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Supporting a decision for metro station restoration based on facility assessment: application to Cairo metro stations

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Abstract

Subway stations play a significant role in big cities today. This research aims to develop an integrated system that makes the best use of the budgets allocated for the rehabilitation of Cairo metro stations, based on stations condition assessment. The main problem is the lack of accurate assessment and decision-making optimization tools for Cairo metro stations condition. This, in turn, adversely affects the stations selected for rehabilitation and, thus, the misdirection (non-optimal) of the budgets allocated to the development of these stations. The appropriate methods and techniques of collecting and analyzing data are applied. They were collected from the reviewed literature concerning subway station facility management systems, as well as experts in the field. Data collection was followed by the analytic hierarchical process (AHP) and linear programming/integer programming and ended with the selection of stations prior to restoration or maintenance depending on the available budget or capital program. This system would be helpful in subway stations facilities decision-making by the concerned authorities like NAT (National Authority of Tunnels) or Cairo Metro Co. This system was applied to a sample of Cairo metro stations and concluded with some results. The first of them is reducing and optimizing the great allocated budgets by using the developed model. Another result is that the most important factors influencing the evaluation of the metro station are the structure, architecture, and hydromechanics, respectively.

Keywords: Facility assessment, Analytic hierarchy process, Decision-making, Subway station

Introduction

The metro is a huge complex network, combining various disciplines: economy, assets, climate, etc. The subway has an important social significance, as well as economic and political ones [1]. The term “Cairo Metro” refers to a rapid transit rail network that serves the urban and suburban areas of the Cairo district. It combines three lines, with more than 70 km of tracks and seventy stations currently in operation, with an average of 3.6 million ridership/day [2].

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The significant role of subways in Egypt conforms with a study which argued that countries, particularly the developed nations, have been putting big assets in the improvement of metro networks. The proficiency of metro frameworks has drawn in expanding interest among authorities, experts, and researchers. Various metro frameworks have been valued with acceptable execution, like New York Metro, Paris Metro, London Metro, and others [3]. Multi-Criteria Decision-Making techniques were used clearly in the management of waste [4], choosing ventilation for projects [5], picking the best strategy of restoration and rehabilitation for diverse project components [6], as well as infrastructure project management [7], and materials providers determination [8].

Many researchers discussed the topics of metro station assessment from different points of view. This paper presented an ex-post, money-saving advantage examination; concentrating on the last fragment of the Athens metro line 3 development, from Egaleo to Ag. Marina station. This segment has been constructed in 2007 and placed in operation in 2014. The venture was evaluated on the grounds of a money growth strategy utilizing the social NPV and social IRR measures. The outcomes showed that the task is not feasible if benchmarked against purely monetary models. Nevertheless, the money-related qualities achieved by the social and ecological advantages that the venture brought rendered the entire advancement attractive and helpful from a money-saving advantage examination point of view [9].

Another study addresses the optimization of the operation for the first and the second lines of Cairo Metro. This study proposed a technique dependent on a field survey of travel time, actual headway, passenger waiting time, aligning and boarding passengers to decide the passenger density on the platform, passenger density in train and target headway. Thus, the operating costs can be saved. The outcomes showed a significant expense saving for both operations and rolling costs [10]. Some other researches attempted to provide methods for assessment and developing individual facilities like noise and evacuation [11, 12]. Some other researches attempted to deal with security, safety, air quality, and energy-saving [13, 14]. Another research used methods like WASPAS and TOPSIS in selecting stations for management [15]. There was a research that used ELECTRE I in subway infrastructure [16]. Other types of studies attempted to assess the infrastructure; however, these researches did not address subway stations' condition assessment as a priority to rehabilitate them and link them with a system to direct the budgets allocated to this vital facility optimally [17].

Another research discussed noise exposure which is related to different health topics. This research introduced an assessment of the acoustic climate at the station foundation and the factors influencing the stage commotion levels. More prominent Cairo Metro Lines 1, 2, and 3 have been chosen as a sample study. The outcome demonstrates that commotion levels are unsatisfactory, contrasted and the global norms of noise rate [18]. Many studies have confirmed shortcomings in the assessment bases of the Cairo metro facility. Some Researches showed that the greater Cairo transit network needs development owing to its demand-coverage insufficiency. The methods needed should be detailed and accurate, which are not available in most developing countries [19]. Another research argued that the transportation master plans are essential in Egypt, and they are not less important than urban master plans, while many cities like Greater Cairo lacking such plans [20]. Whereas, there is a research that showed

a lack of studies quantifying passenger evacuation in relation to Cairo transit, especially with regard to the interchange stations like Nasser station. The results of that research demonstrated that the connection was compliant with the French standard, but it did not fully meet its requirements [21]. Hence, the problem appeared clearly, there was an urgent need to configure a model.

