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Quantifying Multi-Criteria Approach for Identifying the Priority Level of Rural Road Projects

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Abstract: *This paper presented a simplified approach for quantifying the multi-criteria used in road projects prioritization in the developing countries considering the local conditions such as environmental, socio-economic conditions, local characteristics and materials resources. The study scope includes three stages; engineering studies, economic analysis, and quantifying the multi-criteria. Forty three road sections were selected in four governorates in Upper Egypt; Fayoum, Menia, Assuit and Sohag to cover agricultural and desert rural roads. The chosen roads also covered different land uses activities such as industrial, development and agricultural areas. The considered criteria included governorates roads priorities, economic analysis impact, served population, served area type, cost/budget ratio, environmental impact, level of readiness and traffic counts availability. A ranking factor was calculated for each the identified road sections by using three different methods; economic analysis, weighted criteria approach, and equal weights criteria approach. Results of analysis indicated that considering the multi-criteria approach caused a great change in roads priorities. The most effective criteria included the governorate priorities, served population, and served area types. Economic evaluation can't be considered the only prioritization criteria when the government authorities do not search for revenue rather than presenting access to markets and social activities. Finally, a prioritization matrix was developed for calculation of projects ranking factors.*

Keywords: *Road Priority, Multi-Criteria, Quantifying, Socio-Economic Evaluation*

I. Introduction

Rural roads have been considered an important assets used by the World Bank for reducing the poverty levels and consider them as keys for raising living standards in poor rural areas [1]. By reducing transport costs, roads are expected to generate market activity, affect input and output prices, and foster economic linkages that improve agricultural production and other production decisions. Reference [2] indicated that by facilitating access to social service facilities, better roads improve the social outcomes.

During the appraisal of rural road projects, government authorities have measured the benefits based on the vehicle operating cost savings, and time savings. Rural roads agencies have observed that benefits are likely to be much broader [3]. Road projects usually have been evaluated according to the economic evaluation in such a way to investigate whether the project is beneficial to be constructed. The decision makers have the choice to give the priority to a specific project rather than another according to its revenue to the authority.The above analysis is acceptable for the investment companies since the main factor that controls their decision is the benefit or revenue from the investment. Government authorities have other factors that control the decision for applying projects for construction or not. These factors include socio and socio economic parameters that have a greater consideration to the served population for development rural areas and reaching to the basic social activities and markets.

The Road Economic Decision Model (RED) for the economic evaluation of low volume roads of the World Bank [4] is generally used in the economic evaluation of road projects. The model computes the project Internal Rate of Return (IRR) and the Net Present Value (NPV) factors that represent the benefits or revenue of the investment cost [5]. The Model considers multi-criteria giving all the criteria equal weights at the equal levels. The Model collected the criteria for reference only and they are not included on the economic evaluation. The economic analysis of roads requires the definition of their surface roughness. Reference [6] relates the International Roughness Index (IRI) to the measurements of pavement distresses such as rutting, cracking, patching, weathering and raveling. Reference [7] formulates a relationship for predicting the IRI from the pavement surface distresses.

The Office of Quality Improvement, University of Wisconsin-Madison [8] developed a simple proven approach for setting priorities when the amount of work that needs to be done surpasses the available resources. It created a simple prioritization matrix to make tough decisions. The matrix provides a means for ranking projects based on criteria that are determined to be important. Each department should determine its own unique criteria (called your criteria) and weight them based on values, strategic direction, organizational goals, available resources, and so on. The Office Team suggested the important criteria to include the Required Service or Product, the Strategic Alignment and the Value to Customer. The criteria weights included 5.00 for the

Required Service or Product, 4.00 for Strategic Alignment and 4.00 for the Value to Customer. Then, they rated the scale of each criterion from 1.00 to 9.00; they put 1.00 for little effect, 5.00 for medium effect and 9.00 for high effect. Then, the numeric rating the project is given for a particular criterion is multiplied by the criteria's weight to create a priority score.

The State of Vermont Transportation Agency (VTrans) [9] developed a quantitative project prioritization method that assigns a numeric score to competing projects. Under that strategy, greater emphasis is placed on preserving bridges, pavement, culverts and other assets. The work team meetings resulted in setting out the input factors for each type of assets and its relative scores. The considered prioritization factors for Paving Projects included the Pavement Condition Index (20 points), the Benefit/Cost (60 points) and the Regional Priority (20 points). The Hampton Roads Transportation Planning Organization [10] conducted a report on the Prioritization of Transportation Projects in December 2010. It specified three major criteria for the evaluation process; they included the Project Utility (100 points), Economic Vitality (100 points), and Project Viability (100 points). The Pennsylvania Department of Transportation and Federal Highway Administration [11] conducted a report on the Project Prioritization Process & Scoring Methodology. It specified five major criteria for weighting and evaluation process of the highway restoration; they included the classification of the network (31% weight), the Average Annual Daily Traffic (AADT) (12% weight), the International Roughness Index (IRI) (31% weight), the percentage of trucks (14% weight), and the resurfacing date (12% weight). Each of the above mentioned criteria was sub-divided into sub-criteria and each of them had given a special score according to its importance based on the experience of the team work.

