Revista Ingeniería de Construcción. RIC
Vol 37 Nº2 2022 www.ricuc.cl
DOI: 10.7764/RIC.00023.21

ENGLISH VERSION

An integrated infrastructure prioritization model: Case study of tripoli, lebanon

Un modelo integrado de priorización de infraestructuras: Estudio de caso de trípoli, líbano

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Fecha de Recepción: 12/02/2021
Fecha de Aceptación: 21/04/2022
Fecha de Publicación: 02/08/2022
PAG 147-163

Abstract

This paper introduces a novel non-linear weighting model to evaluate the different aspects of infrastructure. In this regard, three approaches are presented to compute the percents of infrastructure indicators, namely analytical hierarchy process, Shannon entropy and fuzzy set theory. A unified weighting model is then proposed to aggregate the weighting vectors obtained from the three approaches. The developed model is designed to model the feedback of the experts, actual condition of the infrastructure and encountered uncertainties. Results highlighted that water has the highest relative importance with 52.65% followed by electricity with 34.12% while telecommunication has the least relative importance with 2.69%. To apply a more practical sense to the proposed framework, a sample assessment of the Lebanese city of Tripoli's civil infrastructure was carried out in this paper. The developed model is expected to support planners and policymakers with a platform that enables them to efficiently evaluate the infrastructure's condition.

Keywords: Condition, infrastructure, indicators, analytical hierarchy process, Shannon entropy, fuzzy set theory

Resumen

Este artículo presenta un novedoso modelo de ponderación no lineal para evaluar los diferentes aspectos de infraestructura. En este sentido, se presentan tres enfoques para calcular los porcentajes de los indicadores de infraestructura, el proceso de jerarquía analítica, la entropía de Shannon y la teoría de conjuntos difusos. Luego se propone un modelo de ponderación unificado para agregar los vectores de ponderación obtenidos a partir de los tres enfoques. El modelo desarrollado está diseñado para modelar la retroalimentación de los expertos, la condición real de la infraestructura y las incertidumbres encontradas. Los resultados destacaron que el agua tiene la mayor importancia relativa con un 52,65 %, seguida de la electricidad con un 34,12 %, mientras que las telecomunicaciones tienen la menor importancia relativa con un 2,69 %. Para aplicar un sentido más práctico al marco propuesto, en este documento se llevó a cabo una evaluación de muestra de la infraestructura civil de la ciudad libanesa de Trípoli. Se espera que el modelo desarrollado apoye a los planificadores y formuladores de políticas con una plataforma que les permita evaluar de manera eficiente el estado de la infraestructura.

Palabras clave: Condición, infraestructura, indicadores, proceso de jerarquía analítica, entropía de Shannon, teoría de conjuntos difusos

1. Introduction

Infrastructure is the essential services and facilities for a country or a specific area. Infrastructure services are quintessential for the growth and development of nations on multiple levels such as healthcare and trade. Currently, infrastructure services in multiple regions around the world are underdeveloped. Today in 2020, the estimated growth requirement for these services lies between US$836 billion and US$1 trillion dollars annually. Additionally, it is predicted that a value between US$65 trillion to US$70 trillion is required to be invested in infrastructure development by 2030. In contrast, the estimated pool of funds that are available for the development of infrastructure is limited to US$45 trillion. Those values show that it is required to either increase the available funds or to manage the available funds in a highly efficient manner or even using a utilitarian manner (Ruiz-Nuñez and Wei, 2015).

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Infrastructure is composed of hard infrastructure or civil infrastructure including roads, tunnels, rail stations, highways, telecommunication (including internet speed and phone reliability), electricity, and sewage networks on one hand; And soft infrastructures consisting of cultural, health and social standards of a country. Currently, Lebanon suffers from a variety of hard infrastructure problems such as road problems. Lebanon roads suffer from traffics, holes, few parking spots, bicycle lanes, and pedestrian networks. It also encounters the electricity issues and the limiting hours of governmental electricity per day. It also experiences the low quality of communication networks, the wastewater, rainwater drainage, and potable water problems. There are many causes of those infrastructure problems such as political influence, poor accountability, absence of vision, the socio-political significance given to the sustainability of infrastructure and many more reasons. These issues have bad impacts on the economy and society.

Upgrading the infrastructure is a way for economic growth in the short term by doing more development projects and in the long term by raising national productivity. For example, stable road conditions can improve the functionality of trade lines and facilitate the process of goods reaching the markets. This can be projected to help decrease poverty in a country by improving the standard of living and increase work opportunities. Tripoli is one of the poorest towns in Lebanon and it requires a lot of development on the level of civil infrastructure, therefore, Tripoli will be the location of the case-study associated with this project. Accordingly, the main motive of this work is to help decision-makers better allocate their budget in a fashion that maximizes the impact of each project that is conducted and each penny that is spent.

The study proposes an assessment technique that measures the level of only civil infrastructure issues in Tripoli. The assessment is a way to help the responsible parties to put an effective path to the development of the city. In other words, due to the aforementioned problems in Tripoli, a need arises for an approach that aids decision-makers identify which level of infrastructure is the most critical for improvement or repair. The proposed approach in this document relies on the use of professional opinions through surveys and decision-making aids to determine which sector of the infrastructure has a higher priority over the rest. The assessment will be done using Shannon entropy, traditional AHP technique and fuzzy set theory to establish a rating system for infrastructure systems. The results will be compared, and conclusions will be drawn.

2. Literature review

This section is divided into sustainable development, infrastructure indicators, multi-criteria decision making techniques, and previous research studies.