That leads us to the research's main problem which is the lack of accurate assessment and decision-making optimization tools for Cairo metro stations condition. This has an adverse effect on the selected stations for rehabilitation, the development of the most needed metro stations, and misdirection of the allocated budget to achieve the optimum benefit.

The aim of this research is to develop a properly integrated system to reduce or make the optimal use of the allocated budgets for Cairo metro stations rehabilitation, according to the ranking of stations condition assessment (using AHP method for station condition assessment and using LP/IP method for budgets optimal use).

Methods

This section will clarify the research methods used in research to reduce or make the optimal use of the allocated budgets for Cairo metro stations rehabilitation according to stations condition assessment. The proposed methodology included the following phases:

- 1- Collecting data and Sampling methods.
- 2- Developing the proposed Model SRAM using AHP and LP/IP methods.
- 3- Model verification and application through brainstorming sessions for validating the model, followed by applying the SRAM model to the stations. See the research methodology outlined in (Fig. 1).

Collecting data and sampling methods

The research data collection methods depend on field surveys, principally semi-structured interviews and brainstorming sessions, as follows:

- 1) A literary review was done in order to identify the criteria and sub-criteria of metro stations and to create a knowledge base for generating survey questions. The identified criteria were organized in hierarchical criteria/sub-criteria which would be used in semi-structured interviews.
- 2) semi-structured interviews were organized by professionals, based on the results of the last step. The semi-structured interview gives the opportunity to ask the target respondents if there are any modifications (adding, deleting, and merging) in the identified criteria. They can add to improve the survey [22]. The first objective of these interviews was to identify the metro station criteria/sub-criteria, then class them into groups. The second objective is to complete a questionnaire for identifying the importance of each metro station criteria/sub-criteria based on his/her experiences. Hence, the relative importance of each identified criterion was determined using a pairwise comparison technique and was applied for comparing the identified criteria. The results from this step included values for all inputs to

feed the model later. The semi-structured interview was designed to collect data from the participants (see Table 3). The respondents should have the following qualifications: (1) having been involved in metro stations projects, at least for 5 years, (candidates with less than 5 years' experience in metro stations were excluded) and (2) being acquainted with metro station criteria /sub-criteria, their applications, and their importance in building. Sixty practitioners (engineers, inspectors, and managers) were identified. Only forty-one participants completed the semi-structured interviews (see Table 1). The semi-structured interviews were divided into two sections: section "A," which comprised the demographic features of the respondents such as the firm category, number of employees, firm major clients, highest academic qualifications of the respondent, years of work experience,

Table 1 Survey participant analysis

Participants	Years of experience	Number of samples	Response total	% of different participants
Engineers	5 to 15	31	20	49%
Managers	10 to 25	10	6	15%
Inspectors	7 to 15	19	15	36%
Total		60	41	

and position of the respondent in their respective firms; and section “B,” which was designed for the respondents to assign a score to each criterion/sub-criteria regarding the importance of a criterion compared to another criterion based on its importance according to Saaty meter. The result of this semi-structured interview will be the input of the Saaty matrices, to get criteria/sub-criteria vector weight and assessment weight as output in (Table 8). The semi-structured interviews approach was preferred because it allows anonymity and freedom of participants and ensures the uniformity of responses and is widely recognized for selecting confirmed information in building knowledge, ensuring the accuracy of answers, and improving the response rate [23]. The survey was conducted from September 2020 until February 2021 (Table 1).

3) Selecting the stations to be applied to the newly developed system was based on two basic criteria:

1. The oldest stations according to their date of construction.
2. The most crowded stations, especially the interchange stations in Cairo mid-town (see Additional file 1: appendices d1, d2, d3).

The study sample was selected using the simple random sampling of Cairo Metro stations according to the aforementioned criteria. Samples analysis is shown in (Table 2) [2].

Developing the proposed model SRAM

The integrated system was developed to reduce or make the optimal use of the allocated budgets for Cairo metro stations rehabilitation, according to the ranking of

Table 2 The sample stations for Cairo Metro

Stations information	Attaba	Sadat	Helwan	Tora El-Asmant	Thakanat El-Maadi	El-Malek El-Saleh
Date of construction	1996	1987	1987	1987	1992	1995
Location	Mid-town	Mid-town	South Cairo	South Cairo	South Cairo	Near historical area
Line no.	2, 3	1, 2	1	1	1	1
Journeys/day	664 (line2)	480 (line 1)	480 (line 1)	480 (line 1)	480 (line 1)	480 (line 1)
	331 (line3)	664 (line2)				
Line1 Capacity/hour	60,000 passengers					
Line2 Capacity/hour	45,000 passengers					

stations condition assessment (using AHP method for station condition assessment and using LP/IP method for budgets optimal use) as follows:

AHP method analysis

The analytic hierarchy process (AHP) was acquainted in 1980 to assist in projects decision-making and to focus on choosing other options in projects [24]. It has been broadly utilized in making a decision in various fields and used to assist with tackling different issues such as the selection area for real estate project research [25], evaluation methods for contractors in construction [26], urban construction by making a correlation with algorithms [27], and decision-making in civil engineering projects [28]. The AHP permits the design of criteria/sub-criteria hierarchical structure. It was selected because the AHP is widely used in multi-Criteria Decision-Making and, so far, the AHP is a proven and reliable method [29].

