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BIM-based framework for managing performance of subway stations

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ABSTRACT

Rapid transit systems are considered a sustainable mode of transportation compared to other modes of transportation taking into consideration number of passengers, energy consumed and amount of pollution emitted. Building Information Modeling (BIM) is utilized in this research along with a global ranking system to monitor Indoor Environmental Quality (IEQ) in subway stations. The research is concerned with developing global rating system for subway stations' networks. The developed framework is capable of monitoring indoor temperature and Particulate Matter (PM) concentration levels in subway stations. A rating system is developed using Simos' ranking method in order to determine the weights of different components contributing to the whole level of service of a subway station as well as maintenance priority indices. A case study is presented to illustrate the use of the proposed system. The developed ranking system showed its effectiveness in ranking maintenance actions globally.

1. Introduction

Rapid transit systems have gained a lot of tension due to the large number of passengers using these systems worldwide. These systems provide a safe and a rapid tool of transportation to daily commuters. In addition, they are considered a sustainable, environment-friendly mode of transportation. Many subway stations have been constructed several years ago and they are prone to deterioration and failure to provide acceptable services. As a result, there is an urgent need to maintain subway station at an acceptable level that provides a safe and comfortable service to users. The process of maintaining subway stations at an acceptable level requires fund allocation among existing running subway stations. Across the world, the majority of rapid transit systems consist of several interchanging lines. The importance of every line varies according to some factors such as number of users and importance of locations the line serves. Similarly, subway stations vary in importance due to several factors such as the availability of using other modes of transportation. Subway stations connecting two or more lines in the rapid transit network have more importance compared to other subway stations. Its asset managers should determine the factors which affect the level of importance of every component inside subway station. Determination of components' importance and maintenance priority indices is a complex task and is governed by the preferences of the asset managers. There is a real need to prioritize maintenance actions among different subway stations according to their importance and contribution to the whole level of service. Asset managers need a proper maintenance/rehabilitation in order to mitigate the consequences of service failure in rapid transit systems.

PM_{10} and $PM_{2.5}$ concentrations have a great effect on the health of passengers and can cause many dangerous diseases [1]. Greater Cairo has high rates of pollution in terms of PM levels and different pollutant gases [2]. The United States Environmental Protection Agency (EPA) defines the PM as a combination between very small particles and liquid droplets. PM has many sources such as dust particles and metals [3]. PM_{10} is defined as particles that have a diameter which is less than 10 μm while $PM_{2.5}$ is the particles with diameters less than 2.5 μm [4]. Few research studies addressing subway station asset management or monitoring indoor environmental quality for subway stations were conducted. Also, research studies that address network level asset management were few. Although BIM has proved to be a powerful tool in construction research and industry, research efforts have been made to enable integration between BIM and monitoring indoor environmental quality [5]. This research study tackles a new approach to use BIM in monitoring IEQ for subway stations. In the first part of this research study, an attempt to monitor indoor environmental quality using BIM and modern communication technology is developed. The second part of this research study seeks development of a network level maintenance rating system for subway stations.

2. Background

Previous attempts have been made to develop asset management plans. Semaan and Zayed [6] developed stochastic diagnostic model for subway stations taking in consideration different functional condition criteria. The model is capable of identifying functional condition criteria, set up the hierarchical structure of criteria and assesses criteria's weights. The allocated weights to these criteria were determined using

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the analytical hierarchy process. Then, the Preference Ranking Organization Method of Enrichment Evaluation (PROMETHEE) was used to find out the multi-criteria performance index. Hegazy [7] has developed a visual asset management system that considers environmental, economic and social issues. The system is concerned with capital renewal for buildings and it consists of five components; building inventory, condition assessment, inspection schedules, fund optimization and GIS reports. The system has several features: 1) the inspector would hold an ultra-mobile personal computer (UMPC) to do the inspection task utilizing digital floor plan for the building; and 2) optimization model that is used to allocate limited budget over several needed rehabilitation actions in order to achieve higher sustainability index. In order to allocate the limited budget between different components, an index is used to determine the component priority.

Many attempts have been developed in order to maintain different types of assets such as subway stations, sewer systems, bridges and roads at an acceptable condition. These attempts vary on their capabilities and tools used in system development. It is essential for any developed asset management system, regardless the type of the asset, to determine the importance of each component and its priority for maintenance decisions. The prioritization methods can be based on heuristic rules or driven from personnel experience [8]. Chassiakos et al. [9] have developed a bridge management system which is used for planning maintenance activities for concrete bridges. A scoring model was developed in order to determine the priorities of maintenance actions. The bridge management system consists of three main modules: determining priorities of maintenance actions, identification of alternative feasible treatments and planning of bridge stock. Priorities of maintenance are determined using weighted bridge parameters. Values for bridge parameters are assigned and the priority of maintenance is calculated for each bridge involved in the system. Some of weighted bridge parameters were defined to be considered in the evaluation including, defect type, traffic load, environmental conditions and bridge age. Weights are assigned to every bridge parameters and sub parameters. Maintenance priorities are directed towards bad condition bridges that have high weights. The weights of parameters were determined by experience and adjusted by trial and error.

