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].
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-criterion 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) |
| 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        | A23     | A24     |
| 3        | 1/A13 | 1/A23    | 1       | a34     |
| 4        | 1/A14 | 1/A24    | 1/A34   | 1       |
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.

\[
\text{SUM} = \sum (I_i \times C_i) = C' \\
I = \text{STATION NAME}, \quad C = \text{cost}, \quad i = \text{station criteria}
\]

(1)

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 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 |

| Table 5 | The thresholds of ranking stations |
|---------|----------------------------------|
| Station weight value | Index | Proposed action |
| 8 ≤ swv ≤ 10 | Good condition | Long term/inspection in 2 years |
| 6 ≤ swv ≤ 8 | Acceptable condition | Medium term/inspection in 1 year |
| 3 ≤ swv ≤ 6 | Poor condition | Short term/inspection in 6 months |
| 0 ≤ swv ≤ 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

| Criteria symbol | Fs  | va | pl | dr |
|------------------|-----|----|----|----|
| Criteria Fire standpipe | 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 | $1f_s + 2va + 1pl + .5dr \leq 3.25 \text{ m}$ |

$.25 \text{ m} = \text{rest of budget will be added to the next priority of stations}$
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.

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

![Fig. 4](image)

**Fig. 4** Main criteria weight level pie chart. *Many figs for charts for the whole six main criteria and the other sub-criteria are available in appendices*

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| 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       |
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 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.