The hierarchy is used in this research to show the structure of criteria and sub-criteria in subway stations as illustrated in (Figs. 2 and 3). It was drawn using literature studies of the world systems in metro stations. Then, it was presented to a specific group of experts through semi-structured interviews to determine the criteria/sub-criteria of stations [30]. AHP (analytic hierarchy process) allowed for the application of data and experience in a rational and comprehensive way. It also helps decision-makers to create preference gauges and weightings instead of determining them randomly.

The principles and axioms of AHP The AHP depends on three principles. The first one, the mutual principle, demands that, if A_{ij} is a pairwise relation of components i and j , defining how much the component i is bigger than component j , so $A_{ji} = 1/A_{ij}$. For example, if i is six times bigger than j , so j is $1/6$ of i . The second principle (analogy) requires that parallel components cannot vary significantly because they would cause bigger mistakes in assessment [31]. See the AHP sample matrix in (Table 3). The third principle states that the priority of the objects within the hierarchy does not depend on judgment on the objects of least value. Thus, the comparison of alternatives depends on the most important objects [32].

Mathematical principles of AHP The initial phase is to match the dynamic issue in a hierarchical style. Then, the needs are set up, for example, to make a paired comparison. Paired comparison of criteria is created based on importance. When contrasting criteria with respect to their family member significance, pair-wise examinations are

essential to the AHP strategy. When contrasting a couple of criteria, a proportion of relative significance of the criteria can be set up. This proportion need not be founded on some norm scale. However, it only addresses the relationship of the two standards being analyzed. the scale created by Saaty is shown in (Table 4) [24].

Then, the AHP technique is used to get the Eigen vector of criteria/sub-criteria of the station, which will help later in the criteria field assessment.

Assessment management The assessment of absolute rank for a specific station relies upon two outcomes: Field assessment for each sub-criteria, and the preference vectors processed for the sub-criteria utilizing the AHP. The field assessment for every sub-criterion increases with the relative weight for that sub-criterion to acquire a weighted field assessment. The summation of weighted field assessments for all sub-criteria related to criteria gives the weighted field assessment for a specific criterion. The threshold of total stations weight is set by the decision-maker to select station criteria /sub-criteria for rehabilitation [24]. See Table 5.

Likewise, weighted field assessment is recorded for every criterion. The summation of these weighted field assessments at the criteria level gives the complete value of a specific station. To get positioning for the stations, the stations are ranked in descending order of the absolute value. The capital program grants funding for a specified number of stations/criteria to be restored with restricted funds. A decision must be made to incorporate the most desired stations/criteria for recovery. Station evaluation is a major advance in the selection course. After evaluating the stations and the capital program was determined, the decision-maker chooses a threshold to be considered in the evaluation cycle.

Using LP/IP method in selection stations criteria to be restored

The study used this method because its resulting values are more realistic and flexible. The limitations and the destinations of the examination are viewed as linear. The goal

Table 3 AHP Sample pairwise matrix

CRITERIA	1	2	3	4
1	1	A12	A13	A14
2	1/A12	1	A 23	A24
3	1/A13	1/A23	1	a 34
4	1/A14	1/A24	1/A34	1

Table 4 Saaty meter

Assessment	Explanation
1	Evenly significant
3	A little further significant
5	Highly further significant
7	Very highly further significant
9	Frequently further significant
2, 4, 6, 8	Median rates

of the interaction is to boost the number of stations to be selected depending on the current capital program based on the breakdown required and the weight dictated by the AHP. LP/IP programming was applied in these steps as follows:

- For this situation, the integer variables and values are multiplied to frame a linear function. This is accomplished for all the factors. At this point, the integer variables and values are added up and set equivalent to the accessible expense. In this case, the integer variables are the station names, integer values are the expense for making sub-criteria rehabilitation.

$$\text{SUM} = (I_i * C_i) = C' \quad (1)$$

$I = \text{STATION NAME}, C = \text{cost}, i = \text{station criteria}$

The summation capacity will incorporate all stations that can be chosen for maintenance.

