A Component-Based Approach in Assessing Sewer Manholes

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ABSTRACT

Infrastructure asset management domain has an extensive advancement in condition assessment and rehabilitation decision models. However, most of the focus is devoted to pipelines, giving little attention toward manholes. Recent studies revealed that more than three-million manholes in the United States (US) have structural deficiencies. Defective manholes are a main source of the inflow/infiltration and contribute up to 50% of the collection system's input to treatment plants. As a result, it is of great importance to assess them on a regular-basis to avoid any operational and structural failure. The main objective of this study is to develop a condition assessment model for sewer manholes. The model divides the manhole into several components and filters the possible observed distress in each element. Later, the study determines the relative importance weight of each component using the Analytic Network Process (ANP) decision-making method. Moreover, the condition of the manhole is computed by aggregating the condition of each component with its corresponding weight. As a result, the proposed assessment model will enable decision-makers to have a final index suggesting the overall condition of the manhole and a backward analysis to check the condition of each component. Thus, better decisions are made pertinent to maintenance, rehabilitation, and replacement actions.

INTRODUCTION

Current practices rely on a distress-based evaluation of sewer assets that is based on pre-developed sewer protocols applied to inspection results (Kaddoura and Zayed 2018, Kaddoura et al. 2018). These protocols are either designed by local municipalities or by agencies' experts in the field. The protocols classify sewer defects into different sub-defects where each sub-defect has an associated specific severity value. The severity value depends on the extent of the observed defect in the system. Higher grades are associated with higher critical defects' attributes. Several studies were performed to assess sewer pipelines, disregarding the evaluation of manholes. Yet, some minimal approaches were later introduced to assess sewer manholes.

Hughes (2009) proposed a manhole condition assessment that was based on the structural degradation and excessive infiltration/inflow (I/I) occurring in an asset. The author suggested a five-point rating system for the I/I and the structural evaluations for all manhole items except for the manhole cover inflow. Manhole cover inflow could be estimated based on a number of parameters such as the drainage area, the depth of ponding, the number of holes in a cover, its condition and its frame-bearing surface. The manhole items on which its condition is dependent upon were listed as the cover, frame seal, chimney, cone or corbel, wall, pipe seal, bench, and invert or channel. Hughes (2009) suggests that these rates can be adjusted and that they are project specific. The defect flows that the author considered range between 0 and 6.1 litres per minute. The I/I ratings are No I/I, Minor I/I (weeper), Moderate I/I (dripper), Heavy I/I (runner) and Severe I/I (gusher) as displayed in Table 1. The manhole structural condition was based on items similar to those of the manhole in addition to the steps. The condition rating was based on a one to five scale, in which one represented a Good condition while the five rating describes a poor condition, as indicated in Table 1.

Table 1. ASCE Condition Ratings for Manholes (Hughes 2009)

Condition Rating	I/I Observed	Structural Condition Observed
Good	No I/I	No structural defects
Fair +	Minor I/I	Minor defect identified
Fair	Moderate I/I	Multiple minor defects or moderate defect identified
Fair-	Heave I/I	Multiple moderate defects or major defect identified
Poor	Severe I/I	Major defects identified

Besides, Bakry et al. (2016) used the multiple regression method to assess manholes rehabilitated by chemical grouting. The authors relied on different factors and subfactors in their evaluation that were expected to impact the condition of manholes. Despite the minimal errors obtained, the methodology could only be applicable to rehabilitated manholes that have homogenous environment as the case study used.

Over time and due to the continuous industrial demand to standardize manhole assessment, the National Association for Sewer Services Companies (NASCCO) introduced a protocol that grades sewer manholes. The Manhole Assessment Certification Program (MACP) adopts the same grading scheme as in the Pipeline Assessment Certification Program (PACP). The MACP standard uses the same coding system, defect descriptions and grading values, and the weighted average method in supplying a condition index for the manhole.

The standard has two different levels to assess manholes. Level one inspection provides basic condition assessment information to evaluate the general condition of a manhole, while Level two inspection records the detailed defects observed. The detailed inspection records the observed defects in chimney, cone, wall, bench, and channel. Despite the importance of one component to another, the MACP evaluation considered similar weights for the evaluated components. Therefore, this study aims to enhance the assessment of sewer manholes by implementing the Analytic Network Process (ANP) computations in determining the importance weights of the distinct components in the manhole. The weights are computed after evaluating the responses of the questionnaires sent to experts in the field. The methodology presented in this study can still adopt the evaluations given by MACP database for each component. However, the weights introduced in this study can be used to calculate the overall grade of the manhole to have a better understanding of the actual condition of the most important components.