2.1 Sustainable Development

Globally, cities consistently work to improve their services and to be more developed. They work on improving their infrastructures such as buildings, roads, power supplies, networks, sub-indicators, etc. Yet, improper or miscalculated improvements can lead to social inequality, damages to the environment, or other harmful impacts. Multiple researchers have explained the importance of economic and environmental issues, especially in an urban platform. A review of literature sources claims that having a balance between development in the economic, social and environmental areas is needed for a successful sustainable development (Boyer et al., 2016). According to (Barbier, 1987), sustainable development is when the social, environmental and economic goals increase at the same time. However, (Munda, 2005) highlights that it is difficult to increase the different goals simultaneously. For that reason, the study should be done using multi-criteria decision analysis. Much of the human population lives in urban platforms which serve as centers of industry and economic growth. Therefore, the unplanned development of cities can have bad impacts on society and the environment (Alonso et al., 2015). Many important factors should be taken into consideration when considering the sustainable development of a city such as the existing environmental issues, economic growth, and the distribution of the population and political structure (Malkina-Pykh, 2002). The sustainable development of infrastructure should be done taking into consideration the environment and the quality of human life because "you can't do business on a dead planet". The social factors are more influenced in the sustainable development of infrastructure than economic and environmental factors and they should be considered in the long and short terms for each project (Valdes-Vasquez et al., 2013). Infrastructure projects can help in the growth of the economy, the involvement in societies and the participation in political practices (Asomani-Boateng et al., 2015). The studies on the social impacts on infrastructure are still an interesting topic of research till now and according to (Gannon et al., 1997) and (Keulemans and de Walle, 2017), the infrastructure itself may have reduced social impact. Many researchers have utilized measures of the environmental impact as key assessment criteria in their research due to its great impact on the short and long terms (Torres-Machi et al. 2015); (Torres-Machi et al. 2014). The most used methods in assessing the infrastructure projects, since the mid of the 20th century, are the monetization-based methods (Mostafa and El-Gohary, 2014). A successful sustainable development of infrastructure should consider

DOI: 10.7764/RIC.00023.21

different factors such as social (long term and short-term factors), socio-political, environmental and economic factors including other sub-factors that go beyond the financial benefits of projects.

2.2 Infrastructure Indicators

To identify the most common indicators the first step is to look at the common pattern in previous literature. Multiple researchers cited three main indicators when studying sustainable development and they are the economic, social and environmental conditions of a given area. For example, (Nader et al., 2008) identified 110 development indicators at the municipal level. The environmental, social, and economic indicators play an essential role in sustainable development, but to sustain this approach the city should have enough data to do the development and should know its systems accurately. The indicators must also depend on the location, the environment, the attitude and the traditions of each city (Diamantini et al., 2000).

(Addanki and Venkataraman, 2017) found that a high population may lead to environmental issues and limit economic growth. Accordingly, municipalities and governments should work on laying out the plans of sustainable development taking into consideration the issues that a city is facing. Also, (Murphy, 2012) and (Boström, 2012) have worked on developing prevention approaches for a wide variety of urban issues while constructing a sustainable development plan for urbanscapes. (Abed, 2017) added the importance of the social factors in the sustainable development of infrastructure. However, the authors note that sustainable development is dominated by the economic and environmental indicators in most studies.

(Sun et al., 2016) suggested that the essential sub-indicators for a sustainable economy are the structure of the industry and levels of green production (low in carbon). And the social sub-indicators are justice, education, and healthcare. Finally, environmental sub-indicators are environmental technology, the amounts of environmentally friendly investments and the reduction of energy waste.

2.3 Multi-criteria Decision-making Techniques

The applications of previous methods for assessing infrastructure sustainability projects are limited. The most used methods in such projects are multi-attribute utility theory (MAUT), analytical hierarchy process (AHP), preference ranking organization method for enrichment evaluation (PROMETHEE), elimination and choice expressing the reality (ELECTRE), etc. But, according to researchers these models still have some limitations such as the lack of consideration in terms of risk or shareholders. MAUT is used under uncertain conditions. It provides weights and scores according to previous data for each indicator. The use of MAUT helps decision-makers determine which alternative to choose from a wide range of alternatives (Seppälä 2003). This method was widely used. AHP is a pairwise comparison technique between different alternatives using a scoring scale from 1 to 9 based on Saaty's scale (Gervásio et al., 2012). In other words, each criterion will be compared by the other by a number from 1 to 9 where 1 is equally important and 9 is extremely important than the other criteria. This ratio helps AHP to form many matrices then those matrices will be a way to calculate the weights for each criterion.

PROMETHEE and ELECTRE are two popular methods but these methods are weak because they are difficult to use and to develop the results (Benoit and Rousseaux, 2003); (Geldermann et al., 2000). PROMETHEE was developed by (Brans, 1982) then extended by (Brans and Vincke, 1985). PROMETHEE is a useful method in decision making and it is widely used in environmental and financial management. It is also based on the pairwise comparison. Shannon's entropy is an objective way to find the weight of a criterion for decision-making problems using a mathematical formula. However, the subjective ways of multi-attribute decision making (MADM) like AHP are more usable but also Shannon entropy concept was used in many filed like physics and transportation because it gives a general measure fuzziness and degree of randomness and uncertainty (Lotfi and Fallahnejad, 2010). Fuzzy logic deals with uncertain systems. It helps to present variables with a certain degree of randomness. Fuzzy logic is used to allow membership for unknown variables such as time, force, and distance with a degree of uncertainty. The membership usually starts with zero and continues. Fuzzy logic can be done in many shapes and the results are indicated along a horizontal axis (Cox, 1994).

2.4 Previous Research Studies

Some studies aimed at exploiting the use of multi-criteria decision making algorithms for assessing the condition of infrastructure systems. (El-khateeb et al., 2021) analyzed the performance condition of railway infrastructure using a defect-based model. The overall condition was obtained based on rails, sleeper, track geometry, ballast and insulated rail joints. The weights of defects and railway components were derived stepping on fuzzy analytical network process. Technique for order preference by similarity to ideal Solution (TOPSIS) was implemented to integrate weights and severities of defects to generate the overall condition. (Saluja et al., 2021) studied the performance condition of pavement surface using TOPSIS. In their study, falling weight deflectometer was used to gather information in relation

DOI: 10.7764/RIC.00023.21

with the distresses affecting the pavement. Analytical results evinced that chainage 500 m is a nearly ideal case scenario, and chainage 1000 m and 2000 m imply a poor pavement surface quality.
(Alsharqawi et al., 2021) adopted the use of quality of function deployment to estimate the overall bridge deck condition. The tackled defects encompass joint problems, pop-outs, deposits, delamination, spalling, corrosion, cracking and scaling. The correlation levels between defects were used to interpret the weights of defects. Then, quality function deployment was implemented to evaluate the performance condition of bridge decks. (Salman et al., 2021) introduced a condition rating of residential road network. The studied defects involved cracking, curvature, ravelling, rutting, attached deposits, etc. Analytical hierarchy process was utilized to compute the weights of defects and estimate the condition of road network.