- The function is built upon specific requirements that are pertinent to the analysis. The sum of every combination of station choices will be more than or equivalent to (0). The result for the integer value is either equivalent to (1) or (0).
- The solver programming is utilized to run the investigation regarding conditions and imperatives referenced before. The program invents various determinations based on expense factors. The target of this analysis is to augment all the potential parts to choose criteria or stations to be restored.
- The stations or a criterion with esteem (1) implies that this criterion/station is chosen for maintenance and others with a value equal to (0) are not being thought of. This examination and organization are made for either criteria levels or stations levels.

Table 5 The thresholds of ranking stations

Station weight value	Index	Proposed action
$8 < \text{swv} \leq 10$	Good condition	Long term /inspection in 2 years
$6 < \text{swv} \leq 8$	Acceptable condition	Medium term /inspection in 1 year
$3 < \text{swv} \leq 6$	Poor condition	Short term /inspection in 6 months
$0 < \text{swv} \leq 3$	Critical condition	Immediate/quick action

To clarify the information introduced in Table 4, the useful model f will be assessed utilizing linear programming/integer programming (LP/IP). The initial step for the examination utilizing the LP/IP is as follows:

For example, the station criteria are taken as symbols as fs , va , pl , and dr . Each of these values is introduced in (Table 6). At this point, the table is set up with variable values, integer values, the budget for the restoration of criteria, and afterwards, the credit value. The available budget represents the surplus of assets (3.25 M LE). See Table 4.

Row 2 includes criteria.

Row 3 variables values (estimated budget for every criterion restoration).

Row 5 the unknown integer values (binary numbers 0 or 1) means the criteria or sub-criteria will be selected totally or ignored totally.

Row 6 objective maximization function, to get the most benefit of the allocated budget. The limitations or constraints of the equation and the relationship are presented in Table 6.

Model verification and application

This is the last phase of the methodology in which brainstorming sessions were done to verify the model, followed by application of the model to the preselected samples of Cairo metro stations through two main steps:

- 1) Brainstorming sessions are considered one of the best common identification systems in construction projects [33]. Two brainstorming sessions were conducted, with four experts in the field of metro stations projects, to apply and validate the model criteria and results and the model suitability for application in Metro stations.
- 2) Applying the SRAM model to six Cairo metro stations. More details will be explained in model application in the discussion of model application.

Results and Discussion of model application

The SRAM (Stations Rehabilitation Assessment model) portrayed previously was applied to Cairo metro stations to demonstrate its advantages and validity. The assessment reports had been accomplished for a sample of stations in the Cairo Metro network, two of them are interchange stations as below: Attaba and Sadat stations, the

Table 6 LP/IP for sample criteria factors

Criteria symbol	fs	va	pl	dr
Criteria	Fire standpipe	Ventil/a.c.system	Plumping	Drains
budget	1 m	2 m	1 m	.5 m
Credit value	3.25 m			
Integer value	0	1	1	0
Max function equation		$1 fs + 2 va + 1 pl + .5 dr \leq 3.25 m$		
.25 m = rest of budget will be added to the next priority of stations		$1 fs + 2 va \geq 0$		
		$1 fs + 2 va + 1 pl \geq 0$		
		$1 fs + 2 va + 1 pl + .5 dr \geq 0$		

other stations are in the first and the oldest line in Cairo Metro network: Helwan, Tora El-Asmant, Thakanat El-Maadi, and El-Malek El-Saleh stations [2]. The Cairo Metro stations were selected to be the case study of the SRAM model application, because of the great area that the Cairo metro framework serves inside the greater Cairo. The Egyptian government allocates millions of dollars to subway stations restoration either through its internal budget or through international loans.

The station assessment results are organized into (1) AHP criteria and sub-criteria weights, (2) practical evaluation of stations, (3) selection and ranking of stations, and (4) ranking depending on cost requirements. Every item of the model results is followed by a detailed explanation and discussion.

Criteria/sub-criteria weights using AHP

The semi-structured interviews gave assessments of structural, architectural, hydro-mechanical, communication /electrical, safety, and passage usage facilities as the main criteria for Cairo metro stations. The pairwise matrix created by Saaty [31] was used to relate factors. The pairwise correlation was utilized to relate between the criteria/sub-criteria components dependent on the Saaty scale which in turn resulted in the criteria weight vector (Table 5). The criteria weights are the most significant to any decision-making particularly to the SRAM model. The SRAM model recommended AHP as it was the most proper technique. The use of the AHP technique produced the criteria weight vector. See Table 7 and Fig. 4.

As stated before, the factors were assessed using the AHP technique. This assessment described the significance of criteria and sub-criterion and their relation to weight vector (Wt. vector) (Tables 7 and 8) and structure sub-criteria ratio chart in Table 9 and Fig. 5.

Practical (field) evaluation of stations

The field assessment is multiplied by the weight vector of sub-criteria to result in the criteria weight assessment. To get the assessment for the criteria (i.e., architecture criteria), the summation of sub-criteria weight assessments is divided by the summation of the weight vector for arch criteria, as shown in Table 10.