Fig. 5 Sub-criteria weight pie chart (structure)
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 ≤ 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 programming 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 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
| Criteria        | Criteria wt. vector | S. criteria wt. v | S. criteria weight | S. criteria weight | S. criteria weight | S. criteria weight | S. criteria weight | S. criteria weight | S. criteria weight | S. criteria weight | S. criteria weight |
|-----------------|---------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| Structure       | 0.315               |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
| Slabs           | 0.039               | 8                 | 0.312             | 8                 | 0.312             | 6                 | 0.234             | 6                 | 0.234             | 6                 | 0.234             | 7                 | 0.273             |
| Beams           | 0.048               | 7                 | 0.336             | 9                 | 0.432             | 7                 | 0.336             | 6                 | 0.288             | 6                 | 0.288             | 6                 | 0.288             |
| Columns         | 0.059               | 9                 | 0.531             | 10                | 0.59              | 8                 | 0.472             | 7                 | 0.413             | 7                 | 0.413             | 6                 | 0.354             |
| Walls           | 0.024               | 7                 | 0.168             | 7                 | 0.168             | 5                 | 0.12              | 6                 | 0.144             | 5                 | 0.12              | 5                 | 0.12              |
| Platform str.   | 0.05                | 5                 | 0.25              | 9                 | 0.45              | 6                 | 0.3               | 6                 | 0.3               | 6                 | 0.3               | 7                 | 0.35              |
| Stairs str.     | 0.05                | 8                 | 0.04              | 9                 | 0.45              | 7                 | 0.35              | 6                 | 0.3               | 5                 | 0.25              | 5                 | 0.25              |
| Path corridor   | 0.03                | 5                 | 0.15              | 8                 | 0.24              | 8                 | 0.24              | 5                 | 0.15              | 5                 | 0.15              | 6                 | 0.18              |
| Signage support | 0.015               | 7                 | 0.105             | 7                 | 0.105             | 6                 | 0.09              | 4                 | 0.06              | 5                 | 0.075             | 5                 | 0.075             |
| Criteria wt. sum|                    |                   | 2.252             |                   | 2.747             |                   | 1.908             |                   | 1.889             |                   | 1.83              |                   | 1.89              |
| Architecture    | 0.173               |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |                   |
| Station appear. | 0.025               | 5                 | 0.125             | 8                 | 0.2               | 6                 | 0.15              | 4                 | 0.1               | 5                 | 0.125             | 6                 | 0.15              |
| Station capacity| 0.018               | 6                 | 0.108             | 7                 | 0.126             | 6                 | 0.108             | 4                 | 0.072             | 5                 | 0.09              | 6                 | 0.108             |
| Stairs N. access| 0.009               | 5                 | 0.045             | 6                 | 0.054             | 7                 | 0.063             | 4                 | 0.036             | 4                 | 0.036             | 4                 | 0.036             |
| No. of entrances| 0.018               | 6                 | 0.108             | 6                 | 0.108             | 6                 | 0.108             | 5                 | 0.09              | 4                 | 0.072             | 5                 | 0.09              |
| Wall&Floor      | 0.011               | 6                 | 0.066             | 7                 | 0.077             | 6                 | 0.066             | 4                 | 0.044             | 4                 | 0.044             | 4                 | 0.044             |
| Warning strips  | 0.015               | 6                 | 0.09              | 6                 | 0.09              | 7                 | 0.105             | 6                 | 0.09              | 7                 | 0.105             | 7                 | 0.105             |
| Track wall      | 0.009               | 5                 | 0.045             | 7                 | 0.063             | 8                 | 0.072             | 5                 | 0.045             | 6                 | 0.054             | 6                 | 0.054             |
| Criteria                      | S. criteria wt. v | Attaba | Sadat | Helwan | Tora El-Asmant | Thakanat El-Maadi | El-Malek El-Saleh |
|-------------------------------|-------------------|--------|-------|--------|----------------|-------------------|------------------|
| Waiting area                  | 0.0167            | 6.01   | 6.01  | 9.015  | 4.067          | 8.01336          | 4.0067           |
| Stairs req.                   | 0.022             | 5.011  | 6.0132| 7.0154 | 5.011           | 6.0132           | 4.0088           |
| Pathway req.                  | 0.013             | 4.0052 | 7.0091| 7.0091 | 4.0052          | 5.0065           | 5.0065           |
| Signage                       | 0.013             | 4.0052 | 6.0078| 8.0104 | 4.0052          | 5.0065           | 4.0052           |
| Criteria wt. sum              | 0.901             | 1.119  | 1.171 | 0.758  | 0.9216          | 0.859            | 0.859            |
| Hydro mechanic                | 0.162             |        |       |        |                |                   |                  |
| Fire standpipe                | 0.055             | 6.033  | 7.0385| 6.033  | 4.022           | 5.0275           | 6.033            |
| Ventil/a.c. system            | 0.039             | 5.0195 | 6.0234| 7.0273 | 6.0234          | 6.0234           | 5.0195           |
| Plumping                      | 0.046             | 6.0276 | 6.0276| 6.0276 | 5.023           | 6.0276           | 6.0276           |
| Drains                        | 0.023             | 6.0138 | 7.0161| 5.0115 | 5.0115          | 5.0115           | 5.0115           |
| Criteria wt. sum              | 0.939             | 1.056  | 0.994 | 0.799  | 0.9             | 0.916            |                  |
| Electrical/communication      | 0.138             |        |       |        |                |                   |                  |
| Lighting                      | 0.04              | 5.02   | 6.024 | 6.024  | 6.024           | 6.024            | 6.024            |
| Ducts/tray                    | 0.03              | 7.021  | 5.015 | 6.018  | 6.018           | 7.021            | 5.015            |
| Signal cables                 | 0.03              | 8.024  | 6.018 | 5.015  | 7.021           | 7.021            | 5.015            |
| Public address system         | 0.017             | 7.0119 | 6.0102| 7.0119 | 5.085           | 4.0068           | 4.0068           |
| Cust. info. services          | 0.02              | 3.006  | 5.01  | 5.01   | 3.011           | 4.006            | 4.008            |
| Criteria          | S. criteria wt. vector | S. criteria wt. v | Attaba | Sadat | Helwan | Tora El-Asmant | Thakanat El-Maadi | El-Malek El-Saleh |
|-------------------|------------------------|-------------------|--------|-------|--------|----------------|------------------|------------------|
| Safety            | 0.115                  |                   |        |       |        |                |                  |                  |
| Use hazards       | 0.013                  | 5                 | 0.065  | 5     | 0.065  | 5              | 0.065            | 5                |
| Fire protection   | 0.031                  | 5                 | 0.155  | 7     | 0.217  | 7              | 0.217            | 3                |
| Air quality       | 0.013                  | 3                 | 0.039  | 6     | 0.078  | 8              | 0.104            | 6                |
| Security          | 0.02                   | 7                 | 0.14   | 7     | 0.14   | 8              | 0.16             | 5                |
| Noise level       | 0.013                  | 3                 | 0.039  | 4     | 0.052  | 8              | 0.104            | 6                |
| Evacuation plans  | 0.025                  | 2                 | 0.05   | 5     | 0.125  | 9              | 0.225            | 6                |
| Criteria wt. sum  |                       |                   | 0.488  | 0.677 | 0.901  | 0.564          | 0.564            | 0.635            |
| Passenger usage facilities | 0.097 |                   |        |       |        |                |                  |                  |
| Day usage cir.    | 0.02                   | 3                 | 0.06   | 6     | 0.12   | 5              | 0.1              | 6                |
| Passage cont.zone | 0.018                  | 7                 | 0.126  | 7     | 0.126  | 8              | 0.144            | 5                |
| Special needs Ppl.| 0.012                  | 3                 | 0.036  | 6     | 0.072  | 6              | 0.072            | 4                |
| Level of service  | 0.018                  | 3                 | 0.054  | 5     | 0.09   | 7              | 0.126            | 5                |
| Ventilation       | 0.019                  | 3                 | 0.057  | 5     | 0.095  | 8              | 0.152            | 6                |
| Energy saving     | 0.01                   | 5                 | 0.05   | 6     | 0.06   | 7              | 0.07             | 5                |
| Criteria wt. sum  |                       |                   | 0.383  | 0.563 | 0.664  | 0.512          | 0.46             | 0.434            |
### Table 11 SRAW 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 |
|----------|---------------------|-------------------|--------|-------|--------|----------------|------------------|------------------|
|          |                     |                   |        |       |        |                |                  |                  |
|          | 1                   | 1                 |        |       |        |                |                  |                  |
| Total station assessment weight | 5.792 | 6.934 | 6.427 | 5.297 | 5.483 | 4.867 |
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 12 Thresholds stations ranking and actions |
|------------------------------------------------|
| **Station weight value** | **Index** | **Proposed action** | **Ranked stations** |
|-------------------------|-----------|---------------------|---------------------|
| 8< swv ≤10             | Good condition | Long term/inspection in 2 years | N/A |
| 6< swv ≤8              | Acceptable condition | Medium term/inspection in 1 year | Sadat/Helwan |
| 3< swv ≤6              | Poor condition | Short term/inspection in 6 months | Tora el asmant/Thakanat ELmaadi/ ELmalek ELsaleh |
| 0< swv ≤3              | Critical condition | Immediate/quick action | |