Moazami et al. [10] have introduced a maintenance and rehabilitation prioritization system for urban roads with regard to limited budget. The developed system takes in consideration factors such as: pavement condition index, traffic volume, road width and maintenance cost. Fuzzy logic modeling was utilized in order to define a model that includes the aforementioned factors. The fuzzy logic modeling gave more accurate alternatives. AHP was used in order to set priorities for each alternative. Yehia et al. [11] have developed a decision support system that can suggest repair and rehabilitation strategies for concrete bridge decks based on extensive literature review and interviews with bridge maintenance experts. A precise assessment for the condition of transportation infrastructure is the major component of the maintenance and rehabilitation process. The developed decision support system provides precise detailed information about repair materials and method. Knowledge gathered from the literature review and the expert interviews were modeled in a decision tree forming the rules for the decision support systems. Lee and Kim [12] have suggested an algorithm to optimize maintenance, rehabilitation, activities at the network level for bridges. Genetic algorithms have been used in order to prioritize maintenance and rehabilitation actions. Maintenance activities were modeled as multi-objective combinational problem. Hadzilacos et al. [13] proposed a decision support system (DSS) for water main rehabilitation to optimize the rehabilitation scheme for water main segments. The prioritization of rehabilitation actions is done based on potential hazards and cost of rehabilitation. The developed DSS has three main modules; analysis, optimization and background information. Le Gauffre et al. [14] have introduced a sewer asset management system using fuzzy linguistic variables. Performance indicators have been classified into several categories depending on sources of uncertainty. Sewer condition grading resulting from CCTV reports is subjected to fuzzy modeling to identify misclassification errors. Performance indicators are determined taking into consideration inaccurate data.

Building Information Modeling (BIM) is considered an immense advancement in the construction sector. BIM tools help users to visualize their facilities, estimate different costs, share information and create customized add-ins applications. The simulation of operation for a constructed facility can be developed using BIM [15]. The information incorporated within a BIM-based model is considered of great help for facility managers. A BIM file can be linked via URL and/or external or internal server to comprise more useful information such as contracts, survey information, procurement files, warranty information, purchase requests, operation and maintenance manuals and inspection report [16].

Several techniques have been found in the literature that enable multi-criteria decision-making (MCDM) in different applications including construction. These techniques includes; Analytical Hierarchy Process (AHP) [17], Simos' ranking method [18,19], ELECTRE [20–22], Fuzzy Logic, PROMETHEE [23] and the Superiority and Inferiority Ranking technique (SIR) [24,25]. In this research, Simos' ranking method is used to determine the weights of different components contributing to the level of service of a subway station and maintenance priority indices in order to set the rehabilitation strategies of subway station.

3. Proposed framework

The main purpose of the developed framework is to monitor Indoor Environmental Quality (IEQ) and determine maintenance priority indices for inspected components. First, a Wireless Sensor Network (WSN) is deployed in a subway station and connected to a BIM-based model. A hand held device that is used to measure particulate matter concentration in subway station is utilized to monitor indoor air quality. WSN readings and particulate matter concentration levels are visualized in the BIM-based model. The visualization of WSN reading and particulate matter readings initiates the triggers for detailed inspection tasks. The user is required to rank the importance of rapid transit network attributes. The weight attributes are calculated using Simos' ranking method. Finally, maintenance priority indices are determined based on the condition stored in the BIM-based model and weights of rapid transit network attributes. The measurements of the IEQ indicators are strongly related to the developed ranking system so as to rank maintenance priority actions is the component's condition state. IEQ indicators help asset managers to assess the components' conditions. For example, if the PM readings are exceeding a certain threshold at a certain location, then, a specific filtering system needs to be maintained/replaced. Fig. 1 illustrates a schematic diagram for the developed framework. The framework consists of two main parts; BIM-based Model and Subway Maintenance Ranking System. The first part is essentially designed to store subway Components' Conditions. It receives its input from Wireless Sensor Network Data and Particulate Matter Measurement Device Data. These data act as condition preliminary indicator for asset managers. For example, if thermal comfort indicator data measured by the WSN are below a certain threshold then a certain component shall be inspected. After the inspection of different components in the subway station, condition scores are stored in the BIM-based mode. At this point the role of the second part of the developed framework comes. Using the condition scores stored in the BIM based model and utilizing Simos' ranking method, a maintenance priority indices are generated as shown later in this study. PM concentration levels are measured using the Aerocet-531 hand held device in three different subway stations in Greater Cairo. Measurements are incorporated with typical subway station BIM-based model. The large number of passengers using Cairo Metro everyday requires some investigation to the current level of different pollutants such as particulate matter (PM_{10} and $PM_{2.5}$) in subway stations. In this research study, PM_{10} and $PM_{2.5}$ are measured at the platform level of a subway station in the second line of Cairo