Table 7 Main criteria level pairwise comparison Matrix using AHP

	1	2	3	4	5	6	7
	Structure	Arch	Hydro mechanic	Elect/Comm	Safety	Passage facilities	Wt. vector
1 Structure	1	2	3	2	3	2	0.315
2 Arch	1/2	1	1	1	2	2	0.173
3 Hydro mechanic	1/3	1	1	1	2	2	0.162
4 Elect/Comm	1/2	1	1	1	1	1	0.138
5 Safety	1/3	1/2	1/2	1	1	2	0.115
6 Passage usage facilities	1/2	1/2	1/2	1	1/2	1	0.097
Summation	3.1667	6	7	7	9.5	10	1

Many tables calculated by the AHP method for the whole sub-criteria are available in the appendices

To explain Table 11, every sub-criteria weight vector (column 4) is multiplied by its field assessment (column 5) to give a sub-criteria weight assessment (column 6). Every station criteria/sub-criteria will follow the previous step to get the criteria assessment summation. For example, in the next station, the weight vector (column 4) is multiplied by its field assessment (column 7) to give sub-criteria weight assessment (column 8), and so on. All sub-criteria assessment weights are summed in row 11 for structure criteria assessment weight summation, and in rows 23, 28, 34, 41, and 48 for other criteria assessment weight summation. All criteria and sub-criteria weight assessments are summed in row 50, to give the overall station assessment weight which will be used in the ranking of stations for restoration. The positioning of the stations at the level of criteria depends on the field assessment weight for each station at the criteria level of the hierarchy structure. The stations are positioned in ascending order of the total station weight assessment.

In another way of thinking, it can be ranked depending on the criteria/sub-criteria field assessment weight priority. For example, the sub-criteria column structure in Helwan stations is prior in restoration than the sub-criteria electrical lighting as sub-criteria in Attaba station.

Table 8 The hierarchy weight vector analysis of stations criteria

Criteria	Criteria wt. vector
Structure	0.315
Arch.	0.173
Hydro mechanic	0.162
Electrical/comm	0.138
Safety	0.115
Passenger usage facilities	0.097

Table 9 The hierarchy weight vector analysis of stations Sub-criteria (structure)

Criteria	Criteria wt. vector	Sub-criteria	Sub-criteria wt. vector
Structure	0.315	Slabs	0.039
		Beams	0.048
		Columns	0.059
		Walls	0.024
		Platform structure	0.05
		Stair's structure	0.05
		Path corridor	0.03
		Signage support	0.015

Note: The summation of every sub-criteria weight vector = the criteria weight vector.

The total weight vector of criteria/sub-criteria = 1

Many tables calculated for the rest of all other sub-criteria are available in appendices

Selection and ranking of stations

After assuming the station condition, the decision-maker or management has to interpret these indices in a proper manner. The research used a condition scale with thresholds. The selected scale is a universally accepted, logical, and easy to interpret scale [32]. Arranging the total weight of the stations depends on the institution's policy which is directed towards maintaining the station with the highest priority and, then, moving to the next station in priority.

The aforementioned ranking depends on the total weight vector of stations that was classified for Cairo metro stations according to the Saaty scale (Table 12). Thus, the stations' criteria should be evaluated using LP/IP as a step towards optimization for restoration.

Table 10 Weight assessment for criteria/sub-criteria of architecture

Criteria	Sub-criteria	Arch	Sub-criteria assessment	Weight assessment
Sub-criteria weight vector.	s.c 1	0.02574	5	0.1287
	s.c 2	0.0181	6	0.1086
	s.c 3	0.00964	7	0.06748
	s.c 4	0.0181	8	0.1448
	s.c 5	0.01054	5	0.0527
	s.c 6	0.01596	4	0.06384
	s.c 7	0.00964	3	0.02892
	s.c 8	0.016996	6	0.101976
	s.c 9	0.021868	5	0.10934
	s.c 10	0.013209	4	0.052836
	s.c 11	0.013209	3	0.039627
Sum		0.173002	5.195425486	0.898819
Arch. criteria weight assessment 0.8988/0.173=5.19				

Ranking based on budget requirements

The obtainable funds represent one of the significant stages of the assessment. The expenses program is created based on the necessary expenses for the stations' restoration on one hand, and assigned funds for the chosen stations for restoration on another hand. There are other government organizations and private subsidizing and private investors expected to be an effective factor in the station recovery program. The budgets mentioned in Table 13 are assumed.

The next description will clarify the utilization of linear programming for the choice process. For example, the hydro-mechanical criteria will be analyzed at five stations using the LP/IP method. The result (1) means that the mechanical item of that station is chosen for restoration. The result (0) means that the hydro/mechanical criteria of that station are not chosen for restoration (see Table 14).

