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Expert Choice-Based Approach on Analytical Hierarchy Process for Pavement Maintenance Priority Rating Using Super Decision Software in Addis Ababa City, Ethiopia

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Abstract Untimely maintenance activities resulting from budget fluctuations and improper prioritization can lead to further pavement deterioration. Selecting the most cost-effective maintenance activities to control and minimize road users' risk under current budget constraints is necessary. The study tried to fill the gap that decision-makers in Addis Ababa City Road Authority often performed pavement repair and maintenance without considering a systematic procedure. Ten road sections selected that are planned for pavement maintenance in the study area. The most dominant distresses ranked in Decision Analysis Module in Excel, including road class, weights for each criterion, and sub-criteria obtained using the Analytical Hierarchy Process approach and calculated in Super Decision Software for maintenance prioritization. Results indicated that the developed analytical hierarchy process model works sufficiently and yields adequate output for providing accurate decisions. Hence, considering the multi-criteria to prioritize the pavement sections for maintenance, this model can give affirmative action for the decision-maker.

Keywords: *analytical hierarchy process, cost-effective maintenance, decision analysis module in excel, pavement maintenance prioritization*

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1. Introduction

Road network maintenance of a country is crucial to the overall infrastructure development. Most projects depend on good road transport network infrastructure to deliver goods and services [1]. For the sustainable development of a country, a well-maintained road transport network infrastructure is fundamental in promoting socio-economic and industrial developments. Economically, road transport infrastructure has been found to boost cities' livelihood, which are the primary sources of national economic activities and growth and the countryside's agricultural sector [2]. The road transport sector in Africa contributes significantly to the economic growth and poverty eradication in the continent in various ways, primarily through trade and tourism. Pavements are a critical component of the inland transport system. It is essential to maintain the existing pavement network in its serviceable condition within the available resources. Due in part to improper and irregular maintenance, excessive road deterioration results in increased Vehicle Operating Costs (VOC), an increased number of accidents, and generally reduced reliability of transport services [3]. Sustainable funding for road maintenance has, however, proven to be particularly difficult for many developing countries. Many developing countries manage a road system that is larger than they can afford. Therefore, there is a need to maximize the returns on the limited funds available [4]. The function of pavement maintenance is to diminish pavement deterioration and extend the life of the pavement.

Based on their relative perceived urgency of repair, engineers and managers can prioritize and schedule the maintenance of pavement sections. Some decision-making methods have been introduced and implemented under the Pavement Management System (PMS) study to prioritize pavement maintenance activities. These methods vary from simple ranking to complicated optimization [5]. A widely adopted practice is to express maintenance priority in the form of a priority index, computed utilizing an empirical mathematical expression. Though convenient to use, practical numerical indices often do not have a clear physical meaning. They cannot accurately and effectively convey the priority assessment or intention of highway agencies and engineers. In an attempt to overcome this limitation, this study explores using an Analytical Hierarchy Process (AHP) to prioritize pavement maintenance activities. The main aim is to identify an approach that can reflect highway agencies' and engineers' engineering judgment more closely.

According to [6], the AHP method solves the complex decision making with pairwise comparison form a multilevel hierarchical structure through a set of pairwise comparisons to solve complex problems. Score weights derived from meeting the goal and sorted in ranking order [7]. Deferred maintenance activities resulting from budget fluctuations can lead to deteriorated pavement conditions and expose road users to a higher risk level. As a result, there is a need for methods to select the most cost-effective maintenance projects to control and minimize the risk for road users under current budget constraints. By doing so, the agency can choose and implement the most profitable projects within the budget constraints and revise their maintenance plans to accommodate budget fluctuations.

Nowadays, the rating approach in Analytical Hierarchy Process (AHP) is one of the most effective techniques in the decision-making process, which was used to facilitate the prioritization of alternatives based on essential parameters like pavement condition index, traffic volume, and road type [8].

Road authorities around the world emphasize more on better efficiency and lower expenses due to limited funds. Since maintenance expenditures usually comprise half the annual road infrastructure funds, it is essential to prioritize efficiency in road maintenance [9]. The inadequate road infrastructure is also increasingly limiting farmers in applying pesticides and fertilizers and transporting their produce on the harvest. To facilitate import and export activities, the East African Community (EAC) identified five major transport corridors in the East African region [10]. It was since 1942 that road maintenance and rehabilitation duty within Addis Ababa had become the responsibility of the Roads and Building Department of the Addis Ababa city. However, the city was unable to cope with its maintenance duties due to a lack of resources, particularly experienced personnel in road construction [11,12]. In Addis Ababa city, the road work funding is allocated by the government. However, the new situation shows that the allocated funds always do not meet the financing needs. In other words, there is a lack of funding for effective road management. Decision-makers often performed pavement repairs without considering the maintenance priority and without utilizing a systematic procedure. These kinds of arbitrary decisions do not usually guarantee the effectiveness of budget allocation.

In this study, the prioritization of road sections for maintenance conducted using the approach of the Analytical Hierarchy Process (AHP) in dealing with different kinds of decision problems. AHP is a flexible, straightforward, and provides a rational and consistent way for decision-making; thus, complex decision-making simplified to many small comparison tasks. This study tried to apply the expert choice approach based on the Analytical Hierarchy Process for the priority rating of pavement maintenance in Addis Ababa city. The study determined the percentage of damage of distresses for the sample roads using a visual condition assessment survey. It also included the ranking of the most dominant distresses that govern the selection of maintenance priorities for the selected roads using a decision analysis module for excel. Also, it included the ranking of sample roads for maintenance based on the weights of each criterion and sub criterion's using the Analytical Hierarchy Process approach in Super Decision Software.

2. Research Methodology

The study conducted at Addis Ababa City and found at the Horn of the African continent with Geographical coordinates $9^{o}1'48''$ North and $38^{o}44'24''$ East, and an average elevation of 2,355m above sea level. It has a total area of about 530.14 Km^2 and a population of more than 8.0 million, according to the 2018 Census. The city is divided into ten administrative sub-cities and 99 Kebeles. The ten sub-cities, the roads that are planned for maintenance during the study period, only ten road sections are selected.

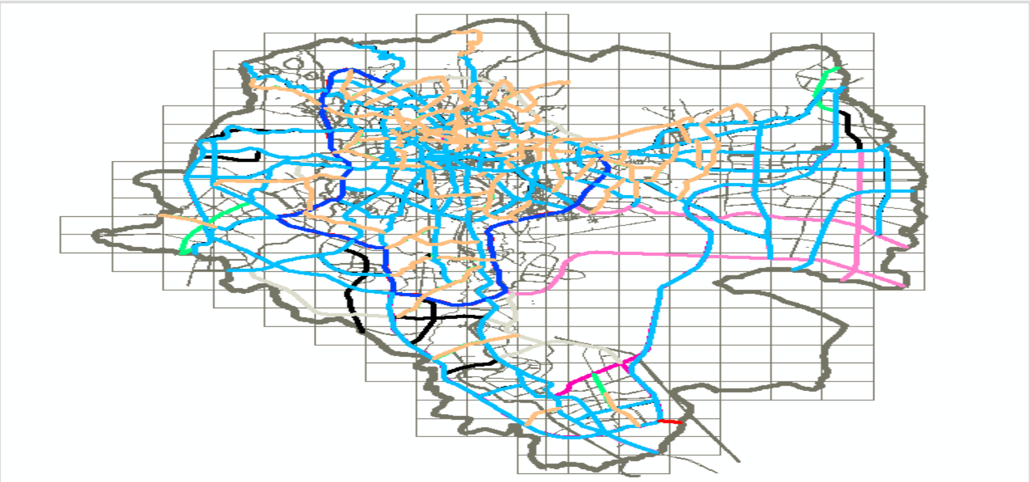


Figure 1. Map of the Study Area (Source: AACRA Road Master Plan Road Network, 2018)

2.1. Study Design

Explanatory, descriptive, and comparative studies are used. The occurrence of specific distress on the selected sample roads was briefly explained by taking a pictorial account of the phenomena after that, the result compared with the previous studies and related literature. The study included ten road sections from different road hierarchies.