The Metropolitan Planning Organization (MPO) for the Tulsa metropolitan area [12] established a selection process for the distribution of Surface Transportation Plan (STP) funds. Priority funding will be given to projects that meet its federal regulations, and help advance the Regional Transportation Plan in different transportation areas. The seven evaluation criteria and their weights were set by the team work experience; they included Travel Time Improvements (16 points), Safety Improvements (20 points), System Maintenance and Management (16 points), Project Preparation (16 points), Livability (10 points), Freight Movement and Intermodal Linkages (12 points), and Special Benefits (10 points) with a total of 100 points. The Fredericsburg Area Metropolitan Planning Organization [13] conducted a methodology used for the evaluation and prioritization of road projects. The methodology was conducted based on the collective experience of other Metropolitan Planning Organizations and localities. The methodology used readily accessible information in evaluating projects based on the major factors; Congestion relief (30 points), Safety and Security (30 points), Environmental Impacts (16 points), Public and Community support (8 points), funding and Implementation Considerations (8 points), and smart Growth/Mobility (8 points). The organization team work set an experience guide for the scoring of the sub-divided categories of each of the above mentioned factors; all the scores were set based on the experience of the team work.

It is concluded from the previous literature that the evaluation criteria for the prioritization process differs greatly from one organization or department to another. It differs also according to the goal of the study; strategic planning study or specific study. Each organization considered its prioritization factors and they are unique for each process taking into consideration the local circumstances. The weighting scores for each factor or criteria may differ from one organization to another. There is not a systematic procedure for defining the criteria weightings and scores. All criteria weights and rating scores are defined by conducting meetings and discussions based on the experience of the team works.This paper tried to allocate and quantify the local affecting factors that can be considered important in the prioritization process of the local rural roads. The following sections present the objectives of the study as well as the study methodology. Data collection section presents the definition of road sections and their current situation, roads inventory, inspection and evaluation of pavement conditions, defining maintenance/rehabilitation upgrading strategies, and traffic survey. The followed sections included the economic analysis and the multi-criteria quantification approach. The analysis of results, conclusion and recommendations were come on the end of the study. The study objectives included presenting a simplified approach for quantifying the multi-criteria used in road projects prioritization taking into consideration the environmental and socio-economic conditions, the local area characteristics and materials status. It included also prediction of simplified prioritization matrix including the weights and recorded scores of the considered multi-criteria.

II. Methodology

To study methodology was divided into three stages; including the engineering studies, the economic analysis, and the quantification process of the local multi-criteria.

A. Engineering Studies

The engineering studies included identifying the highest priority roads in the study area, identification of evaluation criteria and relevant factors, specifying the list of roads proposed for construction, performing

traffic counts, road pavements inventory, defining maintenance/upgrading strategies and cost estimates.

B. Economic Analysis

The economic analysis included defining vehicle fleet characteristics, the investment costs of road sections, forecasting future traffic, determining the Internal Rate of Return (IRR) for each road section using the World Bank's RED model and ranking road sections according to their economic evaluation criteria (IRR).

C. Multi-Criteria Quantification

The quantification of multi-criteria included defining a set of local criteria affecting roads evaluation, investigating the effect of each criterion on road ranking, defining the relative weight and record score for each criterion through performing many meetings and discussions with governments' road experts, roads directorates Engineers, and defining the average weights and scores of the specified criteria.About thirty five roads relatives in the four governorates were given a prepared form including all the intended criteria and each of them was asked to give a record for each criterion and its relative weight to the other criteria. The collected data were then filtered and analyzed to isolate the criteria records from the criteria weighting. Then, the criteria were shortened to the specified eight criteria and had taken the mentioned weights described in the following sections.The Ranking Factor (RF) is the combination of all the considered criteria. It is calculated by multiplying the criteria weights by its corresponding categories record scores and then the summation of the calculated values is the Ranking Factor (RF); Equation (1) presents this relationship.

$$RF = \sum_{i=1}^{n} P_i R_i \quad \text{..... (1)}$$

Where; RF is the Ranking Factor, %
Pi is the relative weight % of criterion i
Ri is the corresponding statues record of criterion i, %
n is the number of the considered criteria

III. Data Collection

Multiple activities were performed in order to accomplish the overall objectives. Such activities included identification of roads of highest priorities, site visits, pavement surface condition survey, collecting data to the identified roads, traffic counts survey, and analysis of the collected data.

A. Road Sections Definition

Forty three road sections were selected in four governorates to cover as much as different types and characteristics of rural agricultural and desert roads; these governorates included Fayoum, Menia, Assuit and Sohag, as shown on Table 1.

B. Roads Inventory and Survey

Road inventory sheet has been used to record all physical properties for each road segment including section length, width, shoulders widths, side slopes, adjacent water canals, level of water in the adjacent canals, speed humps, …… etc.

C. Inspection and Evaluation of Pavement Conditions

Inspection of pavement surface conditions for road sections were carried out using the Visual Inspection Method including distress types, severity, and quantities as well as the most famous distresses. Each kilometer of road section was inspected and evaluated through calculating its Pavement Condition Index (PCI), and then the average rating for the whole road was identified.

D. Defining Maintenance/Rehabilitation Upgrading Strategies

Suitable rehabilitation/upgrading strategy for each road section was specified according to the pavement condition rating as set by the General Authority for Roads, Bridges and Land Transportation manuals and according to the Egyptian Code for Urban and Rural Road Works [14]. The rehabilitation strategies include "Do Nothing" for excellent and very good pavement conditions, "Overlay" for good pavement conditions, "Upgrade" for fair and poor conditions and "Reconstruction" for very poor and failed pavement conditions.

E. Traffic Survey

Traffic surveys were carried out for the selected roads to define the traffic volumes as well as traffic composition and amount of movements on each road section.