The meaning of this condition is to consider that the function, for any station criteria to another, is linear. This equation constraints are explained as follows:

The first constraint is the summation of each station variable and is positive ≥ 0 . See rows 9–12. The second constraint is the total summation of the station criteria $\leq$ the available budget or fund (10 million le in row 7). The third constraint is the resulting values: these are binary (0) or (1) which means that the criteria would be selected or not. To increase the benefit of the fund, a max function is created, see row 6. The last table describes hydro/mechanic criteria selection for rehabilitation of some stations depending on available cost using LP/IP. The result showed that some stations had been selected for rehabilitation in hydro-mechanic criteria but others had been not selected. The summation of other criteria results will present the full rehabilitation station or partial rehabilitation stations. The ranking can be used in the classification of the stations for rehabilitation by programing the stations with the same LP/IP technique (**Microsoft Engine: Simplex LP** to determine the selected criteria for restoration from the excluded ones. See Table 15 for the example of El-Malek El-Saleh station [34].

After the integration programing is achieved for all the other stations, it will be aggregated in a table to determine whether the criteria will be fully or partially restored. This

Table 11 SRAM criteria and sub-criteria of stations weight assessment (Continued)

Criteria	Criteria wt. vector	S. criteria	S. criteria wt. v	Attaba	Sadat	Helwan	Tora El-Asmant	Thakanat El-Maadi	El-Malek El-Saleh				
				S. criteria assess	S. criteria assess	S. criteria assess	S. criteria assess	S. criteria assess	S. criteria assess				
Hydro mechanic	0.162	Waiting area	0.0167	6	0.1	9	0.15	4	0.067	8	0.1336	4	0.067
		Stairs req.	0.022	5	0.11	6	0.132	7	0.154	5	0.11	6	0.088
		Pathway req.	0.013	4	0.052	7	0.091	7	0.091	4	0.052	5	0.065
		Signage	0.013	4	0.052	6	0.078	8	0.104	4	0.052	5	0.052
		Criteria wt. sum		0.901	1.119		1.171		0.758	0.9216		0.859	
		Fire standpipe	0.055	6	0.33	7	0.385	6	0.33	4	0.22	5	0.33
		Ventil/a.c. system	0.039	5	0.195	6	0.234	7	0.273	6	0.234	6	0.195
		Plumping	0.046	6	0.276	6	0.276	6	0.276	5	0.23	6	0.276
		Drains	0.023	6	0.138	7	0.161	5	0.115	5	0.115	5	0.115
		Criteria wt. sum		0.939	1.056		0.994		0.799	0.9	0.916		
Electrical/ communication	0.138	Lighting	0.04	5	0.2	6	0.24	6	0.24	6	0.24	6	0.24
		Ducts/tray	0.03	7	0.21	5	0.15	6	0.18	6	0.18	7	0.15
		Signal cables	0.03	8	0.24	6	0.18	5	0.15	7	0.21	7	0.15
		Public address system	0.017	7	0.119	6	0.102	7	0.119	5	0.085	4	0.068
		Cust. info. services	0.02	3	0.06	5	0.1	5	0.1	3	0.06	4	0.08

Table 11 SRAM criteria and sub-criteria of stations weight assessment (Continued)

Criteria	Criteria wt. vector	S. criteria	S. criteria wt. v	Attaba	Sadat	Helwan	Tora El-Asmant	Thakanat El-Maadi	El-Malek El-Saleh
				S. criteria assess	S. criteria weight	S. criteria assess	S. criteria weight	S. criteria assess	S. criteria weight
		Criteria wt. sum		0.829	0.772	0.789	0.775	0.808	0.688
Safety	0.115	Use hazards	0.013	5	0.065	7	0.091	5	0.065
		Fire protection	0.031	5	0.155	7	0.217	3	0.093
		Air quality	0.013	3	0.039	6	0.078	6	0.078
		Security	0.02	7	0.14	7	0.14	5	0.1
		Noise level	0.013	3	0.039	4	0.052	6	0.078
		Evacuation plans	0.025	2	0.05	5	0.125	6	0.15
		Criteria wt. sum		0.488	0.677	0.901	0.564	0.564	0.635
Passenger usage facilities	0.097	Day usage	0.02	3	0.06	6	0.12	6	0.12
		Passage cont.zone	0.018	7	0.126	7	0.126	5	0.09
		Special needs Ppl.	0.012	3	0.036	6	0.072	4	0.048
		Level of service	0.018	3	0.054	5	0.09	5	0.09
		Ventilation	0.019	3	0.057	5	0.095	6	0.114
		Energy saving	0.01	5	0.05	6	0.06	5	0.05
		Criteria wt.sum		0.383	0.563	0.664	0.512	0.46	0.434

Table 11 SRAM criteria and sub-criteria of stations weight assessment (Continued)