Dabous et al., 2020) presented a utility approach for condition assessment of pavement sections. Their approach considered a set of pavement distresses such as rutting, edge cracking, longitudinal cracking, alligator cracking and bleeding. The overall condition of pavement sections was estimated using evidential reasoning approach. Their analysis showed that rutting is the most important defect followed by alligator cracking while edge cacking is the least important defect. (Abdelkader et al., 2020) created an integrated multi-criteria decision making model to evaluate the performance condition of bridge decks. They targeted surface and subsurface defects including corrosion, delamination, cracking, spalling and scaling. Fuzzy analytical network process was exploited to find the relative importance weights of defects. An integration of TOPSIS and grey relational analysis was implemented to compute the condition rating index of bridge decks.

In view of previous studies, it can be observed that most of previous studies focused on maintenance budget allocation of bridges and pavement. In this regard, there is lack of studies that dealt with telecommunication and electricity networks. In addition, the budget assignment models mainly focused on performance condition of infrastructure systems, whereas they overlooked social and environmental aspects which could heavily influence the decision-making process. It is also observed that the developed weight interpretation models were primarily established on analytical hierarchy process which fails to consider the performance indices of the infrastructure systems, and solely considers the experts' feedback. Hence, it is believed that merging between subjective and objective weight interpretation models could come up with more accurate assessment of the performance indicators of infrastructure systems.

3. Research methodology

The general methodology is illustrated in (Figure 1). The first step is to conduct a literature review to determine: (1) previously developed indicators by researchers worldwide, (2) proven techniques that are regularly used for decision making, and (3) novel techniques that are emerging in the decision-making field and require further assessment. Infrastructure can be divided into two main categories: hard and soft. The target of this study is the hard infrastructure which is defined as the physical infrastructures such as roads, bridges, water networks, other provided services, and their quality. The main criteria for the selection of assessment indicators are (1) the repetitiveness of the indicator, i.e., it is found in multiple journal papers, and (2) the applicability of the indicator to the city under study, i.e., Tripoli, Lebanon. The findings are further described in (Table 1). After the development of the indicators, an indicator list is compiled and divided into relevant fields such as electricity and transportation, the field are also derived from literature due to their repetitiveness but also represent the common grounds for the proper functionality of any modern city.

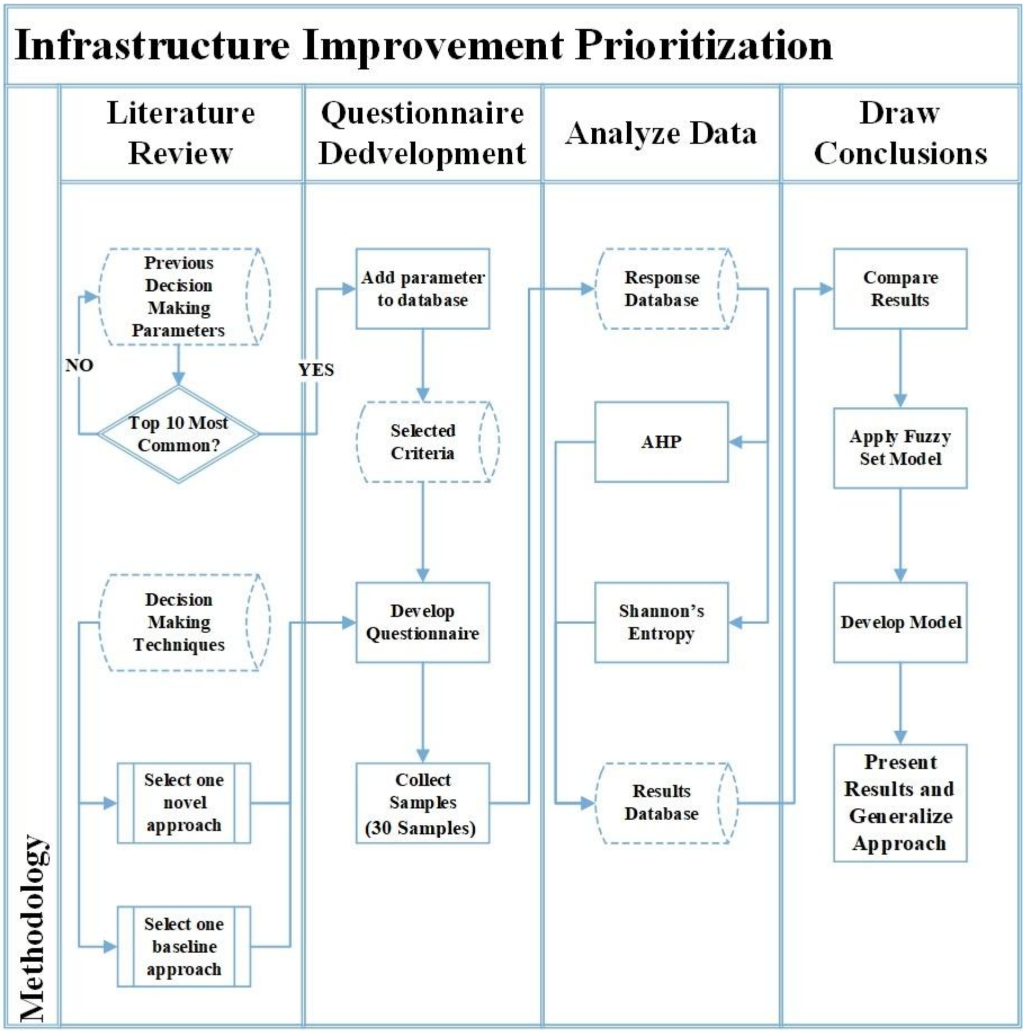


Figure 1. *Framework of the proposed research methodology*

The first selected decision-making technique for the assessment is AHP because it is a proven method that has been in use for multiple decades and has regularly provided good results. The second technique is Shannon's Entropy which is an emerging novel technique that has many promising results. Based on the developed list of indicators and the selection of the two assessment techniques, the questionnaire is developed to fit both techniques and encompass all the indicators. The next step would be the collection of responses from certified engineers working in the public field within the target city, Tripoli. The minimum required number of responses was 30 and that is to establish statistical significance. Once the required number of responses was collected, the responses were analyzed using both techniques and the ranking results were developed by each. The results were then compared, and then to combine the benefits of both techniques, a fuzzy model was developed using the results of both techniques. The fuzzy model aims to combine the mathematical benefits of both techniques and to formulate a more comprehensive outcome. A non-linear weighting model is then established to combine the advantages of analytical hierarchy process, Shannon entropy and fuzzy-based model. In this context, the developed model is capable of capturing the experience of the experts, the objective data of the indicators and uncertainties associated with the indicators.