1. Count duration and timing

Traffic counts surveys were conducted for Eight (8) Hours on working days. This specified duration is chosen to cover the morning and the afternoon peak hours that have the high traffic volumes during the day. It covered the morning peak hours (from 07:00 to 11:00) and the afternoon peak hours (13:00 to 17:00). The morning peak hours represent the traveling hours for students and the employees as well as the other routine daily trips of other peoples. The afternoon peak hours represent the return hours of them. Traffic survey locations were chosen to cover a reasonable length of the road sections. For long roads, different locations were chosen for traffic survey while one location was chosen for each of the short road sections.

2. Prediction of average daily traffic (ADT)

Average Daily Traffic (ADT) is predicted by calculating the counted traffic volume during the specified duration (8 hours), and then multiplied by a mathematical combination of the day factor, the seasonal factor, and the hourly factor. All these factors have been investigated and an approximate combination factor was calculated to be 1.35 times the counted 8 hours traffic volumes. Table 1 also shows the Average Daily Traffic (ADT) for all road sections.

IV. Strengthening (Upgrading) Works

Rehabilitation works include three basic tasks, they are; Reconstruction, Upgrading, and Overlay. The reconstruction will be performed for road sections that rated as very poor or failed; this rate is subjected to the destroyed road sections. The upgrading will be performed for road sections that rated as poor to Fair; this rate is given to sections with cracks and/or other distresses that were not reached to higher severities. The overlay strategy was suggested to road sections that have good ratings.

V. Cost Analysis

Cost analysis and estimation for the proposed rehabilitation/upgrading strategies was conducted for the specified roads. It includes the estimation of the quantities of different tasks of each strategy. The suggested rehabilitation/upgrading strategies were specified based on the existing pavement quality and its corresponding rating. Table 1 also provides the estimated rehabilitation/upgrading costs.

VI. Economic Analysis

Economic analysis of road sections was performed using the Roads Economic Decision Model (RED) of the World Bank that developed to improve the decision-making process for the development and maintenance of rural roads. The model performs economic evaluation of road investments options using the consumer surplus approach and is customized to the characteristics and needs of traffic volumes, which measures the benefits to road users and consumers of reduced transport costs. This approach was preferred to measure the value added to productive users in the project zone of influence. The steps in determining the cost benefit analysis of road project included determining the basic road characteristics, setting up vehicle fleet characteristics, investigation of population, Average Daily Traffic (ADT), and annual traffic growth rate (r) & vehicle composition for each road section.

It also included setting out roads identification, currency, and evaluation date, identification of economic unit prices/utilization/service life of vehicle types, setting up road agency economic cost factor, calculation of Vehicle Operating Costs/Travel time & accident Costs; Identifying and quantifying the costs and benefits; Estimating the Internal Rate of Return (IRR) and Net Present Value (NPV) discounted at 12% discount rate. The details of economic analysis as well as the sensitivity analysis for the identified road sections are presented on another paper by the Author; the final economic analysis results for the identified road sections are shown on Table 1.

VII. Multi Criteria Quantification

Prioritization of road projects is influenced by a combination of multiple factors (multi-criteria) such as; governorates priorities according to its importance for the social impacts to the population, available budget, and the cost/benefit analysis. Other criteria may affect the prioritization of roads; they include the served population, area type, materials availability and readiness level as well as traffic count availability.

A. Criteria Weighting

The local criteria that affect the ranking of road projects have been defined; they include governorate priorities, economic impact, served population, served area types, available budgets (Cost/Budget ratio), environmental impact, level of readiness for implementation; and traffic count availability. Based on the experience of road experts in highway agencies, authorities, and co-operations, many discussions and meetings were performed at the considered governorates to define the relative weights of each criterion and the evaluation

record scores of their categories. After analyzing the collected data, it is believed that the most important criteria for ranking road projects are the governorate priorities. On second important criteria comes the economic impact of the road project and the served population. Those elements/criteria keep the highest percentage within the others. The served area type is coming on the third importance since it is directed to serve as much population as possible through locating in areas with potentials. Remaining criteria are also important but they are technically related issues. Table 2 presents the defined criteria and their weights.