| 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            |
| Hydromechanic | 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                | 106              |
| Available cost | 27             | 10.25    | 21        | 15        | 14.25             | 12.5                | 106                 | 106                  |
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 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 \(3 \times h.m/sadat + 2.5 \times h.m/helwan + 5 \times h.m/tora + 1.5 \times h.m/thakanat + 1 \times h.m/el m. saleh\) \(\leq 10.00\)

\(3 \times h.m/sadat + 2.5 \times h.m/helwan \geq 0\)

\(3 \times h.m/sadat + 2.5 \times h.m/helwan + 5 \times h.m/tora \geq 0\)

\(3 \times h.m/sadat + 2.5 \times h.m/helwan + 5 \times h.m/tora + 1.5 \times h.m/thakanat \geq 0\)

\(3 \times h.m/sadat + 2.5 \times h.m/helwan + 5 \times h.m/tora + 1.5 \times h.m/thakanat + 1 \times h.m/el m. saleh \geq 0\)

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             |                          |
| st    | Ar    | hm      | ec          | sa     | pu            | total                    |

| 3.5   | 2.5   | 2.5     | 2           | 1.5    | 2             | 12.5                    |
| 3.5   | 2.5   | 6       | 2           | 0      |               |                          |
| 3.5   | 2.5   | 8.5     | 2           | 0      |               |                          |
| 3.5   | 2.5   | 10.5    | 2           | 0      |               |                          |
| 3.5   | 2.5   | 10.5    | 2           | 0      |               |                          |

*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
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 (ELimination Et Choice Translating Reality)

Supplementary Information
The online version contains supplementary material available at https://doi.org/10.1186/s44147-021-00060-6.

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.
Acknowledgements
Great thanks to Professor Mohamed Hussein Abdel-Kader for his effort in general supervision of the research. Also, the case study was greatly assisted by metro national authorities of tunnels and metro in Egypt. The authors are grateful to the experts and directors of Cairo Metro for the technical support offered during the preparation of this work.

Author's contributions
The author has made the research, and the author has read and approved the manuscript.

Funding
Not applicable.

Availability of data and materials
Not applicable.

Declarations

Competing interests
The authors declare that they have no competing interests.

Received: 22 June 2021 Accepted: 11 December 2021
Published online: 20 January 2022

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