Table 1. *Selected assessment criterio*

Infrastructure	***Criteria***
Transportation	*A1. Numbers of cars/capita*
	A2. Average transit per individual (km)
	A3. Average time spent on roads per km (min)
	A4. Condition of roads
	A5. Pedestrian network coverage
	A6. Bicycle networks coverage
	A7. Parking availability
Telecommunication	*A8. Access to phone network (landline and cellular)*
	A9. Access to the internet
	A10. Quality of phone connection (landline and cellular)
	A11. Usage of phone (landline and cellular)
	A12. Usage of internet
	A13. Quality of internet
Energy and electricity	*A14. Number of provider service hours per day*
	A15. Number of external generator beneficiaries
	A16. Number of external generators per area
	A17. Usage per capita
	A18. Energy waste (percentage)
	A19. Solar energy generation
Water and wastewater	*A20. Water system pressurization*
	A21. Water consumption per capita
	A22. Water quality
	A23. Access to drinkable water
	A24. Sewer network coverage
	A25. Sewage processing efficiency

3.1 Analytical Hierarchy Process

The AHP model is developed using a well-known method in obtaining weights. The AHP method relies on comparing one criterion performance concerning one or more criteria using Saaty's synergistic. AHP helps decision-makers calculate the weight of each criterion. The first step in AHP is to do numerical pair comparison between all criteria and sub-criteria according to their importance or repairing prioritization this step is done in the survey. When comparing each criterion and sub-criteria to their importance a ratio can be established. The ratio serves to put a numerical relationship between two criteria or sub-criteria. The numerical comparison is done using Saaty's scale of measurement. Saaty's scale values are from 1 to 9 where:

- *Number 1: means equally important to repair*
- *Number 3: means slightly more important to repair*
- *Number 5: means strongly more important to repair*
- *Number 7: means very strongly more important to repair*
- *Number 9: means extremely more important to repair*
- *Numbers 2, 4, 6 and 8: intermediate values*

The comparison in the survey is used numbers from 1 to 5 these numbers are automatically transformed to Saaty's scale in the AHP excel model where 1=1, 2=3, 3=5 and so on. The ratios of importance help in forming a matrix between criteria.

DOI: 10.7764/RIC.00023.21

3.2 Shannon Entropy

Shannon's entropy is a novel technique that serves as a decision-making aid. The technique determines the weight of each indicator and ranks the indicators according to their condition. The application of the model can be divided into the following steps:

The first step is data normalization. In this regard, all the collected data are normalized using (Equation 1) where p_{ij} *is the normalized value and* x_{ij} *is the collected data from the Google form for each criterion. This process is used for the unification of units and scales of the criteria and transforms all data into common units to allow the comparison between them. (Table 2) below shows the data collected only for transportation from Google form responses that rank all the criteria from 1 to 5 according to their condition. In this context, m presents the number of rows or number of responses and n represents the number of indicators.*

$$\boldsymbol{p_{ij} = \frac{x_{ij}}{\sum_{j=1}^{m} x_{ij}}} \qquad (1)$$

After normalizing the data, the entropy (h_i) *is computed. The entropy interprets the number of ways in which a system may be ranked. So entropy* (h_i) *is calculated using (Equation 2).*

$$\boldsymbol{h_i = -h_0 \sum_{j=1}^{m} p_{ij} \times ln p_{ij}} \qquad (2)$$

Where;

$$k = \frac{1}{ln\,(m)}$$

The third step involves computing the degree of diversification (d_i) *and it is computed using (Equation 3).*

$$\boldsymbol{d_i = 1 - h_i} \qquad (3)$$

Where;

d_j *represents the degree of diversification of* j*-th attribute.*
The fourth step encompasses interpreting the weights of attributes. This can be done by employing (Equation 4).

$$\boldsymbol{w_i = \frac{d_i}{\sum_{i=1}^{n} d_i}} \qquad (4)$$

Where;

w_i *refers to the weight of each attribute.*

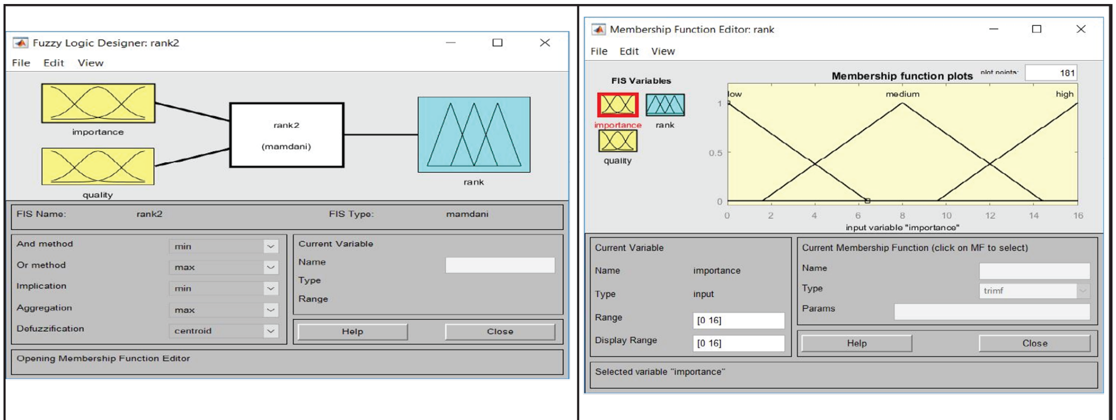
Table 2. *Summary of sample of the obtained responses*

Number of cars per capita	***Average transit distance on the roads per individual***	***Average time spent per km on the roads***	***Condition of the road***	***Pedestrian network coverage***	***Bicycle network coverage***	***Number of parking available***
3	3	3	4	3	4	4
5	5	5	2	3	1	2
5	3	5	2	2	1	2
3	2	4	1	3	1	2
3	5	5	5	5	5	5
4	4	4	1	1	1	2

3.3 Fuzzy-based Model

In this section, Fuzzy modeling is used to combine the AHP and Shannon's entropy results. The values of the weights and the quality of each indicator are assessed and scored using a MATLAB tool. The first step in the fuzzy model development is the identification of the elements to be utilized in the model. (Figure 2(a)) shows that the two main inputs are importance and quality. Importance represents the AHP weights that were previously determined. The quality represents Shannon's entropy results for all given criteria. The "centroid" method was selected to be utilized as the method of defuzzification of choice. The output of the fuzzy model is the final rank of each criterion.