Table 1: Roads Characteristics, Investment Costs and Economic Analysis Results

Gov.	Road Sec.	District	Length (km)	Width (m)	Type	ADT (vpd)	IRI	Cost, M$/km	C/B Ratio	NPV, M$	MIRR, %
Menia	R 01	Edwah	12.0	6.00	Existing	3770	6	0.207	0.311	12.806	24%
	R 02	Magha	10.0	6.00	Existing	3770	6	0.207	0.259	10.671	24%
Muhit Road	R 03	Mazar	08.5	6.00	Existing	3770	6	0.207	0.220	9.071	24%
	R 04	Samal	10.0	6.00	Existing	3770	4	0.207	0.259	5.230	20%
	R 05	Samal	09.5	6.00	Existing	3770	4	0.207	0.246	4.968	20%
	R 06	Minia	10.0	6.00	Existing	1050	4	0.207	0.259	0.232	13%
	R 07	Minia	10.0	6.00	Existing	1050	4	0.207	0.259	0.232	13%
	R 08	Qorqas	17.0	6.00	Existing	1050	4	0.293	0.623	-0.848	11%
	R 09	Malawi	10.0	6.00	Existing	3285	4	0.207	0.259	4.339	19%
	R 10	Malawi	10.0	6.00	Existing	3285	8	0.207	0.259	13.939	26%
	R 11	Mowas	12.0	6.00	Existing	950	8	0.207	0.311	3.390	18%
Serry Basha Road	R 12	Magha	07.0	6.00	Existing	265	8	0.201	0.176	-0.018	12%
	R 13	Mazar	10.5	6.00	Existing	265	8	0.201	0.264	-0.026	12%
	R 14	Matai	04.0	6.00	Existing	265	6	0.201	0.101	-0.209	10%
	R 15	Samal	12.0	6.00	Existing	265	6	0.201	0.302	-0.626	10%
	R 16	Samal	13.0	6.00	Existing	265	4	0.201	0.327	-1.331	7%
	R 17	Minia	17.0	6.00	Existing	265	4	0.201	0.427	-1.741	7%
	R 18	Qorqas	15.0	6.00	Existing	265	6	0.201	0.377	-0.783	10%
	R 19	Malawi	04.0	6.00	Existing	265	8	0.201	0.101	-0.010	12%
Khergen Road	R 20	Edwah	10.0	6.00	Existing	1816	8	0.130	0.163	8.307	25%
	R 21	Edwah	09.0	6.00	Existing	1816	6	0.130	0.146	4.864	23%
	R 22	Magha	04.5	6.00	Existing	1816	4	0.130	0.073	1.145	19%
	R 23	Mazar	10.0	6.00	Existing	1816	4	0.130	0.163	2.545	19%
	R 24	Mazar	10.0	6.00	Existing	1816	4	0.130	0.163	2.545	19%
	R 25	Matai	08.0	6.00	Existing	1816	4	0.130	0.130	2.036	19%
	R 26	Samal	16.0	6.00	Existing	1816	4	0.130	0.260	4.072	19%
	R 27	Minia	10.0	6.00	Existing	1816	4	0.130	0.163	2.545	19%
Fayoum	R 28	G. Saad	16.0	8.00	Existing	2940	8	0.174	0.348	13.434	24%
	R 29	Tobhar	13.0	8.00	Existing	2492	8	0.185	0.301	8.848	22%
	R 30	Sonors	18.0	8.00	Existing	1813	8	0.208	0.468	3.485	16%
	R 31	Defino	06.0	6.00	Existing	786	20	0.160	0.120	5.839	25%
	R 32	Shawsh	06.5	6.00	Existing	62	20	0.163	0.132	0.496	15%
Assuit	R 33	Dronka	10.0	8.00	New	4780	20	1.091	1.364	39.032	22%
	R 34	Dronka	11.0	8.00	New	4780	20	1.091	1.500	42.935	22%
	R 35	Manflot	14.0	6.00	Existing	2565	4	0.198	0.347	1.659	15%
	R 36	Manflot	14.0	6.00	Existing	2565	6	0.198	0.347	4.324	18%
	R 37	B Korra	12.0	6.00	Existing	574	4	0.188	0.282	0.066	12%
	R 38	B Korra	12.0	6.00	Existing	574	6	0.188	0.282	1.640	16%
	R 39	Dierot	10.0	6.00	Existing	590	4	0.186	0.233	-0.177	11%
	R 40	Dierot	10.0	6.00	Existing	590	6	0.186	0.233	0.901	15%
Sohag	R 41	Jehina	10.0	6.00	Existing	1674	4	0.200	0.250	0.060	12%
	R 42	Jehina	10.0	6.00	Existing	1674	4	0.200	0.250	0.060	12%
	R 43	Jehina	12.0	6.00	Existing	530	8	0.200	0.300	-0.302	11%
Notes: C/B : Cost/Budget Ratio,			IRI: International Roughness Index,			NPV: Net Present Value,			MIRR: Modified Internal Rate of Return		

B. Multi-Criteria Categories and Weights

Each of the above mentioned criteria is divided into categories with relative record scores. The following subsections describe these categories and their relative scoring based on the analysis of the collected data from the performed meetings and discussions.

Table 2: Defined Criteria and their Weights

No.	Key Criteria	Weight, %
1	Governorates Priority	25
2	Economic Impact	20
3	Served Population	20
4	Type of Served Area	15
5	Cost / Budget Ratio	5

6	Environmental Impact	5
7	Readiness Level & Preliminary Studies Availability	5
8	Traffic Count Availability	5
	Total	100%

1. Governorate priorities

Weight of this criterion is based on the importance of the road from the opinion of Governorate Officials. The higher priority road project will take a record of 100% and the following priority road will take 50% while the third priority will take 25%.

2. Economic impact

This criterion uses the Internal Rate of Return (IRR) to rank the road projects. Five categories are classified; the highest is for roads with IRR greater than 100% and then followed by four categories ranging from 0 to 99%. Table 3 describes the categories of this criterion and their relative weights.

3. Served population records

Categories for this criterion are divided into seven levels based on the served population. The highest record 100% is given to road section that serves more than 200,000 capita while the lowest 10% record score is given for that serves 20,000 capita or less. Table 4 provides served population categories and their relative record scores.

Table 3: Economic Impact (IRR) Categories

IRR Category	Record, %
IRR $\geq$ 100	100
50 $\leq$ IRR $<$ 100	75
25 $\leq$ IRR $<$ 50	50
12 $\leq$ IRR $<$ 25	25
0 $<$ IRR $<$ 12	0

Table 4: Served Population Categories Records

Population Category, Capita	Record, %
Population $>$ 200,000	100
101,000 $<$ Population $\leq$ 200,000	75
81,000 $<$ Population $\leq$ 100,000	50
61,000 $<$ Population $\leq$ 80,000	40
41,000 $<$ Population $\leq$ 60,000	30
21,000 $<$ Population $\leq$ 40,000	20
Population $\leq$ 20,000	10

4. Served area records

Areas to be served with roads are classified into four categories representing the major four types of activities; they include Industrial, Development, Productive and Agricultural Areas. The highest record 100% is given to the areas of potential; industrial, development and productive. A lower record 50% is given to the agricultural area.