Criteria	Criteria wt. vector	S. criteria wt. v	Attaba	Sadat	Helwan	Tora El-Asmant	Thakanat El-Maadi	El-Malek El-Saleh
			S. criteria assess	S. criteria assess	S. criteria assess	S. criteria assess	S. criteria assess	S. criteria assess
			weight	weight	weight	weight	weight	weight
1	1	1	5.792	6.934	6.427	5.297	5.483	4.867
Total station assessment Weight								

Table 12 Thresholds stations ranking and actions

Station weight value	Index	Proposed action	Ranked stations
$8 < swv \leq 10$	Good condition	Long term /inspection in 2 years	N/A
$6 < swv \leq 8$	Acceptable condition	Medium term /inspection in 1 year	Sadat/Helwan
$3 < swv \leq 6$	Poor condition	Short term /inspection in 6 months	Tora el asmant/Thakanat ELmaadi/ELmalek ELSaleh
$0 < swv \leq 3$	Critical condition	Immediate /quick action	

helps the decision-maker to manage his plan and his budget through an appropriate time schedule. The outcomes will be summed up in (Table 16). It could also be made for stations, not for criteria as applied in the previous table. Those stations would be selected either for full rehabilitation or for partial rehabilitation.

Conclusions

A new model SRAM had been innovated to reduce or make the optimal use of the allocated budgets for Cairo Metro stations rehabilitation, according to stations condition assessment. It had been applied in the case study of Cairo metro stations; first, by collecting data and choosing sample stations for application, followed by model development using (1) AHP method for station condition assessment based on data collected from the questionnaire instrument from 41 experts in semi-structured interviews and (2) LP/IP method to allocate the available budgets in optimal use ending with model application and verification on six case study stations. This model has proved that it is applicable. Criteria/stations could be assessed numerically and ranked. The SRAM model used in this research contributes to the body of knowledge by integrating the AHP method with the LP/IP method to facilitate the evaluation and optimization of the identified criteria/stations; which is lacking in prior studies.

The criteria assessment of metro stations was essentially influenced by structure, architecture, and hydromechanics criteria. The most influential criteria through AHP

Table 13 The criteria/station costs and the available costs

Criteria	Wt. vector	Ataba	Sadat	Helwan	Tora El-Asmant	Thakanat El-Maadi	El-Malek El-Saleh	Criteria total cost	Available cost
Structure	0.315	10	2	8	4	4	3.5	33	30.5
Arch	0.173	6	4	6.5	4	3	2.5	27	23.25
Hydro mechanic	0.162	4	1	3	3.5	3	2.5	18.25	16.75
Elect/comm	0.138	3	1	2	1	2	2	12.25	11
Safety	0.115	4	1.5	1	1.5	2	1.5	12.1	11.5
Passage usage facilities	0.097	3	2.5	3	2	1.5	2	15	13
Station total cost	1	30	12	23.5	16	15.5	14	117.6	
Available cost		27	10.25	21	15	14.25	12.5	106	106

Table 14 Using LP/IP for hydro mechanics criteria in metro stations

Integer variable	h.m/sadat	h.m/helwan	h.m/tora elasmant	h.m/thakanat el maadi	h.m/el-malek el-saleh	Sum
Cost	1	3	3.5	3	2.5	13.00
Integer value	1	1	1	0	1	10 M LE

Obtainable budget 10 M LE

The rest of this example is 3 million to be added to the prior criteria in LP/IP programing

MAX 3 h.m/sadat+ 2.5 h.m/helwan + 5 h.m/tora + 1.5 h.m/thakanat + 1 h.m/el m. saleh

3 h.m/sadat+ 2.5 h.m/helwan + 5 h.m/tora + 1.5 h.m/thakanat + 1 h.m/el m. saleh ≤ 10.00

3 h.m/sadat+ 2.5 h.m/helwan ≥ 0

3 h.m/sadat+ 2.5 h.m/helwan + 5 h.m/tora ≥ 0

3 h.m/sadat+ 2.5 h.m/helwan + 5 h.m/tora + 1.5 h.m/thakanat ≥ 0

3 h.m/sadat+ 2.5 h.m/helwan + 5 h.m/tora + 1.5 h.m/thakanat + 1 h.m/el m. saleh ≥ 0

application (structure, architecture, and hydromechanics) were the selected criteria for rehabilitation in all stations included in the research sample. Using the Saaty scale, it was clear that there were deficient stations (Tora El Asmant/Thakanat ELmaadi /ELmalek ELSaleh), that required “short-term” mediation, while it was clear that there were Moderate stations (Sadat/Helwan), that required medium-term mediation. Based on the results of this research, it is recommended that more researches be developed to make interface software to facilitate processing data derived from this model, and to develop other models which help in optimization the budget of new station construction in metro or other stations networks (i.e., railway station, tram station, monorail stations), and also to identify the age criteria of metro stations is recommended in future researches.

