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Defect- and component-based assessment model for manholes

Khalid Kaddoura[a,*], Tarek Zayed[b]

[a] Department of Building, Civil and Environmental Engineering, Concordia University, 1455 Blvd. de Maisonneuve W, Montreal, PQ H3G 1M8, Canada
[b] Dept. of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

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ABSTRACT

Although manholes are significant assets in sewer networks, their assessment is receiving little attention compared to sewer pipelines. It was reported that more than three-million manholes in the United States (US) were structurally weak and prone to collapse. To avoid sudden failure, systematic manhole condition assessment model is required. Therefore, the primary objective of this study was to develop a component-based condition assessment model for sewer access holes. The methodology was based on integrating the Quality Function Deployment (QFD), Decision-Making Trial Evaluation Laboratory (DEMATEL) techniques to study the causality relationship between the defects in the nine identified components of the manhole. The relative importance weights of the components were found by deploying the Analytic Network Process (ANP) and were used to compute the overall condition of the asset. Based on the results, the roots were the highest influence power in many of the components. In addition, the wall, cone, cover and frame, and seals components were higher importance weights compared to the remaining components. This model was tested on an actual case study from the city of Edmonton in Canada and compared with actual values. The model produced an average validity percentage (AVP) of 76.24%. The developed model is expected to enhance the assessment of manholes and therefore provide robust conclusions. Besides, the model offers a backward analysis to pinpoint critical components in the manhole. Consequently, better decisions are made pertinent to maintenance, rehabilitation, and replacement interventions.

1. Introduction

Manholes are significant elements in infrastructure networks as they provide access to sewer maintenance (Sever et al., 2013), and accommodate all geometrical changes of sewers (Martino et al., 2002). They are concrete assets and therefore prone to deterioration similar to buried linear elements (Hughes, 2002). Nevertheless, the concentrations of hydrogen sulfide (H_2S) emissions are less due to larger geometrical dimensions of manholes compared to pipelines (Tran et al., 2011). The accumulated emissions of H_2S can be a primary reason for the manhole failure due to the continuous corrosion and degradation of the manhole components (Kaushal et al., 2018). According to Sever et al. (2013), more than three-million manholes have structural deficiencies in the United States (US) and need immediate interventions. Furthermore, defective manholes are one of the main sources of inflow/infiltration (I/I) to the collection networks and can contribute up to 50% of the inflow within the collection system (Hughes, 2002). As a result, the designed flow will vary and results in additional wastewater treatment costs. The incapability to withstand the excessive I/I could lead to sewer flooding (Lee et al., 2013) and jeopardize the environment and habitats.

Condition assessment modeling is a widely used technique in life-cycle and asset management domains, as it provides a large volume of the required data in decision-making tools (Angkasuwansiri and Sinha, 2014). These tools need comprehensive information of the current state of the asset along with the existing distress (structural and operational) to aid decision-makers in selecting the required rehabilitation method. Although there are standardized protocols for condition assessment, many municipalities in the US and Canada developed their models and applied them in their practices. However, there is still a significant gap in the assessment of sewer manholes compared to pipelines (Sever et al., 2013) and failing to preserve them could expedite the assets' degradation (Anbari et al., 2017). Many municipalities lack comprehensive databases pertinent to the conditions and defects of the manholes. Therefore, decision-makers will not be able to monitor the state of the manholes during their service lives. In addition, several utility agencies in Canada assess manholes based on the peak scores disregarding other observed defects during inspections. These subjective conclusions, which may differ from one practitioner to another, could mislead the rehabilitation decisions.

* Corresponding author.
E-mail addresses: kh_kaddo@encs.concordia.ca (K. Kaddoura), tarek.zayed@polyu.edu.hk (T. Zayed).

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Consulting the literature, very few studies and formalized protocols were designed to evaluate sewer manholes. In fact, the available ones rely on peak and mean scores which flatten the data and mislead the decision-makers' judgments. To lessen the subjectivity in evaluating the manhole defects and to improve their assessment, a comprehensive tool is required to provide a systematic approach to grading the observed distress. Thus, decision-makers are aware of the current states of the manholes to conclude effective prioritization and rehabilitation plans that maximize the assets' efficiencies and meet their required level of service (Vladeanu and Matthews, 2018).

2. Background

Condition and prediction assessment models are tools that are used to grade the current states of the sewer assets. However, few models were developed in assessing sewer manholes. The National Association of Sewer Service Companies (NASSCO), released a manhole condition assessment protocol in 2010 based on the response of the industry's demand to code and assess manhole defects. The methodology is similar to the Pipeline Assessment and Certification Program (PACP), as it incorporates the identical PACP defect coding system. It consists of two different inspection levels: level 1 and level 2. The first level is based on gathering manhole information and includes general condition evaluation. However, the second level relies on detailed information gathering and defects recording. The grades range between 1 and 5, where 1 corresponds to an acceptable structural condition and 5 describes a failed state.