5. Cost/budget ratio records

This criterion is used to indicate how a specific road fits within the budget limits. Basics of this criterion are; the estimated cost for construction and the allocated budget. The highest record 100% is given to road sections with cost/budget ratio equal to or less than 0.100 so that the allocated budget for each governorate shall cover more than one road. The lower records are given to those above 1.00. The cost/budget categories are shown in Table 5.

6. Environmental impact

Categories of this criterion are following the World Bank Environmental Guidelines that divides them to three categories. They include Category A (Black), Category B (Grey) and Category C (White). A records of 25%, 50% and 100% are given to the three categories respectively as the white category is considered the best impact on the environment and the black category is the worst one.

Table 5: Cost/Budget (C/B) Ratio Categories Records

Cost/Budget (C/B) Category	Record, %
0.000 $<$ C / B Ratio $\leq$ 0.100	100
0.100 $<$ C / B Ratio $\leq$ 0.200	90
0.200 $<$ C / B Ratio $\leq$ 0.300	80

0.300 < C / B Ratio ≤ 0.400	70
0.400 < C / B Ratio ≤ 0.500	60
0.500 < C / B Ratio ≤ 1.000	50
1.000 < C / B Ratio ≤ 1.500	25
C / B Ratio > 1.500	0

7. Level of readiness

This criterion interprets easiness of road construction or by other wording the possible constraints that limit road construction as; a) Current construction of utilities i.e. water, sewerage, electric cabling etc. and b) Sever construction conditions i.e. mountainous areas, undefined route etc. This criterion also includes the availability of preliminary planning and studies. The highest record 100% is given to road with no constraints for implementation with availability of preliminary plans. Table 6 presents the categories of this criterion and their recording scores.

Table 6: Level of Readiness for Implementation

Implementation	Preliminary Plans	Symbol	Record, %
Easy	Available	EA	100
Easy	Unavailable	EU	50
Difficult	Unavailable	DifU	0

8. Traffic count availability

Traffic volumes on road sections are determined either through physical counts or predicted from other roads. Therefore traffic count has been performed for the existing roads and predicted for the new roads. The higher record 100% is given to road sections that have traffic counts, while 50% record is given to road sections that have predicted traffic. The 0.0% record is given to short length roads that haven't neither counted nor predicted traffic.

C. Calculation of Ranking Factor (RF)

The ranking factors (RF) for all road sections were calculated using equation 1. Table 7 presents the relative percentages and records as well as the Ranking Factors (RF).

VIII. Analysis of Results

A. Economic Analysis Prioritization

The economic analysis results for the identified road sections are shown on Table 1. It shows the calculated IRR and NPV for all road sections for the four governorates. The prioritization of road sections based on the IRR percentage indicates that for Menia governorate, road sections number R10 has the first priority with IRR = 26%, R20 has the second priority with IRR = 25%, while R01, R02, R03 have the third priority with IRR = 24%. It shows that, based on the economic evaluation, the road projects that have higher traffic volumes shall be more appraised for construction and have higher priority because the most effective factor in the economic evaluation is the revenue from save in vehicle operating cost (VOC) and travel time those directly related to the average daily traffic.

For Fayoum governorate, road section R31 has the first priority with IRR = 25% and followed by road section R28 with IRR = 24% while road section R29 comes on the third priority with IRR = 22%. Although road section R31 has ADT = 786 vpd and doesn't considered the higher one comparing with road sections R28 & R29 those have ADT = 2940 vpd & 2492 vpd respectively, it has the first priority due to having a roughness index = 20 which is higher than that for roads R28 & R29 those having IRI = 8. This indicates that the roughness index has greater effect on the IRR value because the higher roughness index refers to bad pavement performance that needs rehabilitation or upgrading strategy.

For Assuit governorate, roads R33 & R34 have the first priority with IRR = 22% and followed by road section R36 with IRR = 18% while road section R35 comes on the third priority with IRR = 15%. The first priorities road sections in this case have the higher traffic volume 4780 vpd and higher IRI = 20 since they are new roads. The higher traffic volume and higher roughness index resulted in higher IRR and higher priorities. For Sohag governorate, road sections R41 & R42 have the first priority with IRR = 12%. The two road sections have the higher traffic volumes and the roughness index. The third section in this governorate is not appraised for upgrading from the economic point of view.

B. Multi-Criteria Prioritization

Table 7 shows the Ranking Factor calculations according to the weighted multi-criteria using Equation 1. It shows that the ranking factor is affected by the multi-criteria weights and their categories records mentioned in Tables 2 through 6. It shows that the calculated ranking factor (RF) is mostly reflecting the effect of the considered multi-criteria. Results indicated that the multi-criteria weighted parameters give ranking

factors different than those of the economic analysis ranking. The overall ranking of road sections of Menia, Fayoum and Assuit Governorates were greatly changed where as those for Sohag Governorate didn't be changed. The change in ranking of Menia and Assuit roads were happened due to the change in local characteristics such as governorate priorities, served population, and served area type. For Fayoum governorate roads, the ranking change was happened due to the change in the served population; road section R28 was jumped from rank 2 to rank 1 due to considering the effect of the served population because it has the highest, 270,000 capita, served population in the governorate roads. The no change in ranking of Sohag roads was happened due to the homogeneous characteristics of them. This approach is more suitable for prioritization of road projects those have different local characteristics that differ from one road to another. Results also indicated that roads that haven't special local characteristics didn't affected by the multi-criteria consideration.