2.2. Sample Size and Sampling Procedures

In this research, it was not possible to include all the road sections of Addis Ababa city planned for maintenance for 2018. Hence. Only ten representative road sections were selected using a purposive sampling technique. The sampling technique considered fair representative road classes and road sections showing various types of distresses.

2.3. Methods of Data Collection and Management

Data collection plays a significant role in the output of the study.

2.3.1. Data Collection Instrument

The instruments used to conduct a field condition assessment survey: wheel odometer, scale, and tape measure.

2.3.2. Data Collection Method

Quantitative and qualitative data are employed.

- Interview
- Field condition survey
- Questioner
- Road classification

Pavement condition data collected along the ten road sections to identify the different types of distresses. The survey was conducted by walking through the road sections and measuring the length from the beginning to the end of each road section using an odometer instrument and recording the existing distresses using the AACRA Office format.

2.4. Data Processing and Analysis

The data obtained from primary and secondary data collection are analyzed using Super Decision Software by applying the Analytical Hierarchy Process (AHP) concept.

2.4.1. The Analysis of Identified Dominant Distresses

The dominant distress was examined using the field condition assessment survey data. It was the percentage of damage of each distress calculated for each selected road section. The length and width dimensions of the road sections obtained from the field survey then followed the calculation of percent damage. The first step was done by calculating the Distress area (DA) of the road section. It was obtained by multiplying the Length and the Width of the total damage of the distress and the Total damage area (TDA) obtained by summing up all the distressed, damaged areas.

The percentage of damage was calculated using the formula;

$$Percent\ (\%)\ Distress = DA / TDA * 100 \qquad (1)$$

Where: DA - Distress Area,
TDA - Total Damage Area.

Table 1. Study sample road sections

Road No., Name Origin - Destination	Road Hierarchy	Total Area (m^2)
Road-1: Sar Bet -Minaye Building	PAS	9870
Road-2: Alemtsehay Bridge-Wolega Hotel	SAS	25900
Road-3: Adissu Gebeya-Comercial Bank Powlos Branch	SAS	11942
Road-4: Paster - Shewa Tsega (Mesalemiya)	Locale	6874
Road-5: Berbere Tera -Mola Maru (Kebele Meznagna)	Locale	5719
Road-6: Debrezeit Menged -Sene Zetegn-Behere Steige	Collector	7030
Road-7: Leadership Institute Jan Meda	Locale	5400
Road-8: Alert Round About -Fm Radio Station	SAS	12250
Road-9: Asfaw Tekle Hotel - Ehil Berenda	Collector	27000
Road-10: Kolfe Cooperative School - Filidoro School	PAS	42408

Figure 2. Distress data collection (Source: Field survey)

The analysis of distresses data used Decision Analysis Module for Excel (DAME). There were scenarios considered in getting the maximum occurrence of distress occurred on the selected roads. The framework used was by taking an Area and the Severity of each distress and the Variants (distresses) prepared by incorporating the visually observed distress on the study road sections. There are three different methods in DAME for the evaluation weights of criteria, the variants as well as the scenarios/users. These are Saaty's Method, Geometric Mean Method, and Fuller's Triangle Method. Among these three methods, the Geometric mean method used in this study to rank the distresses. By taking the top five ranked distresses from DAME, the processing and analysis for the prioritization of roads for maintenance are manipulated and performed on the Super Decision Software.

2.4.2. Prioritization of Pavement Sections for Maintenance on Super Decision Software

The prioritization of maintenance road sections based on the ranking was processed and analyzed the data obtained from DAME. The data from DAME were used as sub-criteria and road class. For each criterion and sub-criterion, pairwise comparison was employed to get the percentage influence in the prioritization of road sections. To determine the weights for the alternatives on Super Decision Software, the first step was to build a hierarchy model.

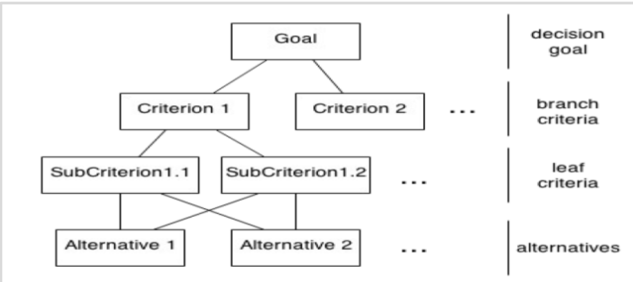


Figure 3. Hierarchy of goal, criteria, sub-criteria, and alternative on Super Decision Software

The lines connecting the goal to each criterion means that the requirements must be pairwise compared for their importance concerning the purpose. Similarly, the lines connecting each criterion to the sub-criteria were pair wisely compared to the alternatives mean the alternatives are pairwise compared as to which is more preferred for that criterion and sub-criterion. Thus, the hierarchy showed the connectivity of other options, criteria, and sub-criteria to the goal-the weightage factors for each preference calculated using a pairwise comparison matrix. The matrix was filled using the AHP concept. In the AHP, there are scales with values from 1 to 9 to rate the relative preferences for the items. Based on the judgmental preference, questionnaires are distributed for the maintenance experts in the Addis Ababa City Road Authority(AACRA). Using the obtained questionnaires, the pairwise comparison matrix was filled in Super Decision Software, as shown in Figure 4.

The reliability of the data obtained was checked for consistency and sensitivity analysis. The consistency shows whether the questioner data can be logically accepted or not using consistency ratio, accepted if it is less than 0.1, and the sensitivity performed to analyze how the alternatives change as it varies the priority of a criterion. A definite reciprocal matrix consisting of a different set of pairwise comparison is represented with i, j, and n. Where n, indicates the number of alternatives being compared within one set of pairwise comparisons, a_{ij} denotes the importance of alternative i over alternative j.

The judgmental values to each element in matrix A are assigned, and the priority vector w is determined. Saaty's Eigenvector method is often applied to derive the alternatives' priorities and compute the value of w_0, the principal Eigenvector. The vector corresponding to the largest Eigenvalue, $_{max}$ of the matrix A [13,14,15].

The comparison among the Analytical Hierarchy Process (AHP) and the current approach used by the AACRA are compared in the fourth section of this study.

3. Results and Discussion

3.1. Road Condition Assessment Survey Result

A road condition assessment survey was conducted along the ten road sections and recorded all the data needed using the condition assessment survey sheet of AACRA. In the sheet, the severity, width, and length were recorded.

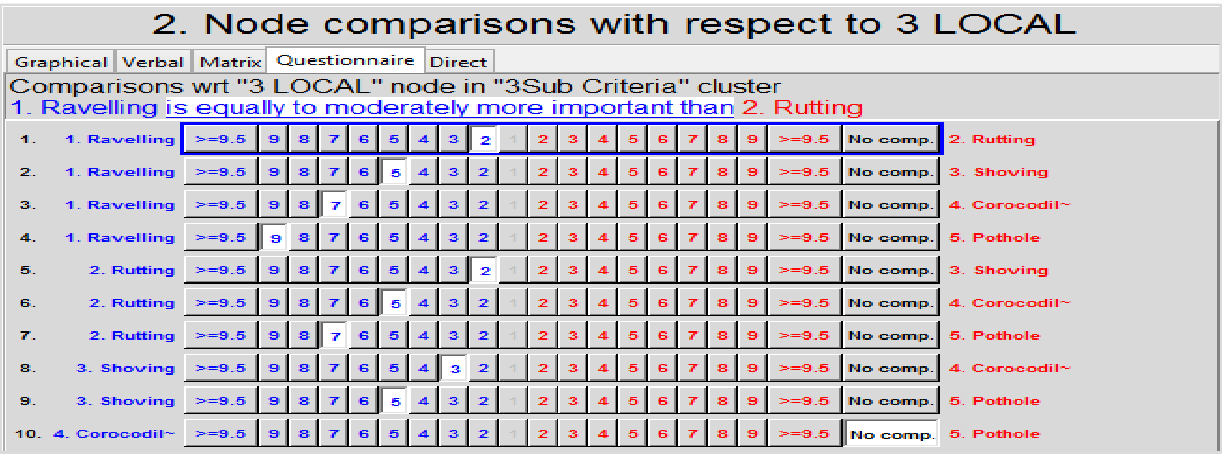


Figure 4. Pairwise Comparison Matrix

Table 2. Distress Data and Percentage Damage for Sample Road-1

The road from Sar Bet to Minaye Building	Distress Area (DA) L*W of distress	Total Damage Area (TDA)	Damage (%)
Potholes	130	1310	9.92
Alligator Cracking	130	1310	9.923
Subsidence	150	1310	11.45
Longitudinal Cracking	20	1310	1.53
Raveling	230	1310	17.56
Edge break	650	1310	49.62

Road Sample-1 started at Sar Bet and ended at Minaye Building. It has a total length of 1410m and 7m carriage width. The length between the two successive stations had 400m except for the end station that was 212m. The road number assigned by AACRA as No.188.1. It has a classification of Principal Arterial Street (PAS). Along this road section, six types of distresses are observed and recorded for each station, as shown above, the distress area and percent damage are calculated. Table 2 indicated the percent damage for Sample Road-1.