The membership function development is done by identifying the ranges and plots of the inputs and outputs. A triangular distribution was selected due to its ease of use and comprehension. The input ranges for AHP were selected according to the smallest and the largest weights determined by the AHP findings in the previous model. (Figure 2(b)) displays the membership function that was identified. Similarly, (Figure 2(c)) shows the membership function that was developed by the results that were collected from Shannon's entropy model. The resulting membership function is illustrated in (Figure 2(d)) as a result of the fuzzy model. The output of the membership function is between 0 and 10. (Figure 3) highlights the list of rules that were utilized to achieve the final ranking model.



FIS Name: rank2 FIS Type: mamdani

And method min

Or method max

Implication min

Aggregation max

Defuzzification centroid

Opening Membership Function Editor

Current Variable

Name importance

Type input

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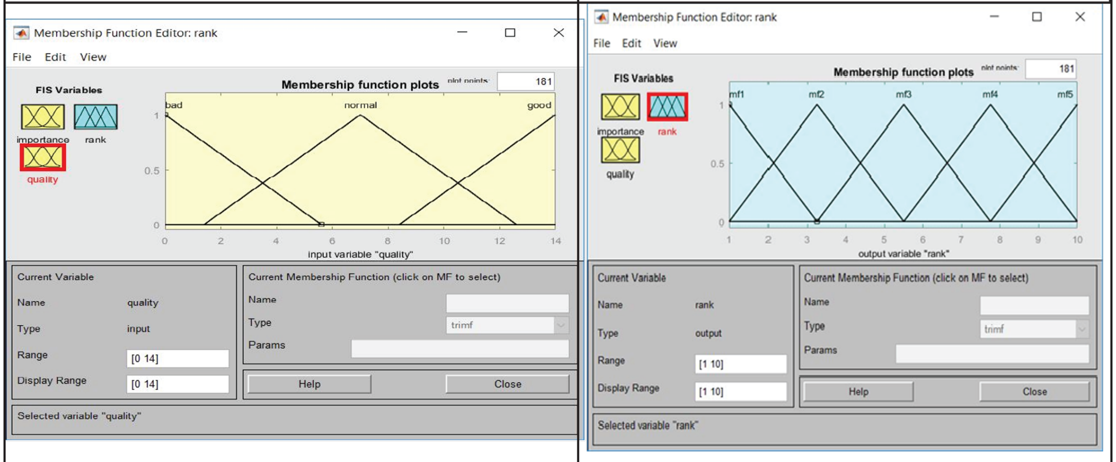
Selected variable "importance"

a) Membership function **b) Membership functions plots for importance**



Current Variable

Name quality

Type input

Range [0 14]

Display Range [0 14]

Selected variable "quality"

Current Variable

Name rank

Type output

Range [1 10]

Display Range [1 10]

Selected variable "rank"

c) Membership function plots for quality **d) Membership function plots for rank**

Figure 2. *Membership functions utilized for the development of the fuzzy model*

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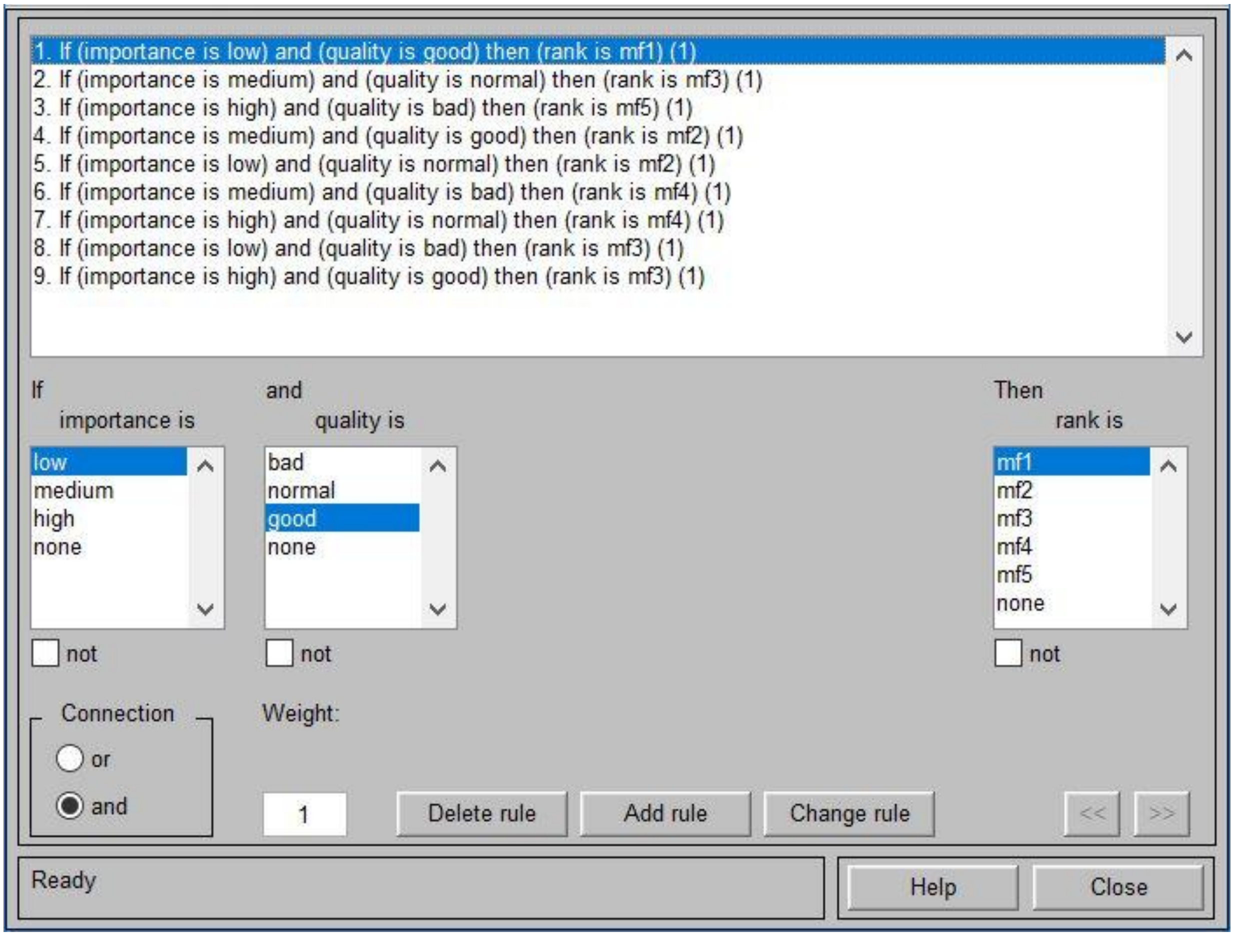