Model limitations

Not all metro stations are the same in their characteristics. This model has limitations.

Table 15 LP/IP for El-Malek El-Saleh station criteria optimization

Stru.	Arch.	Hydro.m	Elect. comm	Safety	Passenger use	Criteria	Integer values *	
1	1	1	1	0	1		relation	limits
st	Ar	hm	ec	sa	pu	total		
3.5	2.5	2.5	2	1.5	2	12.5	≤	12.5
3.5	2.5					6	≥	0
3.5	2.5	2.5				8.5	≥	0
3.5	2.5	2.5	2			10.5	≥	0
3.5	2.5	2.5	2	1.5		10.5	≥	0
3.5	2.5	2.5	2	1.5	2	12.5	≥	0
Stru.	Arch.	Hydro.m	Elect. comm	Safety	Passenger use			
3.5	2.5	2.5	2	1.5	2	12.5		

*Note: the constraints are similar to those in previous tables

The result is the binary integrated row (row 2)

Other stations criteria optimizations are available in appendices

Table 16 The results of the criteria by using integer programming (IP) aggregation

Criteria	El-malek El-saleh	Tora El Asmant	Thakanat Elmaadi	Attaba	Helwan	Sum
Structure	1	1	1	1	1	5
Arch	1	1	1	1	1	5
Hydro mechanic	1	1	1	1	1	5
Elect/comm	1	0	1	1	0	3
Safety	0	1	1	1	1	4
Passage usage facilities	1	1	0	0	1	3

The summations in bold indicate that the criteria structure, architecture, and hydromechanics need complete restoration for all selected stations, and there are three criteria that need to be restored in some other stations

The first limitation of this model is that the stations were considered in the operation phase. So, the model is useful for station assessment during the operation phase. What if the project is in the pre-construction or in the construction phase? Hence, future efforts can be directed toward the use of SRAM in making the optimal use of the allocated budgets for the Cairo metro stations' pre-operation phases. Another limitation is that the model ranking depends on the priority of the station weight, not on the priority of the criteria/sub-criteria weight. Hence, the direction is to maintain station by station, not criterion by criterion. To change the direction to maintain criterion by criterion, the priority of ranking must be updated from stations weights to criteria/sub-criteria weights according to the policy of the decision-maker. For example, the sub-criteria structure columns criterion (0.472) in Helwan station is prior in restoration than the sub-criteria electrical lighting criterion (0.2) in Attaba station. The last limitation is that this model hierarchy structure includes station criteria and sub-criteria, but does not include more divisive criteria levels. To get to these complex criteria division structures, the used matrices and analyses in the applied model have to be upgraded to meet these requirements.

Abbreviations

AHP: Analytic hierarchical process; SRAM: Stations Rehabilitation Assessment Model; LP/IP: Linear programming/integer programming; NPV: Net present value; IRR: Internal rate of return; WASPAS: Weighted Aggregated Sum Product Assessment; TOPSIS: Technique for Order Performance by Similarity to Ideal Solution; ELECTRE: Élimination et Choix Traduisant la Réalité (Élimination Et Choice Translating Reality)

Supplementary Information

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Additional file 1. Appendix A. Table a2 architecture Criteria pairwise comparison Matrix Using AHP. Table a1 structure Criteria pairwise comparison Matrix Using AHP. Table a3 hydromechanics Criteria pairwise comparison Matrix Using AHP. Table a4 electric/communication Criteria pairwise comparison Matrix Using AHP. Table a5 safety Criteria pairwise comparison Matrix Using AHP. Table a6 passenger facilities Criteria pairwise comparison Matrix Using AHP. Fig a1,a2.Sub- Criteria weight pie chart (structure and architecture). Fig a3, a4. Sub- Criteria weight pie chart (hydro-mechanic and electric /communication). Fig a5, a6. Sub- Criteria weight pie chart (Safety and Passenger facilities). Appendix B. Table b The hierarchy weight vector Analysis of stations Criteria. Appendix C. TABLE c1. Integer Programming for el malek el saleh station criteria. Table c2. Answer Report for el malek el saleh station criteria. TABLE c3. Integer Programming for tora el asmant station criteria. TABLE c4. Integer Programming for thakanat el maadi station criteria. TABLE c5. Integer Programming for Attaba station criteria. TABLE c6. Integer Programming for Helwan station criteria. TABLE c7. Integer Programming for sadat station criteria. TABLE c8. Integer Programming for the criteria (hydro mechanics) Restoration of the Stations. Table c9 Answer Report for the criteria (hydro mechanics) Restoration of the Stations.

Additional file 2. Summary Traffic Report line 1

Additional file 3. Summary Traffic Report line 2

Additional file 4. Summary Traffic Report line 3

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Author's contributions

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