Table 3. Summary of Distress Data and Percentage Damage for Road-1 to Road-10

Road Section No.	Road Hierarchy	Total Area (m^2)	Distress Types	Distress Area (DA) L*W of distress	Damage (%)
Road-1	PAS	9870	Potholes	130	9.92
			Alligator Cracking	130	9.923
			Subsidence	150	11.45
			Longitudinal Cracking	20	1.53
			Raveling	230	17.56
Road-2	SAS	25900	Potholes	250	20.7
			crocodile Cracking	16	1.32
			Subsidence	24	1.99
			Raveling	272	22.52
			Shoving asphalt	436	36.09
			Lacy Edge	210	17.38
Road-3	SAS	11942	Potholes	156	20.73
			crocodile Cracking	47.5	6.312
			Raveling	285	37.87
			Lacy Edge	264	35.08
Road-4	Locale	6874	Potholes	561	30.1
			crocodile Cracking	315	16.9
			Raveling	888	47.64
			Lacy Edge	100	5.36
Road-5	Locale	5719	Potholes	230.5	20.34
			crocodile Cracking	3	0.26
			Raveling	686	60.55
			Shoving asphalt	202	17.83
			Lacy Edge	11.5	1.02
Road-6	Collector	7030	Potholes	382	36.16
			crocodile Cracking	96	9.09
			Rutting	12	1.14
			Subsidence	3	0.28
			Raveling	521.5	49.36
			Lacy Edge	42	3.98
Road-7	Locale	5400	Potholes	1161	72.47
			crocodile Cracking	9	0.56
			Rutting	141	8.80
			Corrugation	21	1.31
			Lacy Edge	270	16.85
Road-8	SAS	12250	Rutting	240	75.35
			Longitudinal Cracking	34	10.68
			Raveling	34	10.68
			Lacy Edge	10.5	3.3
Road-9	Collector	27000	Potholes	695	14.15
			crocodile Cracking	1301	26.5
			Delamination	250	5.09
			Raveling	2664	54.26
Road-10	PAS	42408	Rutting	710.5	46.33
			Raveling	170	11.09
			Shoving asphalt	397	25.89
			Low Shoulder gravel	256	16.69

The affected pavement area obtained by multiplying the length and width of each distress occurred on the Road-1 section and TDA obtained by summing up the DA values. Likewise, the percent damage was obtained by dividing DA to TDA and multiplying by 100. The same procedures applied for the succeeding Samples Road-2 to Road-10 of the study area. A summary is shown in Table 3.

After calculating the percent damage for all the ten road sections, the next procedure applied was the analysis of the recorded distresses data in the Decision Analysis Module for Excel (DAME).

3.2. Identification of the Most Dominant Distress Types

In this study, a Microsoft Excel add-in called DAME (Decision Analysis Module for Excel) was used to work with scenarios or multiple decision-makers. It allows for easy manipulation with data, utilizes Microsoft Excel capabilities, and displays all intermediate calculations.

To apply the DAME analysis, the decision models are structured into three levels:

- Scenarios
- Criteria (at this circumstances the Area and the Severity of each distresses), and
- Variants (At this scenario the visually identified distress types)

Elements on all three levels are evaluated by direct values obtained from the field condition survey for each distress type. There are three different methods for assessing the weights of criteria, the variants, and the scenarios or users - these are Saaty's Method, Geometric Mean Method, and Fuller's Triangle Method.

This research aims to make the right decision among the alternatives based on the set of criteria and sub-criteria. This contribution introduces a Microsoft Excel add-in DAME, a Multiplicative and additive synthesis supported. All calculations are instant so users can easily see what happens if anything is modified. A bar chart is used for final ordering representation. The proposed software package is demonstrated on a couple of illustrating examples of real-life decision problems. Before the distress types' ranking, first, the area and severity were determined for each distress occurred at each road as described above, and the area and severity of the distress used as input in the decision analysis module for excel add-in.

To get the rank of each distress occurred at the selected roads, a new decision problem was generated by clicking on the "New problem" item in the main DAME menu.

In the top panel of the DAME Software, there are three basic settings named as a number of scenarios, criteria, and variants. In the second panel, the methods that are used to compare scenarios/users and criteria were shown either using pairwise comparison matrix or set weights directly. The following figure shows the process of new problem creation and shows or illustrates how to define the number of scenarios, criteria, and variants used in this study.

In this study, nine scenarios are considered. It was done by assuming that one variant (distress) occurred at nine times among the total ten road samples. The two criteria that were used in this research are the area, and the severity of the distresses that occurred at the sample roads. Before the distresses' ranking, the severity of the distresses are determined from the field condition survey. The area of each distress that occurs at each sample road was calculated by multiplying the length and width of the distress.

Generally, there are two methods for scenario and criteria comparisons. The first one is the pairwise comparison, in which each pair of variants is compared individually; and the second is weights in which the scenario and the criteria were compared based on the set of weights (value assigned for each scenario and criteria) and these values calculated in the DAME Software. In this study, the weights method is applied for both scenarios and criteria comparison.

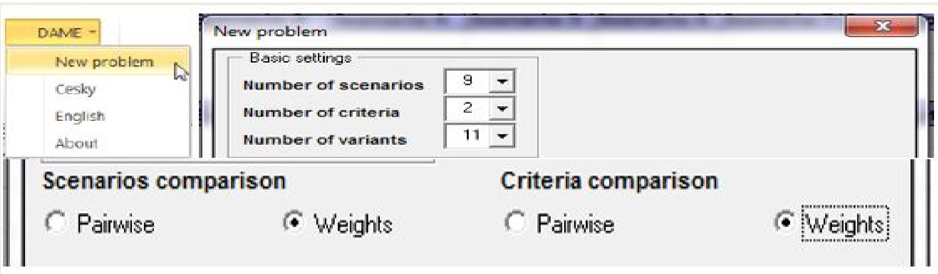


Figure 5. Screen captured showing DAME and New problem characteristics

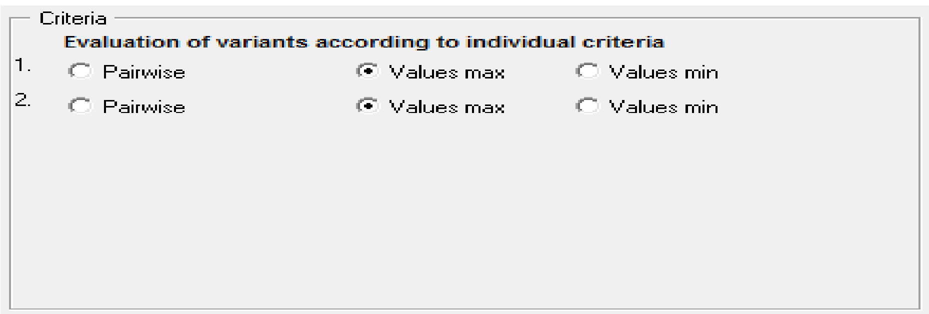


Figure 6. Criteria evaluation options

In the last panel (third panel), the criteria evaluation was done to evaluate variants according to individual criteria. For the criteria evaluation, there are three options.

- Pairwise - each pair of variants is compared individually.
- Values max - indicates maximization criterion where a single value evaluates each variant, e.g., price.
- Values min - indicates a minimization criterion where a single value evaluates each variant, e.g., costs.