ANALYTIC NETWORK PROCESS (ANP)

The ANP method was applied in different applications related to strategic planning, project management, fund allocation, human resources and research and development problems, and supplied satisfactory results (Daher et al. 2017). This method has also been utilized to assess several infrastructure assets, and the methodologies supplied minimal errors compared to actual values. For instance, Hawari et al. (2016) proposed a model that assessed the condition of free-flow and pressurized sewer pipelines by integrating fuzzy logic and the ANP. El Chanati et al. (2015) modeled a performance assessment methodology to assess water pipelines by aggregating several identified factors using the ANP method, and the conditions of oil and gas pipelines were evaluated using the ANP application (El-Abbasy et al. 2015). Due to the successful implementations of ANP in infrastructure management, this study adopts it in the manhole assessment to distinguish the importance of one component to another.

The ANP method is one of the most widely-used multi-criteria decision making process techniques. It is based on considering decision makers' judgments on the factors of involved in certain systems. The root of the ANP method is the Analytic Hierarchy Process (AHP), developed by Saaty in the late 1960's, and which is a general theory of measurements (Saaty and Vargas 2002). It is used to find the relative priorities on absolute scales from both discrete and continuous paired comparisons in multilevel hierarchic structures (Saaty and Vargas 2002). The comparison may be established by actual measurements or by the relative strength of preferences or feelings. Since many problems cannot be structured hierarchically, the ANP was designed to consider the interaction and the inter-dependence of elements involved in a system or network. In other words, the AHP is used to establish a comparison in a vertical direction, unlike the ANP, which considers a comparison in both vertical and horizontal directions.

The first step of the ANP method is identifying the system to be analyzed and then decomposing it through a set of hierarchies or networks. Later, paired comparison judgments in the AHP/ANP are applied to pairs of homogeneous elements. In many cases, the preferences or the judgments are established by a questionnaire given to experts. The fundamental scale of values to represent the intensities of judgments is shown in Table 2.

Suppose that an element Z in an arbitrary system is given a relative importance of k compared to element C, then the relative importance of element C when compared to element Z is 1/k. After collecting the pairwise comparisons from experts, the unweighted matrix considering the relative importance weights is constructed. The next step is forming the weighted supermatrix to consider the interdependency among the elements in the system. At the end, the weighted supermatrix is multiplied by itself until the limit supermatrix is attained, and in which the final local priorities are reached (Yang et al. 2008).

It is very important to consider the computation of the Consistency Ratio (CR) to ensure that expert opinions are not contradicting several aspects in a system. Two parameters are considered in the computation of the CR, the Consistency Index (CI) and the Random Index (RI). The CI is computed using equation 2.

$$CR = \frac{CI}{Random\ Index} \qquad [1]$$

$$CI = \frac{\lambda - n}{n - 1} \quad [2]$$

where

λ is the highest eigenvalue in the pairwise comparison matrix, and

n is the matrix size.

However, the RI depends on the number of elements in the matrix and is determined using Table 3, adapted from (Saaty and Vargas 2002). After determining the two values, the CR is computed accordingly. The pairwise comparison matrix is considered to be consistent if the CR is < 0.1.

Table 2. Intensity of Importance Scales for AHP/ANP

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two attributes contribute equally to the objective
2	Weak	intermediate values
3	Moderate Importance	Experience and judgment slightly favour one activity over another
4	Moderate Plus	Intermediate values
5	Strong Importance	Experience and judgment strongly favour one activity over another
6	Strong Plus	Intermediate values
7	Very Strong or Demonstrated Importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, Very Strong	Intermediate values
9	Extreme Importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of Above	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	

Table 3. Random Consistency Index vs. Elements Number

n	1	2	3	4	5	6	7	8	9	10
Random Consistency Index (RI)	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

RESEARCH METHODOLOGY

The focus of this research is to enhance the overall condition grading in sewer manholes. Figure 1 demonstrates the overall methodology adapted in this paper. A literature review was conducted on decision-making tools and condition assessment models. Several decision-making analysis tools were reviewed along with the current practices in assessing manholes. After selecting the ANP method, a questionnaire was prepared and sent experts in the field. Each response was calculated separately, in which the unweighted supermatrix, weighted supermatrix, and the limited supermatrix were evaluated. The study ensured that a minimal consistency ratio was maintained to have reliable results. Based on the ANP implementation on each questionnaire, the average importance weight of all the responses for each component was considered and suggested for the evaluation.