Nelson et al. (2010), however, described the analysis processes of the manhole data in estimating the I/I to assess the manhole condition. The authors suggested flow rate estimates for manholes for each defect type in each manhole component. A total score was then calculated by multiplying the flow rate by the condition score. Later, a manhole prioritization model was developed based on the calculated total rating, and the location of the manhole. Similarly, Hughes (2009) relied on the I/I estimation and the structural condition flow to determine the condition of sewer manholes. The author relied on a score from 1 to 5 to grade the divided manhole components' structural and I/I defects. The linguistic grades for the I/I distress were No I/I, Minor I/I, Moderate I/I, Heavy I/I and Severe I/I. Furthermore, the structural defects were based on cracks and fractures, and general deterioration defects. The author also provided decision matrixes for manhole rehabilitation actions.

In another related work, Daher et al. (2017) suggested a scheme to evaluate manholes condition after suggesting structural, operational, and installation and rehabilitation defects. In general, the overall methodology of the study was based on a fuzzy expert system, Hierarchal Evidential Reasoning and (HER), and Analytic Network Process (ANP). The author considered five different scales to conclude the overall condition of the manhole. The scale used was excellent, good, fair, poor, and critical. Bakry et al. (2016a), however, developed a multiple regression condition prediction model for rehabilitated sewer manholes. The model predicted the operational and structural conditions of the assets considering distinct variables. The operational prediction model relied on the overall manhole depth, rehabilitation age, chimney material type, radius, and shape. Besides these variables, the structural prediction model considered the chamber material type.

Despite the efforts devoted to assessing sewer manholes, the current researches were limited, as multiple defects and manhole components were neglected. Not only but also, a wide range of the formalized protocols considered equivalent weights to manhole elements, given that some components of the manholes could be more important than the others. Furthermore, distinct codes considered the application of peak and mean scores in the evaluation process, which resulted in an incomplete representation of the overall manhole condition (Daher et al., 2017). Although NASSCO sewer ratings were useful in some applications, the accuracy in reflecting the actual severity and overall condition was a major concern (Vladeanu and Matthews, 2018). Besides, predicting the condition of sewer manholes using some physical, operational and environmental characteristics do not reflect the actual deterioration process of the asset (Elmasry et al., 2017).

As a result, an extensive assessment tool for the manholes is required to enhance the accuracy in calculating the overall condition of the asset, which is one of the main inputs in a selecting a rehabilitation method (Matthews et al., 2018). This study aims at developing a component- and defect- based condition assessment model for manholes by (a) identifying sewer manhole defects for each component; (b) studying the causality relationship of the defects in each element; (c) integrating the Quality Function Deployment (QFD), the Decision-Making Trial Evaluation Laboratory (DEMATEL), and the ANP methods to compute a condition index for the manhole. This approach will provide decision-makers with an alternative systematic assessment tool for sewer manholes including their different components, and a backward analysis to pinpoint critical defects in each component. Therefore, enhanced rehabilitation decisions are performed to preserve these assets.

3. Methods and materials

3.1. QFD

The QFD method is conducted to transfer the customer needs into technical requirements (Sullivan, 1986). It is a Total Quality Management (TQM) concept, as it requires the inclusion of customer needs into project design targets apart from the essential projects' requirements (Dikmen et al., 2005). It focuses on implementing the voice of the customers after assessing their needs, which are usually determined by interviews (Dikmen et al., 2005).

The formulation of the QFD approach starts with the determination of the product policy and the end-user needs into a fundamental concept. Therefore, design requirements are established to form the "WHAT's", which in turn establishes the component characteristics "HOW's" of the product's design. A matrix is then constructed to study the relationship between the HOW's and the WHAT's (Govers, 1996). After that, the absolute weights are determined by aggregating the HOW's and the WHAT's using the factors in the matrix established earlier. Consequently, the House of Quality (HOQ) is finalized to represent the problem in hand.

The QFD technique was utilized in this study as a tool for the condition assessment of manholes and was restructured to suit its application in the infrastructure assessment. Thus, in the context of this research, each component was considered as follows (Alsharqawi et al., 2016):

- The WHAT's were the condition severities. In this research, five different severities were considered: excellent, good, fair, poor, and critical. These severities concluded the components and the overall asset's conditions.
- The HOW's represented the defects observed in each asset under assessment; these were obtained from the inspection reports.
- The relationship matrix was the upper roof component of the QFD approach. It established the relationship between the defects in concern.
- The absolute weights were the weights of the WHAT's, which were concluded after aggregating the HOW's for each WHAT.
- The HOQ represented the complete application of the QFD. Since this study divided the manhole into nine different components, each component possessed a unique HOQ that included the HOW's and the WHAT's based on the considered defects.

3.2. DEMATEL

Davies et al. (2001) discussed the propagation of sewer defects that