For this study, the values max option was selected for the criteria evaluation. This indicated that the distress with the higher severity covering a large area (great extent) could have a higher influence (maximization) on the criteria evaluation.

After the values max option is selected, a new Excel sheet with forms is created, as shown below. On this sheet, the names of all elements were renamed and evaluation criteria and variants using weights, as shown in Table 4.

As shown in Table 4, the eleven variants/alternatives were compared based on the two criteria for the nine scenarios. The results of each scenario comparison based on the set of weights are discussed below.

Scenario 1 is about to compare the maximum combination of the distresses that occur at each road. For each variant (distresses) in scenario 1, the values of area and severity obtained from field road condition surveys were entered for each distress in Decision Analysis Module for Excel, as shown in Table 5.

This procedure is repeated for 9 scenarios; inally, the total weights are obtained, as shown in Table 6.

In Table 6, Nine Scenarios were created for the evaluations of eleven variants in decision analysis for excel to get the weight and the ranking of each variant. It was done by assuming that one variant (distress) occurred at nine roads among the total ten road samples. The two criteria used in this study in DAME are the area and the severity determined from the field road condition survey, as discussed above. The result of the whole comparison of eleven variants (distresses) reveals that raveling distress was ranked. First, the rutting distress type was in second place, potholes were in third place, and the other distress also were ranked as shown in the above table.

Table 4. Shows the Scenarios, Criteria, and Variants

Decision Analysis Module for Excel. Number of scenarios = 9, Number of criteria = 2, Number of variants = 11										
Names of scenarios:										
Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9		
Names of criteria:										
Area	Severity									
Names of variants:										
Pothole	Crocodile crack	Subsidence	Long.crack	Ravelling	Lacy edge	Shoving	Corrugation	Rutting	Delimnation	Low shoulder gravel

Table 5. Evaluation of Variants for Scenario 1

Scenario 1

Criteria Comparison:

Criteria	Value	Criteria weights
Area		0.5
Severity		0.5

Evaluation of Variants According to Individual Criteria:

Area	Value	Severity	Value
Pothole	130	Pothole	2
Crocodile crack	130	Crocodile crack	2
Subsidence	150	Subsidence	3
Long.crack	20	Long.crack	2
Ravelling	230	Ravelling	2
Lacy edge	65	Lacy edge	1
Shoving	202	Shoving	2
Corrugation	21	Corrugation	3
Rutting	12	Rutting	1
Delimnation	250	Delimnation	3
Low shoulder gravel	256	Low shoulder gravel	2

Table 6. Total Weights and Ranked from Nine Scenarios

Total evaluation of variants:

CZn=	Weight	Rank
Pothole	0.065305173	3
Crocodile crack	0.039188854	5
Subsidence	0.025951328	8
Long.crack	0.021401435	10
Ravelling	0.079695903	1
Lacy edge	0.03867146	6
Shoving	0.040744799	4
Corrugation	0.017443236	11
Rutting	0.065987492	2
Delimnation	0.026121423	7
Low shoulder gravel	0.02393334	9

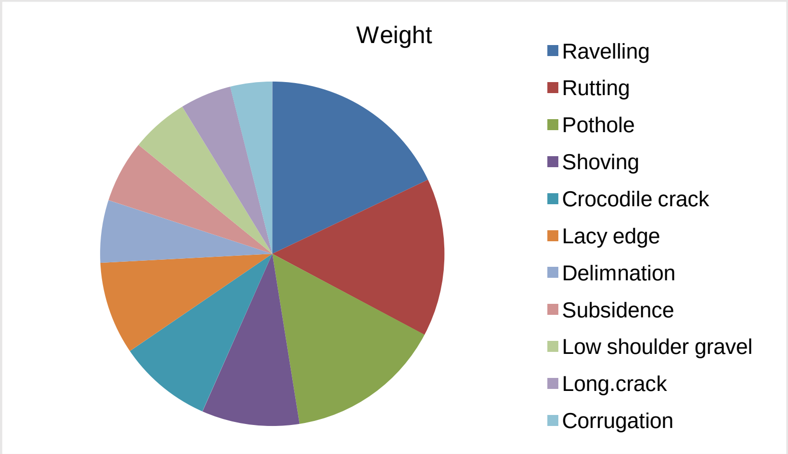


Figure 7. Total Evaluation of Variants

Table 7. Summary of Percentage Damage Area for the Ranked Distresses Comparison

Road Name Origin-Destination	PDA of Raveling (%)	PDA of Rutting (%)	PDA of Shoving (%)	PDA of Crocodile (%)	PDA of Pothole (%)
Road-1: Sar Bet -Minaye Building	17.56	-	-	9.92	9.92
Road-2: Alemtsehay Bridge-Wolega Hotel	22.52	-	36.09	1.32	20.70
Road-3: Adissu Gebeya-Comercial Bank Powlos Branch	37.87	-	-	6.31	20.73
Road-4: Paster - Shewa Tsega (Mesalemiya)	47.64	-	-	16.90	30.10
Road-5: Berbere Tera -Mola Maru (Kebele Meznagna)	60.55	-	17.83	0.26	20.34
Road-6: Debrezeit Menged -Sene Zetegn-Behere Steige	49.36	1.14	-	9.09	36.16
Road-7: Leadership Institute Jan Meda	-	8.80	-	0.56	72.47
Road-8: Alert Round About -Fm Radio Station	10.68	75.35	-	-	-
Road-9: Asfaw Tekle Hotel - Ehil Berenda	54.25	-	-	26.50	14.15
Road-10: Kolfe Coprative School - Filidoro School	11.09	46.33	25.89	-	-

The prioritization pf roads used the percentage damage of ranked distresses and road classification of sample roads to perform in the Super Decision Software. The percentage of damage to the ranked dominant distress is summarized, as shown in Table 7.

3.3. Ranking of Pavement Sections in Super Decision Software

In this study, a hierarchy was developed by considering several parameters at different levels of the structure. The first step in Super Decision Software was creating clusters and nodes for each parameter and linking them, as shown in Figure 8.

Clusters are the collection of nodes that have some logical relationship in a frame. Nodes are elements in the cluster that was pair wisely compared concerning the cluster (parental node) for importance, preference, or likelihood. Clusters will not be compared pairwise in the analytical hierarchy approach. The goal is a final judgment that was achieved. Criteria and sub-criteria are decision factors considered during decision making. Both criterion and sub-criterion are represented by a node on a super decision model. By linking the goal nodes to criteria node, criteria to sub-criteria, and sub-criteria to alternative, the following hierarchy was obtained.