C. Equal Criteria Prioritization

Equal criteria weighting approach includes calculation of Ranking Factor for all roads using Equation (1) considering equal criteria weights. Each of the considered eight criteria had given 12.5% weight to form the 100% total weights. Table 8 presents the computed equal weighted Ranking Factors for all roads. The obtained ranking factors indicated that many roads priorities are slightly changed; some of them were preceded and some others were retreated. This approach is suitable for areas with homogeneous characteristics and need to consider all criteria with the same effect.

D. Comparison between Different Prioritization Methods

Table 8 presents a comparison between the three considered prioritization methods; economic analysis, weighted multi-criteria and equal weights criteria. The Table presents the analysis for the effect of changing the weights of the considered eight criteria. By comparing the ranking factors before and after considering the multi-criteria, the following changes in road ranking were observed: Comparing road ranking without inclusion of multi-criteria (considering the economic impact only) with those of inclusion of the multi-criteria for Menia Governorate, as shown on Table 8, indicated that road sections R10, R20, R01, R02 R03, R21, R04 and R05 had the following ranking 1, 2, 3, 3, 3, 3, 4, 5, and 5 respectively. This ranking was changed after the inclusion of the multi-criteria and became 1, 6, 2, 1, 1, 6, 1, and 1 respectively.

For Fayoum Governorate, the ranking based on the economic impact indicated that road sections R28, R29, R30, R31 and R32 had the following ranking 2, 3, 4, 1, and 5 respectively. This ranking was changed after the inclusion of the multi-criteria and became 1, 2, 3, 4, and 5 respectively.For Assuit Governorate, the ranking based on the economic impact indicated that roads R33, R34, 36, R38, R35, R40, R37, and R39 had the following ranking 1, 1, 2, 3, 4, 4, 5, and 6 respectively. This ranking was changed after applying the multi-criteria and became 1, 1, 5, 6, 2, 3, 4 and 5 respectively.

For Sohag Governorate, the ranking based on the economic impact indicated that roads R41, R42, and R43 had the ranks 1, 1, and 2 respectively. This ranking was not changed after the inclusion of the multi-criteria and remained 1, 1, and 3 respectively.

Finally, a prioritization matrix was developed that included all the identified weighted criteria and their relative categories record scores. The matrix is considered a simplified method to calculate the ranking factor for the intended road projects by the agency or department. The developed prioritization matrix is shown on Table 9.

IX. Conclusion

The final conclusions of this paper refer to that the multi-criteria parameters should be taken into consideration when applying road projects prioritization in rural areas. It shall include government's priorities, socio and socio-economic characteristics, served area type, materials availability, readiness level, and traffic survey availability. Different weights should be given to the chosen criteria to reflect their effects on the ranking process. Each area should have its own suitable criteria and weights that reflect its local conditions and characteristics. This approach is more suitable for prioritization of road projects that have different local characteristics. Equal weighted criteria approach is considered another method for road projects prioritization that gives equal weights for the considered criteria. This approach is suitable for areas with homogeneous characteristics and need to consider all of them with the same effect. The economic benefits should not be considered the only parameters that control the government's road projects prioritization since its goals are not focused on revenue but concentrated on serving the rural areas and increasing productivity. A prioritization matrix is developed and considered a simplified method for calculating a ranking factor for the intended road projects.

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Table 7: Weighted Multi-Criteria Prioritization and Ranking