1. If (importance is low) and (quality is good) then (rank is mf1) (1)
2. If (importance is medium) and (quality is normal) then (rank is mf3) (1)
3. If (importance is high) and (quality is bad) then (rank is mf5) (1)
4. If (importance is medium) and (quality is good) then (rank is mf2) (1)
5. If (importance is low) and (quality is normal) then (rank is mf2) (1)
6. If (importance is medium) and (quality is bad) then (rank is mf4) (1)
7. If (importance is high) and (quality is normal) then (rank is mf4) (1)
8. If (importance is low) and (quality is bad) then (rank is mf3) (1)
9. If (importance is high) and (quality is good) then (rank is mf3) (1)

Figure 3. Development rules of the fuzzy model

3.4 Unified Weight Interpretation Model

A comprehensive weighted model is introduced to combine the advantages of analytical hierarchy process, Shannon entropy and fuzzy-based model. Furthermore, this model is able to alleviate their shortcomings. The combined final weighting vector can be derived using (Equation 5).

$$W^*_i = \frac{W^a_i \times W^s_i \times W^f_i}{\sum_{s=1}^{n} W^a_i \times W^s_i \times W^f_i} \qquad (5)$$

Where;

W^a *represents the weight obtained from analytical hierarchy process.* W^s *refers to the weight obtained from Shannon entropy model.* W^f *stands for the weights of the fuzzy-based model.*

4. Model implementation

The results of the analytical hierarchy process are described in the following lines. In the study we have four infrastructure criteria each one is an alternative. Therefore, a 4 x 4 matrix is developed. (Table 3) shows the matrix between infrastructure criteria. The number 3.6 in (Table 3) is the average of all answers in the survey and implies that transportation is 3.6 times more important than the telecommunication and 0.28 is the invert of 3.6. The number 0.57 in Table 3 is the average of all answers in the survey and implies that transportation is 0.57 times less important than electricity and 1.73 is the invert of 0.57.

After forming the matrix, the matrix should be normalized. To normalize the matrix, the sum of each column should be calculated then the alternatives of each column should be divided by the corresponding sum. (Table 4) represents the normalized matrix of infrastructure. The next step after normalizing the matrix is to calculate the average of each row. These averages are the weight of each criterion. Note that some of the weights are equal to 1. The weights for each infrastructure are shown in (Table 5). The same steps are done for the sub-criteria.

Table 3. *AHP model results for global infrastructure assessment*

Infrastructure	***Transportation***	***Telecommunication***	***Energy and electricity***	***Water and wastewater***
Transportation	*1*	*3.6*	*0.576923*	*0.54*
Telecommunication	*0.28*	*1*	*0.22*	*0.16*
Energy and electricity	*1.73*	*4.47*	*1*	*1.36*
Water and wastewater	*1.87*	*6.40*	*0.73*	*1*

Table 4. *Normalized AHP results for global infrastructure assessment*

Infrastructure	***Transportation***	***Telecommunication***	***Energy and electricity***	***Water and wastewater***
Transportation	*0.205*	*0.233*	*0.228*	*0.175*
Telecommunication	*0.057*	*0.065*	*0.088*	*0.051*
Energy and electricity	*0.355*	*0.289*	*0.395*	*0.446*
Water and wastewater	*0.383*	*0.414*	*0.289*	*0.327*

Table 5. *Finalized AHP results*

Infrastructure	***Weight***
Transportation	*0.210*
Telecommunication	*0.065*
Energy and electricity	*0.371*
Water and wastewater	*0.353*

(Table 6), (Table 7), (Table 8) and (Table 9) report the normalized matrices of the indicators in transportation, telecommunication, energy and electricity, and water and wastewater networks. These normalized matrices are used to derive the local weights of indicators in each respective network. (Table 10) shows the weights of indicators of the various network according to the analytical hierarchy process. It is found that energy and electricity (37.1%) is the most important network followed by transportation network (21%) while telecommunication (6.5%) is the least important network. With regards to indicators, it is inferred that condition of roads (7.73%) is the most important indicator in transportation works while bicycles network coverage (0.82%) is the least important indicator. With regards to telecommunication network, usage of internet (2.67%) and usage of phone (0.25%) are the most and least important indicators, respectively. With respect to energy and electricity network, number of provider service hours per day exhibits the highest relative importance weight while number of external generators per area attain the least level of importance. As for the water and wastewater network, water quality (13.67%) is the most important indicator. On the other hand, water system pressurization (1.81%) has the lowest level of significance. On the grand scheme of things, number of provider service hours per day has the largest relative importance followed by water quality and then condition of roads. On the contrary, bicycle networks coverage and usage of phone manifest the lowest relative importance.