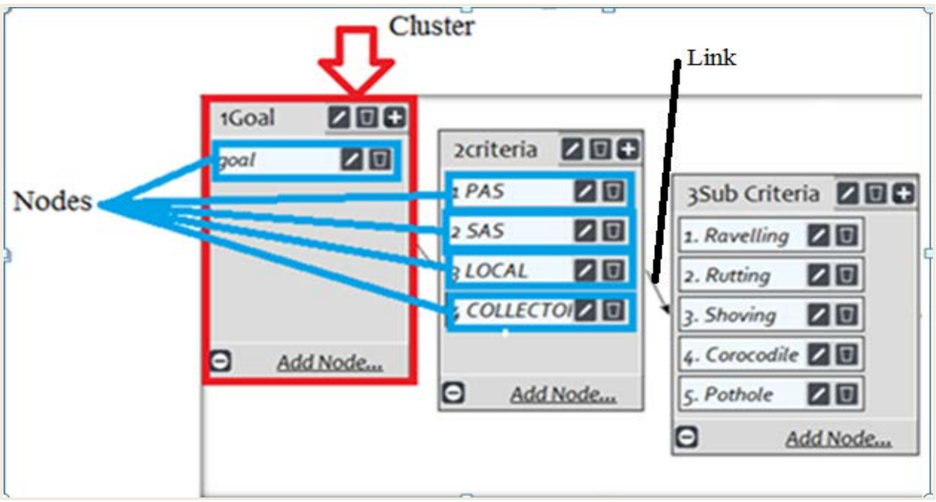


Figure 8. Cluster and Nodes in Super Decision Software

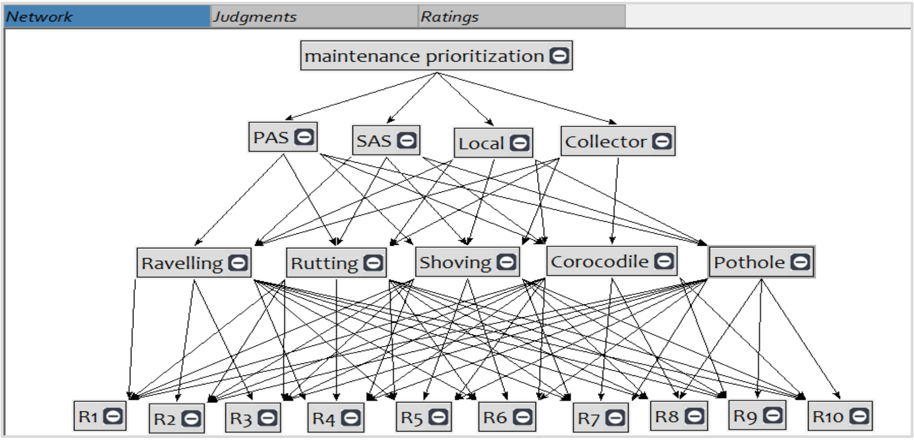


Figure 9. Decision Tree in Super Decision Software

Figure 9 shows the network part of super decision software that expresses the flow from goal to criteria then criteria to sub-criteria & last sub-criteria to alternatives. Maintenance prioritization was put at the top level as an essential goal. Road type classification and pavement surface distress are considered the modeling parameters of criteria and sub-criteria levels. The alternatives are the sample of ten road sections that were ranked. From here, the road section that has maximum priority rating value needs immediate attention from maintenance. The ranking was done on Super Decision Software. After the hierarchy was done, the second part was continued, which has three sub-parts.

The first judgment was to choose a part that shows the comparison to be made; a select node is a parent node in which choose cluster contains a children node compared with the parent node in the system. The second part of the judgment was comparing five possible modes, i.e., graphical, verbal, matrix questionnaire, and direct for entering assessments. Judgments entered in one mode will appear as equivalent judgments in any other mode except for the questionnaire that rounds off judgments from other modes. It is an important part of Super Decision so that the output depends on it. The five parts are discussed below.

3.3.1. Criteria Comparisons

The graphical method of judgments comparison shows the preferences, as shown in Figure 10. The higher the graph, the higher the preference, and the lower the graph gets lower preference concerning the comparison criteria.