Gov.	Criteria	1. Priority		2. Economic		3. Population		4. Area Type		5. C/B Ratio		6. Environ.		7. Readiness Level		8. Traffic		R F	Rank
	Relative %	P1 = 25%		P2 = 20%		P3 = 20%		P4 = 15%		P5 = 5%		P6 = 5%		P7 = 5%		P8 = 5%		100%	
	Road Sec	Pr	Pr R %	IRR, %	IRR R, %	Pop, Cap	Pop R, %	Type	R	Ratio	R, %	Categ.	R	Level	R	St.	R		
Menia (Muhit Road)	R 01	1	100	24%	50	55000	30	A	50	0.3105	70	B	50	E U	50	Av	100	62.00	2
	R 02	1	100	24%	50	45000	30	A	50	0.2588	80	B	50	E U	50	Av	100	62.50	1
	R 03	1	100	24%	50	45000	30	A	50	0.2199	80	B	50	E U	50	Av	100	62.50	1
	R 04	1	100	20%	50	45000	30	A	50	0.2588	80	B	50	E U	50	Av	100	62.50	1
	R 05	1	100	20%	50	45000	30	A	50	0.2458	80	B	50	E U	50	Av	100	62.50	1
	R 06	1	100	13%	25	45000	30	A	50	0.2588	80	B	50	E U	50	Av	100	57.50	3
	R 07	1	100	13%	25	45000	30	A	50	0.2588	80	B	50	E U	50	Av	100	57.00	4
	R 08	1	100	11%	0	60000	30	A	50	0.6226	50	B	50	E U	50	Av	100	51.00	5
	R 09	1	100	19%	25	45000	30	A	50	0.2588	80	B	50	E U	50	Av	100	57.50	3
	R 10	1	100	26%	50	45000	30	A	50	0.2588	80	B	50	E U	50	Av	100	62.50	1
	R 11	1	100	18%	25	55000	30	A	50	0.3105	70	B	50	E U	50	Av	100	57.00	4
Menia (Serry Basha Road)	R 12	2	50	12%	25	40000	20	A	50	0.1759	90	B	50	Dif U	0	Av	100	41.00	12
	R 13	2	50	12%	25	62000	40	A	50	0.2638	80	B	50	Dif U	0	Av	100	44.50	9
	R 14	2	50	10%	0	23000	20	A	50	0.1005	90	B	50	Dif U	0	Av	100	36.00	15
	R 15	2	50	10%	0	70000	40	A	50	0.3015	70	B	50	Dif U	0	Av	100	39.00	14
	R 16	2	50	7%	0	75000	40	A	50	0.3266	70	B	50	Dif U	0	Av	100	39.00	14
	R 17	2	50	7%	0	100000	50	A	50	0.4271	60	B	50	Dif U	0	Av	100	40.00	13
	R 18	2	50	10%	0	87000	50	A	50	0.3769	70	B	50	Dif U	0	Av	100	41.00	12
	R 19	2	50	12%	25	23000	20	A	50	0.1005	90	B	50	Dif U	0	Av	100	41.00	12
Menia (Kherre-gen)	R 20	3	25	25%	50	39000	20	P	100	0.1625	90	B	50	E U	50	Av	100	49.75	6
	R 21	3	25	23%	50	35000	20	P	100	0.1463	90	B	50	E U	50	Av	100	49.75	6
	R 22	3	25	19%	25	17000	10	P	100	0.0731	100	B	50	E U	50	Av	100	43.25	11
Notes:	R : Record	IRR : Internal Rate of Return				Pop : Population		B : Grey		Pred : Predicted		D : Development		Pi : Weighting %				P : Productive	
	Pr : Priority	C/B : Cost/Benefit Ratio				I : Industrial		St. : Statues		Av : Available		Unc : Uncounted		Categ. : Category				A : Agricultural	

Table 7: Weighted Multi-Criteria Prioritization and Ranking, (Continue)

Gov.	Criteria	1. Priority		2. Economic		3. Population		4. Area Type		5. C/B Ratio		6. Environ.		7. Readiness Level		8. Traffic		R F	Rank
	Relative %	P1 = 25%		P2 = 20%		P3 = 20%		P4 = 15%		P5 = 5%		P6 = 5%		P7 = 5%		P8 = 5%		100%	
	Road Sec	Pr	Pr R %	IRR, %	IRR R, %	Pop, Cap	Pop R, %	Type	R	Ratio	R, %	Categ.	R	Level	R	St.	R		
Menia (Kherre-gen Road)	R 23	3	25	19%	25	39000	20	P	100	0.1625	90	B	50	E U	50	Av	100	44.75	8
	R 24	3	25	19%	25	39000	20	P	100	0.1625	90	B	50	E U	50	Av	100	44.75	8
	R 25	3	25	19%	25	30000	20	P	100	0.1300	90	B	50	E U	50	Av	100	44.75	8
	R 26	3	25	19%	25	62000	40	P	100	0.2600	80	B	50	E U	50	Av	100	48.25	7
	R 27	3	25	19%	25	39000	20	P	100	0.1625	90	B	50	E U	50	Av	100	43.75	10
Fayoum	R 28	1	100	24%	50	270,000	100	A	50	0.3480	70	B	50	E U	50	Av	100	76.00	1
	R 29	1	100	22%	50	200,000	75	A	50	0.3006	70	B	50	Dif U	0	Av	100	68.50	2
	R 30	1	100	16%	25	160,000	75	A	50	0.4680	60	B	50	E U	50	Av	100	65.50	3
	R 31	1	100	25%	50	44,000	30	A	50	0.1200	90	B	50	E U	50	Av	100	63.00	4
	R 32	1	100	15%	25	65,000	40	A	50	0.1324	90	B	50	E U	50	Av	100	60.00	5
Assuit	R 33	1	100	22%	50	240,000	100	D	100	1.3638	25	B	50	EA	100	Pred.	50	81.25	1
	R 34	1	100	22%	50	240,000	100	D	100	1.5001	25	B	50	EA	100	Pred.	50	81.25	1
	R 35	2	50	15%	25	132,500	75	A	50	0.3465	70	B	50	E U	50	Av	100	53.50	2
	R 36	2	50	18%	25	79,000	40	A	50	0.3465	70	B	50	E U	50	Av	100	46.50	5
	R 37	3	25	12%	25	120,000	75	A	50	0.2820	80	B	50	E U	50	Av	100	47.25	4
	R 38	3	25	16%	25	45,000	30	A	50	0.2820	80	B	50	E U	50	Av	100	38.75	6
	R 39	3	25	11%	0	80,000	40	A	50	0.2325	80	B	50	E U	50	Av	100	35.75	6
	R 40	3	25	15%	25	210,000	100	A	50	0.2325	80	B	50	E U	50	Av	100	52.75	3
Sohag	R 41	1	100	12%	25	70,000	40	A	50	0.2500	80	B	50	E U	50	Av	100	59.50	1
	R 42	1	100	12%	25	70,000	40	A	50	0.2500	80	B	50	E U	50	Av	100	59.50	1
	R 43	1	100	11%	0	70,000	40	A	50	0.3000	80	B	50	E U	50	Av	100	54.50	2
Notes:	R : Record	IRR : Internal Rate of Retum				Pop : Population		B : Grey		Pred : Predicted		D : Development				Pi : Weighting %		P : Productive	
	Pr : Priority	C/B : Cost/ Benefit Ratio				I : Industrial		St. : Statues		Av : Available		Unc : Uncounted				Categ. : Category		A : Agricultural	

