.2 Uncertainty and sensitivity Analysis: Probability of making the 'wrong' decision

In order to study the stability and robustness of the ranking, uncertainty and sensitivity analysis were conducted. This analysis was carried out to see the effect of the potential errors which may exist in the estimation of the networks performances (objective information as presented in the effect table), and the subjective information representing the relative importance of the criteria and indicators as derived from experts and the relative importance of the objectives as derived from different stakeholders (decision makers; members of the Technical Committee). This analysis included the following:

- Uncertainty analysis – This assumes certain percentages of random error in estimation of the objective and subjective data. Assuming predefined level of errors in the assessment of objective and subjective data do we still get the same ranking or not?

- Sensitivity analysis – This tries to study the stability of the ranking with respect to the most important elements in the objective and subjective data. In other words, how much should some elements in the subjective and objective information change in order to alter the ranking of the networks.

For the uncertainty analysis of "objective information" the consultants have assessed an error margin, in the order of between 15-30% for the different indicators. The error margins were used to perform Monte Carlo analysis for each stakeholder, whereby data scores were randomly varied within the error margins. Part of the results of the uncertainty analysis is presented in Figure 5. The circle represents the probability of each option scoring different rankings, e.g., DTCP Selangor, 75% believe that the branch option ranks first position, followed by 23% who rank it second (allowing for round off error), and in 2% who rank it in third position.

In terms of sensitivity analysis, the relative importance of the objectives to each stakeholder was analyzed. For each stakeholder group, the most important objectives were selected and the sensitivity of the ranking with respect to a change in the priority "weight" was studied. The results showed that the rankings were robust with no evidence of rank reversal in almost all the cases. This confirmed the superiority of the Branch-option in relation to the two other options.

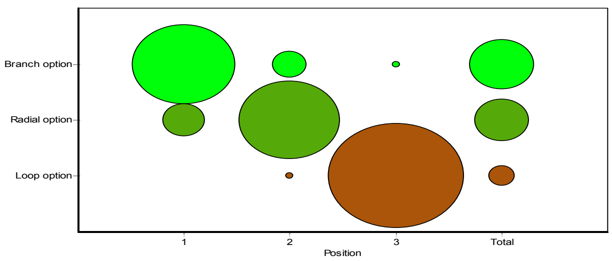

Figure 5. Uncertainty analysis for DTCP municipality

5. DISCUSSION AND CONCLUSION

The value-focused approach MCDA, applied in this study, helped in the design, evaluation, and also provides improvements to the three alternative networks. The primary objective being to meet the overall development trends and transport pattern in the Klang Valley region to year 2020. It also served as a rational way of addressing, approaching and providing a forum for discussion, negotiation, exchange of knowledge and final selection of a rail-network option. The final selection represented a network that was closest to the economic, engineering, environmental, institutional and social objectives as seen by the relevant municipalities, town planning authorities and the related experts (major stakeholders).

In developing the stated goal to its objectives, criteria and finally into various measurable indicators, the designers and decision makers were able to see how the various options performed against such criteria. All of this was undertaken in the context of of priorities and trade-offs (financial and political) warranted to operationalize the required rail network for the Klang Valley.

As a result of this process the Branch-option appeared to be the most effective and efficient option. This was still the case, considering large error margins in the assessment of the impact/performances and priority of various objective, criteria and indicators. The uncertainty and sensitivity analysis showed that although different groups of stakeholders, and planning authorities, had their differences in the importance of various objectives, they all agreed upon the dominance of the Branch-option over the others.

The structured pair-wise comparison method as applied in this study has proven its ease of use within limited time-constraints in the participatory framework. While the MCDA has been undertaken satisfactorily, a number weaknesses were detected which is worth discussing.

Firstly, the efficient operation of feeder bus services was not included as criteria. It is debatable whether all the three options would perform equally well for these criteria. Would topography, traffic conditions, socio-economic and public attitudes towards public transport usage influence each of the options for these criteria?

Further, such sequential approach i.e., deciding on desired rail network first, then attempting to optimize feeder bus services at a later phase, may have overlooked some basic/key requirements of the efficient operation of feeder buses and ridership preferences. If such criteria had been used at an earlier stage of the MCDA this would have enhanced the evaluation process, in particular the value function curve of feeder bus services (which was considered consideration by almost all local authorities). The degree to which decision makers were willing to trade-off re-routing certain lines and related operation costs (for buses and train) could have been factored into the decision making process.

Secondly, having only three (3) rail networks as options, and considering only one scenario (projection of current trends on every aspect), obviously lends itself to gross simplification in term of physical design/pattern possibilities, needs, impacts and performances (for more information see, Sharifi et al., 2004). Thirdly, the present evaluation process has largely used linear value functions (row-max in the absence of value function curve) where for example, the trade-off for a number of strategic centers not served, but are regionally and administratively important for some stakeholders, are not analyzed. A value function curve indicating the level of appreciation of the State and Federal Government concerns towards such strategic centers vis-à-vis various administrative and economic functions could have clarified the level of trade-off required when balancing with other criteria. The latter issue is particularly important to Shah Alam and Petaling Jaya, as both are capital and regional centers respectively, with no direct rail connection linking each other.

Fourthly, although the structured pair-wise comparison technique is relatively simpler and easier to apply compared to the original AHP weighting procedure, it nonetheless encounters certain real participatory problem. In particular, the limited time allotted to the participatory session (about 20 minutes per council in most cases) was slotted within existing council meetings with other standing agenda. This did not permit fuller elaboration of the main objectives (main criteria); and where it was possible, it was largely due to an extended time and the ability of the chairperson to allow for such discussion.

Lastly, as all stakeholders ranked the main objectives from their own perspective (whether statewide (Shah Alam), local (local authorities) or holistically (especially State Town Planners), and despite all stakeholders agreeing upon the dominance of the Branch-option over the others, this does not necessarily benefit equally all local authorities.

This point would require further detailed investigation to seek possible changes to the Branch-option2. Such adjustment and re-routing of alignment should be undertaken at the local level with relevant stakeholders participation (comprising local populations and concerned parties) and further iteration and modeling undertaken. Doing so would enhance better location of rail stations vis-à-vis its immediate (transit-oriented) surrounding, a more realistic appreciation of local constraints and a more coordinated design of access to such stations by various modes (buses, car, walking, cycling etc), and related traffic demand management (TDM) to support it.

The above limitations are understandable as the approach undertaken, within a bounded rationality framework, only addresses a limited area of interest within a complex rail-based and land use environment. However, despite these weaknesses (some of these could be overcome through running the process iteratively), it has given due attention to key social, environmental and institutional considerations (besides economic and engineering consideration) and within a multiple stakeholder perspectives, which otherwise would not be possible in a conventional transportation study It has raised consciousness about the issues involved, enhanced communication and understanding between different stakeholders. It has what Phillips (1989) emphasized: "…a framework for thinking that enables different perspectives on a problem to be brought together with the result that new intuitions and higher-level perspectives are generated".

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