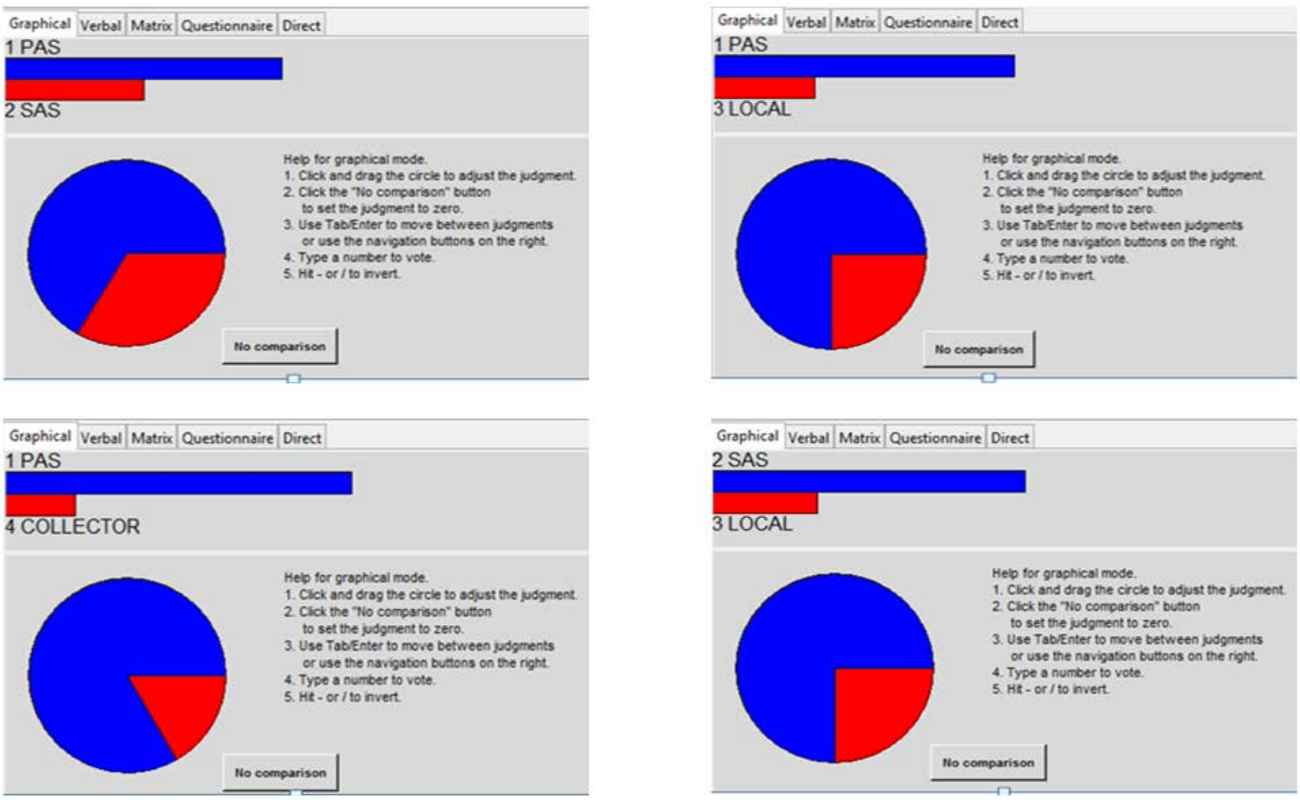


Figure 10. Graphical Representation of Judgments

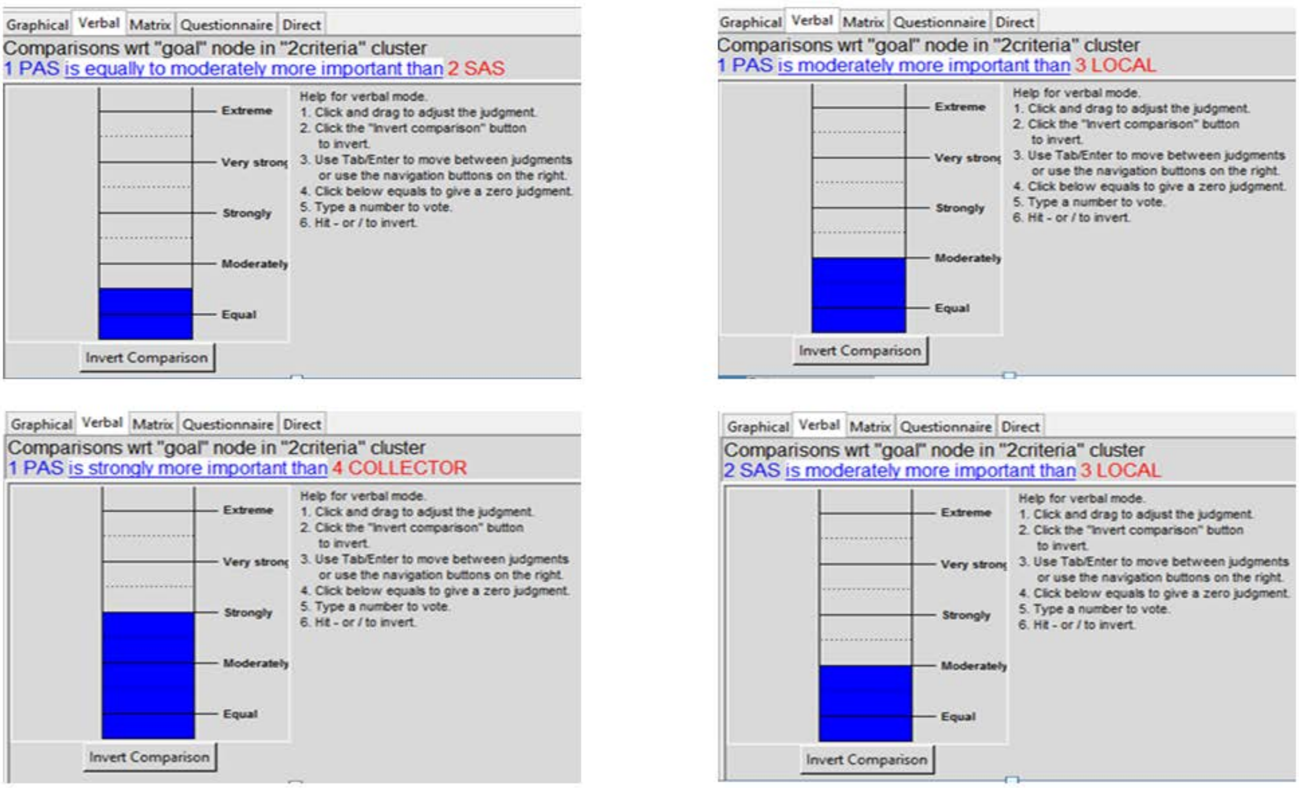


Figure 11. The Verbal Judgment Representations

The more important, more preferred, or more likely, node or criteria are entered. Suppose they have the same value, just simply toggling on the no comparison to make it equal. In the graphical method of judgment, only two criteria can be compared at once. The verbal method of judgments shows the preferences, as shown in Figure 11, based on the measures equal, moderately strongly, and extremely strongly and extremely preferences.

By clicking on the invert comparison button, it is possible to invert dominance. The comparison was written verbally on the above command. The matrix judgments on the Super Decision Software was done by entering judgments in cells by typing numbers from the Fundamental 1-9 Scale. The direction of the arrow indicated which criterion is more important. Double-click arrow to change the dominant element. In the phrase above the matrix, the first element was predominant.

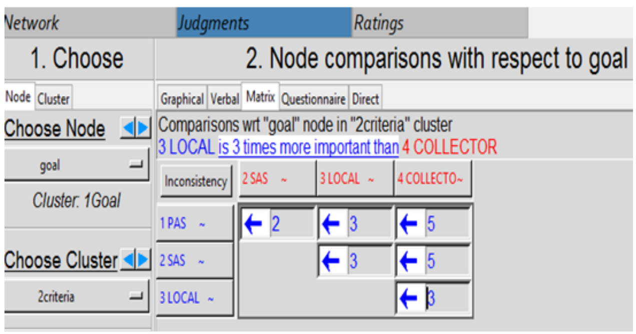


Figure 12. Matrix comparison representation of judgment

The current parent node is the Goal node, and the Criteria nodes are being compared concerning the Goal for importance. The matrix was done based on Satty's Nine Rating Scales, as shown in Table 8 below.

Table 8. Scale for Rating Criteria

Verbal Judgment of Preference	Numerical Rating
Extremely preferred	9
Very strongly to extremely	8
Very strongly preferred	7
Strongly to very strongly	6
Strongly preferred	5
Moderately to strongly	4
Moderately preferred	3
Equally to moderately	2
Equally preferred	1

The fourth comparison judgment type was the questionnaire. It was also done using the nine scales. The phrase above the questionnaire showed the first element was dominant, as shown in Figure 13 below.

The questionnaire was about to choose the judgment on the left or right side of the zero on the questionnaire line that is nearest to the more critical, more preferred, or more likely, node. Then each node was pairwise compared concerning goal on super decision media.

The fifth comparison judgment was the direct comparison of nods; it recorded available real data for the judgment comparison, which was not used in this study.

The third part of the judgment was the results which were obtained from the five comparison judgments. It is the percent influence weightage of criteria concerning the goal to prioritize the pavements. The weights of the criteria were sum to be one. Figure 14 below shows the weightage for the criteria used.

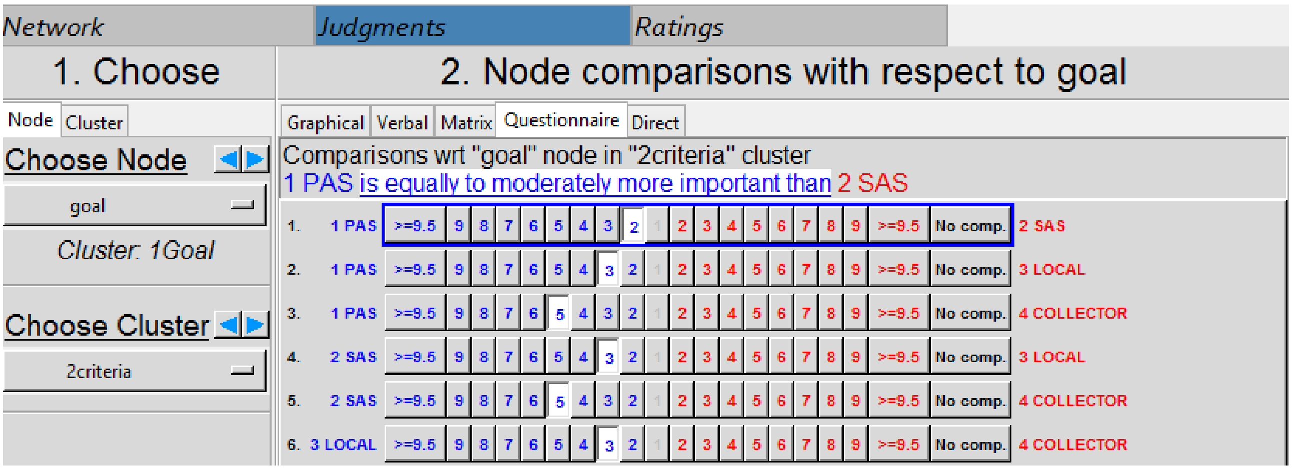


Figure 13. Criteria node comparison with respect to the goal

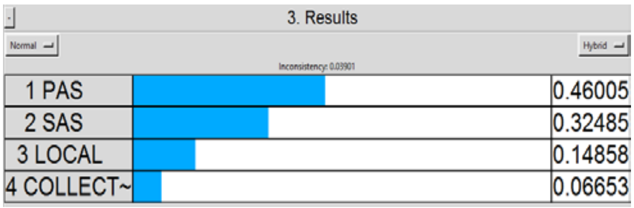


Figure 14. Weights for the Criteria

The above figure shows that Principal Arterial Street indicated the highest score, Sub Arterial Street, was second. At the same time, local and collector got the third and the fourth-ranked, respectively. During the result, the inconsistency should be less than 0.1, or else the comparison should be revised. Hence, in this study, the inconsistency index was 0.0391 less than 0.1, and it implies the data was correct and reasonably representative.

3.3.2. Sub Criteria Comparisons

As discussed above, the study has five sub-criteria that were analyzed and obtained from the Decision Analysis Module for Excel (DAME), represented by the different distress types such as raveling, rutting, and shoving crocodile cracking and potholes. Similarly, the criteria comparison, the sub-criteria, was also done by taking the five sub-criteria for contrast. The data obtained through the questionnaires were distributed to the responsible maintenance engineers and data collectors of the AACRA Office.

In this study, the questionnaire was filled by the maintenance engineers in the form of a matrix, as shown in Figure 15, based on Saaty's 1 to 9 scale. In the questionnaire, the respondent was about to choose the judgment on the left or right side of the zero on the questionnaire line nearest to the more critical, more preferred, or more likely, node. Then each node was pairwise compared in Super Decision.

Figure 15 shows the questionnaire data obtained from the AACRA Office, interpreted and has an inconsistency index of less than 0.1. It means that the less value the inconsistency, the more the data is reliable.

The following figure shows the result for the judgment, which had an inconsistency index of 0.02278 that was less than 0.1. The more the percentage of the weight implies the higher preference concerning the comparison node.

Figure 16 shows how important is Criterion 1 compared to Criterion 2 concerning the objective. In this case, raveling distress indicated a maximum score of 0.49079 out of 1, more important than the others. The second was rutting, and the third was shoving distress. The fourth and the fifth were crocodile cracking, and pothole distresses, respectively. The inconsistency was reasonably representative of the weights used for the rating of the ten selected sample road sections.