Table 6. *Normalized matrix of indicators of transportation network*

	A1	A2	A3	A4	A5	A6	A7
A1	0.088	0.077	0.052	0.092	0.123	0.099	0.601
A2	0.073	0.064	0.045	0.071	0.085	0.108	0.022
A3	0.338	0.281	0.200	0.172	0.297	0.144	0.083
A4	0.414	0.392	0.506	0.437	0.324	0.281	0.219
A5	0.041	0.044	0.039	0.078	0.058	0.132	0.025
A6	0.040	0.027	0.062	0.070	0.020	0.045	0.009
A7	0.006	0.115	0.097	0.080	0.093	0.192	0.040

Table 7. *Normalized matrix of indicators of telecommunication network*

	A8	A9	A10	A11	A12	A13
A8	0.061	0.028	0.025	0.220	0.099	0.024
A9	0.239	0.110	0.125	0.259	0.071	0.307
A10	0.106	0.038	0.044	0.151	0.117	0.008
A11	0.012	0.018	0.012	0.042	0.114	0.032
A12	0.304	0.767	0.184	0.184	0.495	0.519
A13	0.278	0.039	0.611	0.145	0.105	0.110

Table 8. *Normalized matrix of indicators of energy and electricity network*

	A14	A15	A16	A17	A18	A19
A14	0.429	0.480	0.289	0.208	0.325	0.734
A15	0.065	0.072	0.138	0.248	0.087	0.029
A16	0.068	0.024	0.046	0.018	0.048	0.027
A17	0.146	0.021	0.180	0.071	0.041	0.049
A18	0.231	0.145	0.167	0.304	0.175	0.056
A19	0.061	0.258	0.180	0.152	0.325	0.105

Table 9. *Normalized matrix of indicators of water and wastewater network*

	A20	A21	A22	A23	A24	A25
A20	0.054	0.040	0.092	0.042	0.027	0.052
A21	0.085	0.063	0.067	0.059	0.075	0.039
A22	0.240	0.388	0.409	0.517	0.277	0.491
A23	0.260	0.216	0.159	0.201	0.311	0.228
A24	0.236	0.099	0.174	0.076	0.118	0.072
A25	0.124	0.194	0.099	0.104	0.193	0.118

Table 10. *Weights of indicators based on analytical hierarchy process*

			Criteria	**Global Weight**
Transportation	0.21	A1	Number of cars per capita	3.40%
		A2	Average transit per individual	1.41%
		A3	Average time spent on roads	4.55%
		A4	Condition of roads	7.73%
		A5	Pedestrian network coverage	1.25%
		A6	Bicycle network coverage	0.82%
		A7	Parking availability	1.87%
Telecommunication	0.065	A8	Access to phone network	0.50%
		A9	Access to internet	1.21%
		A10	Quality of phone	0.51%
		A11	Usage of phone	0.25%
		A12	Quality of internet	2.67%
		A13	Usage of internet	1.40%
Energy and electricity	0.371	A14	Hours of provider service	15.24%
		A15	Hours of external generator	3.96%
		A16	Number of external generators	1.43%
		A17	Usage of energy per capita	3.14%
		A18	Energy waste	6.67%
		A19	Solar energy generation	6.69%
Water and wastewater	0.353	A20	Water system pressurization	1.81%
		A21	Water consumption per capita	2.28%
		A22	Water quality	13.67%
		A23	Access to drinkable water	8.10%
		A24	Sewer network coverage	4.56%
		A25	Sewage processing efficiency	4.90%

(Table 11) below shows the data collected only for transportation from Google form responses that rank all the criteria from 1 to 5 according to their state. (Table 12) presents the results of relative importance weights for the infrastructure systems and their respective indicators. It is shown that water and wastewater (41.5%) is the highest important system followed by energy and electricity (30.4%) while telecommunication (11.2%) is the lowest important system. It can be also noticed that number of external generators per area (13.42%) is the most important indicator across all indicators, and water quality (11.01%) comes in the second place followed by water system pressurization (10.57%). On the other side, access to phone network (0.47%), access to internet (0.47%) and usage per capita (0.47%) are ranked as the least important indicators.

Table 11. *Data Collected from Google Form for the Telecommunication section*

Access to phone network	***Access to the internet***	***Quality of the phone connection***	***Quality of the internet connection***	***Usage of the phone***	***Usage of the internet***
1	1	3	3	4	5
1	1	4	2	3	5
1	1	4	1	2	5
1	1	4	3	5	5
1	1	3	3	3	3
1	1	4	2	4	4
1	1	5	5	5	5
1	1	3	3	5	5
1	1	3	3	3	4
1	1	3	2	3	3
1	1	3	4	4	4
1	1	4	2	5	5

Table 12. *Weights of indicators based on Shannon entropy*

			Criteria	***Global Weight***
Transportation	*16.2 %*	*A1*	*Number of cars per capita*	*1.72%*
		A2	*Average transit per individual*	*4.63%*
		A3	*Average time spent on roads*	*0.87%*
		A4	*Condition of roads*	*3.68%*
		A5	*Pedestrian network coverage*	*2.19%*
		A6	*Bicycle network coverage*	*0.56%*
		A7	*Parking availability*	*2.56%*
Telecommunication	*11.5 %*	*A8*	*Access to phone network*	*0.47%*
		A9	*Access to internet*	*0.47%*
		A10	*Quality of phone*	*1.69%*
		A11	*Usage of phone*	*2.06%*
		A12	*Quality of internet*	*5.53%*
		A13	*Usage of internet*	*1.28%*
Energy and electricity	*30.4 %*	*A14*	*Hours of provider service*	*4.97%*
		A15	*Hours of external generator*	*4.61%*
		A16	*Number of external generators*	*13.42%*
		A17	*Usage of energy per capita*	*0.47%*
		A18	*Energy waste*	*4.60%*
		A19	*Solar energy generation*	*2.33%*
Water and wastewater	*41.5 %*	*A20*	*Water system pressurization*	*10.57%*
		A21	*Water consumption per capita*	*4.83%*
		A22	*Water quality*	*11.01%*
		A23	*Access to drinkable water*	*6.02%*
		A24	*Sewer network coverage*	*4.17%*
		A25	*Sewage processing efficiency*	*5.29%*

MATLAB puts a score from 1 to 10 for each criterion using fuzzy. The scores are transformed into weights by dividing each score by the sum of the scores. The results are found in (Table 13). The final rank shows that the highest priority goes to the hours of provided electricity (5.73%) which means that this criterion has a low condition and high priority levels according to the respondents and the lowest weight goes to the number of external generator (1.32%) which means that this criterion has high quality and low priority levels according to the respondents. Also, the rank shows that the weights vary between all the alternatives and that the solar energy generation (5.33%) and condition of roads (4.82%) are ranked as the second and thirds most important indicators, respectively. Results also show that usage of energy per capita (4..75%) and number of cars per capita (4.68%) are associated with considerable amounts of importance.