Table 8: Comparison Between Different Prioritization Methods

Gov.	Road Sec.	Length, Km	Economic Analysis		Weighted Criteria		Equal Weighted Criteria	
			MIRR, %	Rank	RF, %	Rank	RF, %	Rank
Menia	R 01	12.0	24%	3	62.00	2	62.50	2
	R 02	10.0	24%	3	62.50	1	63.75	1
	R 03	08.5	24%	3	62.50	1	63.75	1
	R 04	10.0	20%	5	62.50	1	63.75	1
	R 05	09.5	20%	5	62.50	1	63.75	1
a) Muhit	R 06	10.0	13%	8	57.50	3	60.63	3
	R 07	10.0	13%	8	57.00	4	60.63	3
	R 08	17.0	11%	10	51.00	5	53.75	7
	R 09	10.0	19%	6	57.50	3	60.63	3
	R 10	10.0	26%	1	62.50	1	63.75	1
	R 11	12.0	18%	7	57.00	4	59.38	4
b) Serry	R 12	07.0	12%	9	41.00	12	48.13	9
	R 13	10.5	12%	9	44.50	9	49.38	8
	R 14	04.0	10%	12	36.00	15	45.00	11
	R 15	12.0	10%	12	39.00	14	45.00	11
	R 16	13.0	7%	13	39.00	14	45.00	11
	R 17	17.0	7%	13	40.00	13	45.00	11
	R 18	15.0	10%	12	41.00	12	46.25	10
	R 19	04.0	12%	9	41.00	12	48.13	9
c) Kherg-een	R 20	10.0	25%	2	49.75	6	60.63	3
	R 21	09.0	23%	4	49.75	6	60.63	3
	R 22	04.5	19%	6	43.25	11	57.50	6
	R 23	10.0	19%	6	44.75	8	57.50	6
	R 24	10.0	19%	6	44.75	8	57.50	6
	R 25	08.0	19%	6	44.75	8	57.50	6
	R 26	16.0	19%	6	48.25	7	58.75	5
	R 27	10.0	19%	6	43.75	10	57.50	6
Fayoum	R 28	16.0	24%	2	76.00	1	71.25	1
	R 29	13.0	22%	3	68.50	2	61.88	5
	R 30	18.0	16%	4	65.50	3	63.75	3
	R 31	06.0	25%	1	63.00	4	65.00	2
	R 32	06.5	15%	5	60.00	5	63.13	4
Assuit	R 33	10.0	22%	1	81.25	1	71.88	1
	R 34	11.0	22%	1	81.25	1	71.88	1
	R 35	14.0	15%	4	53.50	2	58.75	3
	R 36	14.0	18%	2	46.50	5	54.38	5
	R 37	12.0	12%	5	47.25	4	56.88	4
	R 38	12.0	16%	3	38.75	6	51.25	6
	R 39	10.0	11%	6	35.75	6	49.38	7

	R 40	10.0	15%	4	52.75	3	60.00	2
Sohag	R 41	10.0	12%	1	59.50	1	61.88	1
	R 42	10.0	12%	1	59.50	1	61.88	1
	R 43	12.0	11%	2	54.50	2	58.75	2

Table 9: Developed Prioritization Matrix

Criteria	Criteria	Weight	Categories	Category	Ranking Factor	
No.		%		Scores	Project 1	Project 2
1	Governorate Priority	25	First priority	100		
			Second priority	50		
			Third priority	25		
			Fourth priority	0		
2	Economic Evaluation (IRR)	20	IRR $\geq$ 100	100		
			50 $\leq$ IRR $<$ 100	75		
			25 $\leq$ IRR $<$ 50	50		
			12 $\leq$ IRR $<$ 25	25		
			0 $<$ IRR $<$ 12	0.0		
3	Served Population	20	Population $>$ 200,000	100		
			101,000 $<$ Population $\leq$ 200,000	75		
			81,000 $<$ Population $\leq$ 100,000	50		
			61,000 $<$ Population $\leq$ 80,000	40		
			41,000 $<$ Population $\leq$ 60,000	30		
			21,000 $<$ Population $\leq$ 40,000	20		
			Population $\leq$ 20,000	10		
4	Area Type	15	Industrial	100		
			Development	100		
			Productive	100		
			Agricultural	50		
5	Cost / Budget Ratio, C/B Ratio	5	0.000 $<$ C / B Ratio $\leq$ 0.100	100		
			0.100 $<$ C / B Ratio $\leq$ 0.200	90		
			0.200 $<$ C / B Ratio $\leq$ 0.300	80		
			0.300 $<$ C / B Ratio $\leq$ 0.400	70		
			0.400 $<$ C / B Ratio $\leq$ 0.500	60		
			0.500 $<$ C / B Ratio $\leq$ 1.000	50		
			1.000 $<$ C / B Ratio $\leq$ 1.500	25		
			C / B Ratio $>$ 1.500	0		
6	Environmental Impact	5	White	100		
			Grey	50		
			Black	25		
7	Readiness Level & Available Preliminary Studies	5	Easy & Available	100		
			Easy & Unavailable	50		
			Difficult & Unavailable	0		
8	Traffic Count Availability	5	Available	100		
			Predicted	50		
			None	0		
Total Project Ranking Factor (RF)						