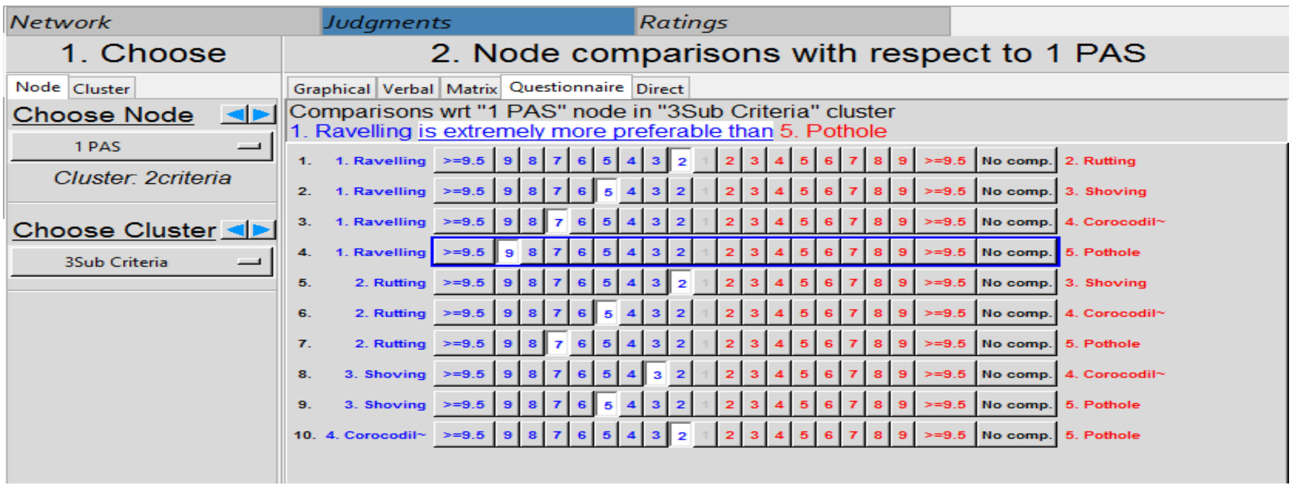


Figure 15. Questionnaire Format Comparison for Sub Criteria

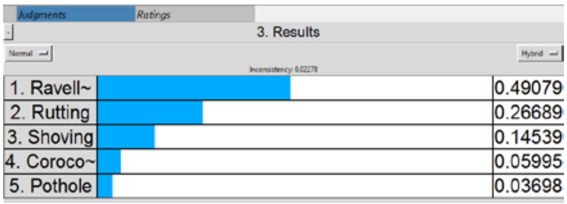


Figure 16. Result of Weights for Sub Criteria

3.3.3. Priority Rating

The final step after finding the weights for the criteria and sub-criteria was the rating of the alternatives. To rate the other options (selected sample road sections), there were three steps followed in general. The first part was about to choose the rating criteria. In this study, both the criteria and sub-criteria considered for the rating of ten road sections, as shown in the figure below.

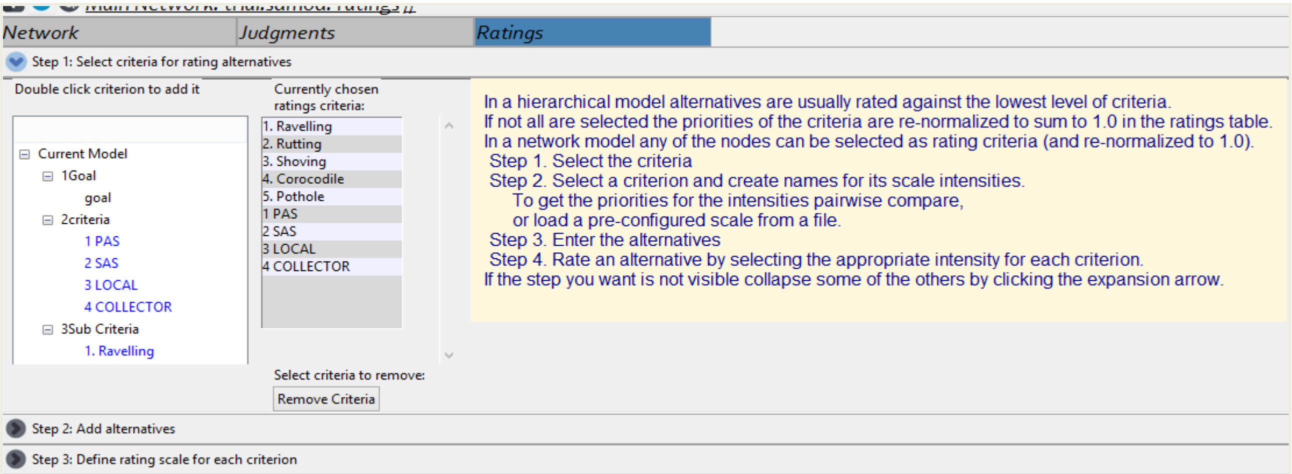
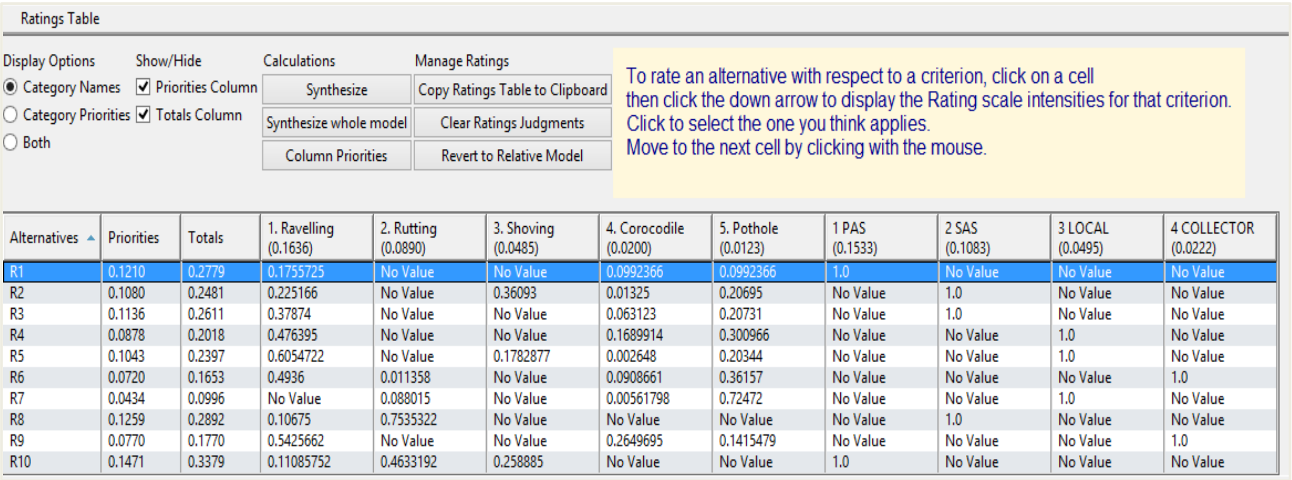
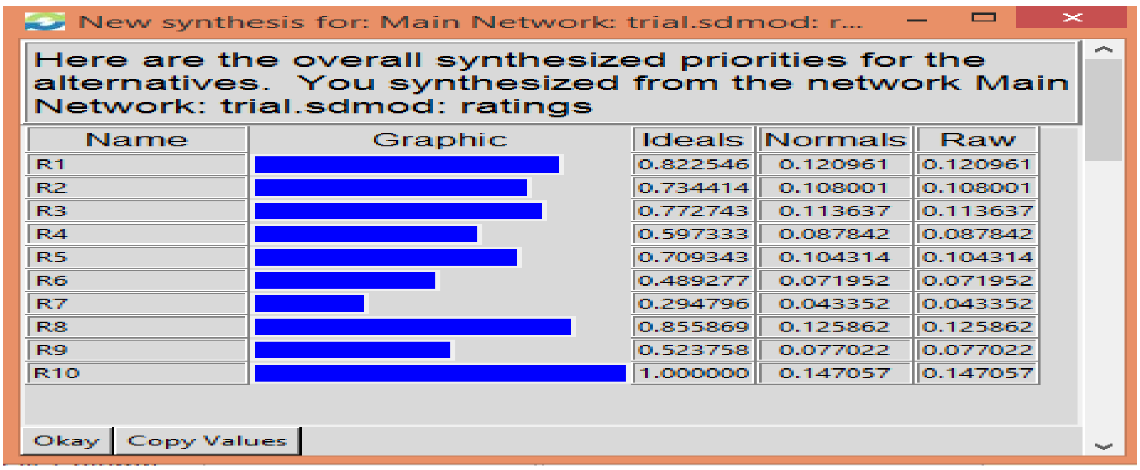