Table 13. *Scoring and weights derived by the fuzzy-based model*

		Fuzzy Score on MATLAB	**Weight**
A1	Number of cars per capita	6.34	4.68%
A2	Average transit per individual	3.81	2.81%
A3	Average time spent on roads	7.15	5.28%
A4	Condition of roads	6.53	4.82%
A5	Pedestrian network coverage	5.04	3.72%
A6	Bicycle network coverage	5.5	4.06%
A7	Parking availability	5.15	3.80%
A8	Access to the phone network	5.5	4.06%
A9	Access to internet	5.5	4.06%
A10	Quality of phone	5.32	3.93%
A11	Usage of phone	5.11	3.77%
A12	Quality of internet	4.02	2.97%
A13	Usage of internet	5.5	4.06%
A14	Hours of provider service	7.77	5.73%
A15	Hours of external generator	5.22	3.85%
A16	Number of external generators	1.79	1.32%
A17	Usage of energy per capita	6.44	4.75%
A18	Energy waste	6.07	4.48%
A19	Solar energy generation	7.22	5.33%
A20	Water system pressurization	3.34	2.46%
A21	Water consumption per capita	4.36	3.22%
A22	Water quality	6.37	4.70%
A23	Access to drinkable water	5.5	4.06%
A24	Sewer network coverage	5.67	4.18%
A25	Sewage processing efficiency	5.29	3.90%

The final weights of the indicators are reported in (Table 7). Results demonstrated that water quality had the highest weight followed by hours of provider service while usage of phone had the lowest weight. In this context, the corresponding weights of water quality, hours of provider service and usage of phone are 31.87%, 19.56% and 0.09%, respectively. At the level of criteria, water is associated with the highest weight and then electricity while telecommunication is associated with the lowest weight. The corresponding weights of water, electricity and telecommunication are 52.65%, 34.12% and 2.69%, respectively. In transportation, condition of roads and bicycle

DOI: 10.7764/RIC.00023.21

network coverage are considered as the most and least important indicators, respectively. As for telecommunication network, the highest and lowest values of weights are linked with quality of internet and usage of phone, respectively. With regards to energy and electricity, hours of provider service and usage of energy per capita are associated with the highest and lowest relative importance weights, respectively. In water and wastewater projects, water quality is appended as the most important indicator while water consumption per capita is appended as the least important indicator.

Table 14. *Final weights of the indicators*

			Criteria	**Global Weight**
Transportation	0.1054	A1	Number of cars per capita	1.23%
		A2	Average transit per individual	0.83%
		A3	Average time spent on roads	0.94%
		A4	Condition of roads	6.18%
		A5	Pedestrian network coverage	0.46%
		A6	Bicycle network coverage	0.08%
		A7	Parking availability	0.82%
Telecommunication	0.0269	A8	Access to phone network	0.04%
		A9	Access to internet	0.10%
		A10	Quality of phone	0.15%
		A11	Usage of phone	0.09%
		A12	Quality of internet	1.98%
		A13	Usage of internet	0.33%
Energy and electricity	0.3412	A14	Hours of provider service	19.56%
		A15	Hours of external generator	3.17%
		A16	Number of external generators	1.14%
		A17	Usage of energy per capita	0.32%
		A18	Energy waste	6.19%
		A19	Solar energy generation	3.74%
Water and wastewater	0.5265	A20	Water system pressurization	2.12%
		A21	Water consumption per capita	1.60%
		A22	Water quality	31.87%
		A23	Access to drinkable water	8.92%
		A24	Sewer network coverage	3.58%
		A25	Sewage processing efficiency	4.56%

(Table 15) provides the correlation coefficients between the studied weight interpretation models in this study. It is found that analytical hierarchy process exhibits the highest correlation with the final unified weighted model. On the other hand, the fuzzy model has the lowest correlation with the unified weighted model. In this context, the correlation coefficients between the pairs of (analytical hierarchy process, unified weighted model) and (fuzzy model, unified weighted model) are 0.89 and 0.37, respectively. It can be also inferred that negative trend exists between Shannon entropy and fuzzy model, whereas a correlation coefficient of -0.53 is present between them.

Table 15. *Correlation matrix of the input and output variables*

	Analytical hierarchy process	***Shannon entropy***	***Fuzzy model***	***Unified weight model***
Analytical hierarchy process	*1*	*0.33*	*0.58*	*0.89*
Shannon entropy		*1*	*-0.53*	*0.48*
Fuzzy model			*1*	*0.37*
Unified weight model				*1*

5. Conclusions

The goal of the project was to develop a novel approach for infrastructure assessment in developing countries and to help decision-makers to put better plans for repairing the civil infrastructure. This goal was achieved by ranking the infrastructure criteria using a comprehensive non-linear weighting model that integrates the relative importance vectors generated from analytical hierarchy process, Shannon entropy and fuzzy logic. The calculations were carried out on Excel and MATLAB. The developed model was applied on a case study of Tripoli, Lebanon. It was revealed that the weights vary between the alternatives. The highest priority goes to the hours of provided electricity which means that the decision-makers should take these criteria as a priority for the development. This result reflects the need for Tripoli to work on the electricity provided hours to help the economic growth in this poor city. The lowest weight goes to the external generator. Also, this result can be explained because in Tripoli there are many external generators and when the government works on improving the electricity provided hours there is no need to work on the external generator. After the provider hours of electricity, solar energy generation and time spent on roads are important alternatives that require improvements and working on and may deliver a wide spectrum of benefits. On the grand scheme of criteria, it was also found that water has the highest relative importance for Tripoli while telecommunication is accompanied with the least relative importance.

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