Figure 17. Selecting the Rating Parameters



Alternatives	Priorities	Totals	1. Ravelling (0.1636)	2. Rutting (0.0890)	3. Shoving (0.0485)	4. Corocodile (0.0200)	5. Pothole (0.0123)	1 PAS (0.1533)	2 SAS (0.1083)	3 LOCAL (0.0495)	4 COLLECTOR (0.0222)
R1	0.1210	0.2779	0.1755725	No Value	No Value	0.0992366	0.0992366	1.0	No Value	No Value	No Value
R2	0.1080	0.2481	0.225166	No Value	0.36093	0.01325	0.20695	No Value	1.0	No Value	No Value
R3	0.1136	0.2611	0.37874	No Value	No Value	0.063123	0.20731	No Value	1.0	No Value	No Value
R4	0.0878	0.2018	0.476395	No Value	No Value	0.1689914	0.300966	No Value	No Value	1.0	No Value
R5	0.1043	0.2397	0.6054722	No Value	0.1782877	0.002648	0.20344	No Value	No Value	1.0	No Value
R6	0.0720	0.1653	0.4936	0.011358	No Value	0.0908661	0.36157	No Value	No Value	No Value	1.0
R7	0.0434	0.0996	No Value	0.088015	No Value	0.00561798	0.72472	No Value	No Value	1.0	No Value
R8	0.1259	0.2892	0.10675	0.7535322	No Value	No Value	No Value	No Value	1.0	No Value	No Value
R9	0.0770	0.1770	0.5425662	No Value	No Value	0.2649695	0.1415479	No Value	No Value	No Value	1.0
R10	0.1471	0.3379	0.11085752	0.4633192	0.258885	No Value	No Value	1.0	No Value	No Value	No Value

Figure 18. Rating of Alternatives based on Criteria and Sub criteria



Name	Graphic	Ideals	Normals	Raw
R1		0.822546	0.120961	0.120961
R2		0.734414	0.108001	0.108001
R3		0.772743	0.113637	0.113637
R4		0.597333	0.087842	0.087842
R5		0.709343	0.104314	0.104314
R6		0.489277	0.071952	0.071952
R7		0.294796	0.043352	0.043352
R8		0.855869	0.125862	0.125862
R9		0.523758	0.077022	0.077022
R10		1.000000	0.147057	0.147057

Figure 19. Synthesis of the whole model

In the hierarchical model, most of the time, the lowest criteria are used for priority rating. However, in this study, both the criteria and sub-criteria were utilized for priority rating road sections. It is believed that both directly influence the target objective. The Super Decision Software recalculated and normalized the matrix weights to give 100% or sum to 1 since the criteria were pairwise compared before. The new recalculated and normalized matrix weights are used with the corresponding data for each sample road that was entered in the Super Decision Software.

In the above Figure 18, it showed the rating table format on Super Decision Software. It was shown that the data for the criteria and sub-criteria were recorded for the ten selected sample road sections. For No value, it implied there is no data for that specific criteria or sub-criteria. The Super Decision Software will calculate the total weights for the roads and give a priority based on the weights. The ratings were obtained from priorities. By synthesizing, the new normalized weights of the criteria and sub-criteria were obtained. Likewise, synthesizing the whole model can provide the possible priorities of alternatives.

The overall synthesis of the ten selected sample road sections is shown in the figure below, indicating a graphic form and priorities in three columns (i.e., ideal, normal, and raw sum). All forms indicated the same ranking of road samples means. It gave high value for R10, R8, R1, R3, R2, R5, R4, R9, R6, and R7.

The synthesis of the whole model shows the importance of alternatives concerning the goal. In this study, there were ten alternative road sections and prioritized maintenance based on calculated and synthesized, as shown in Figure 19. There were three priorities; all indicated the same priority rank with different values.

The higher the priority value implies, the higher urgency needs for road maintenance, while the lower priority means low urgency for the maintenance of the road section. The normal synthesis weights are usually taken as a preference percentage weight for the alternatives. From the synthesis result, it was found out that the sample. Road-10 had a higher weight, and the Road-7 had a lower weight preference with respect to prioritization. The rest R8, R1, R3, R2, R5, R4, R9, R6, and R7 will get the next highest urgency maintenance in descending order. Since the road samples were having a different combination of sub-criteria and criteria values, they had a different normal weightage value. After knowing the ideal, normal, and raw priorities, the next step was about finding the priority weightage for the final rank. It was possible to rate the road samples since the recalculated weights of criteria and sub-criteria were used as comparison weights of the ten road sections.

In the sensitivity analysis, this study considered to analyze how the priorities of the alternatives changed as it varies the priority of a criterion. The sensitivity analysis for the selected road sections performed concerning the objective, as shown in the figure, and there is no variation as the parameters vary. Hence, the road sections were taken as the final ranking for maintenance prioritization. The final ranking showed R10 needs a maximum priority and ranked first. The remaining R8, R1, R3, R2, R5, R4, R9, R6, and R7 ranked 2nd, 3rd, 4th, 5th, 6th,7th, 8th 9th and 10th on maintenance, respectively.

4. Conclusion

In Addis Ababa City Road Authority (AACRA), the maintenance programs were found subjectively as evidence of the unavailability of data used for the previous prioritization techniques. Traditional methods were used without considering multi-criteria in maintenance prioritization that is supposed to be cost and time-saving. Fixed maintenance prioritization technique is not possible to maintain the road sections fairly and will lead the other road sections to further damage, and escalated unexpected maintenance expenses may occur. Generally, the following conclusions on the four points can be drawn from the findings:

4.1. Conclusion on Percentage Damage Determination

In this study, the percentage of damage and damage area calculations performed for all distress types collected on the ten sample road sections. The percentage of damage indicated the amount of distress quantified from 100% damage. It means the coverage of single distress from the total damage. The total damage area was the sum of individual distress areas to determine the coverage of all distresses from the sample road's total area. The percentage of damage was obtained by dividing the individual distress area to the total damage area. Hence, for this study, only five distresses were considered and analyzed on the Decision Analysis Module for Excel (DAME) for further analysis in the prioritization process.

4.2. Conclusion on the Super Decision Software

A multi-criteria consideration to prioritize the pavement sections for maintenance can give a great advantage in annual programming. It was observed that the developed Analytic Hierarchy Process (AHP) model works sufficiently, yields adequate results, and provides accurate decisions. In this research, Super Decision Software was used for the prioritization of the ten sampled road sections. It utilized the Analytic Hierarchy Approach technique that the alternatives are prioritized accordingly by considering four important indices (criteria), including five important sub-indices (sub-criteria) selected objectively. These criteria are based on road classification data for Principal Arterial Street, Sub Arterial Street, Local and collector type of roads taken from AACRA road classification. At the same time, the sub-criteria obtained from the field condition assessment and Decision Analysis Module for Excel results, namely Raveling, Rutting, Pothole, Shoving, and crocodile cracking. All the criteria and sub-criteria were paired wisely compared to know the influence weighs of the criteria and sub-criteria. The comparison of more than one measure application in the same decision can determine the best outcome if there are resources to achieve. Hence, in this study, the ranking revealed how the alternatives are essential to the goal by considering different criteria and sub-criteria. The higher the priority shows, the higher the urgency need for maintenance.

Results indicated that the priority weights of R10 were high. Therefore it received the priority for the maintenance activities, while the other road sections R8, R1, R3, R2, R5, R4, R9, R6, and R7 got 2nd, 3rd,4th, 5th, 6th,7th, 8th 9th and 10th priority rankings for pavement maintenance, respectively.

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