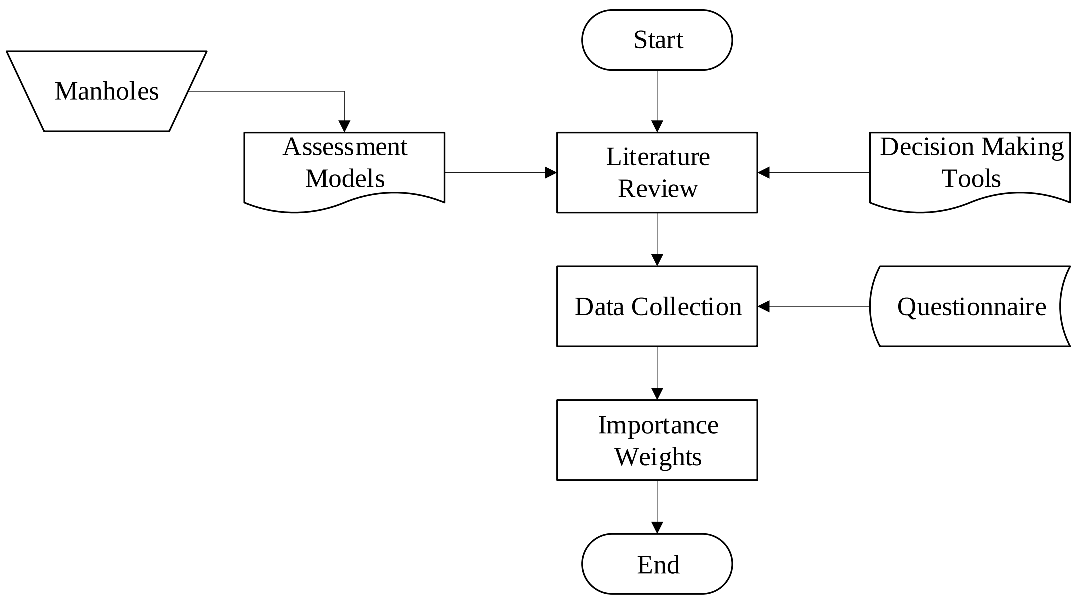

Figure 1. Research Methodology

CONDITION ASSESSMENT MODEL

The manhole components considered in this study are as follows:

a) Pavement: is the part of the rigid or flexible pavement that surrounds the manhole cover. It is considered in the manhole assessment because damaged pavements surrounding the asset can expose other components, causing them to degrade. According to Hughes (2009), signs of voids outside the manhole structure, which can affect the manhole wall strength, can be triggered from observations of alligator cracking in asphaltic concrete, and spalling, cracking, or tipping in pavements. Therefore, the defects pertinent to pavements are based on the damaged part of the pavement.
b) Cover and Frame: The cover is the lid that provides access to the interior of the manhole, and the frame is the cast or ductile ring that supports the cover (Hughes 2009). Defects identified for these components are cracks, breaks, grades, corrosion and inflow.

c) Chimney: The chimney is the narrow vertical part built from either brick or concrete materials with adjusting rings that extend from the top of the cone to the frame and cover (Hughes 2009).
d) Cone: The cone is the reduced section that tapers concentrically or eccentrically from the top wall joint to the chimney or from the frame and cover (Hughes 2009).
e) Wall: The wall is the vertical barrel portion extending just above the bench joint to the cone (Hughes 2009).

Defects pertinent to Chimney, Cone, and Wall components are vertical cracks, horizontal cracks, vertical fractures, horizontal fractures, deformation, holes, breaks, collapse, surface damage, roots, I/I, obstruction, attached deposits and protruding services.

f) Seals: Seals are materials or devices that prevent the intrusion of water at the joints of multiple components (Hughes 2009). Defects pertinent to seals are I/I, cracks and roots.
g) Bench: The bench is the concrete or brick floor of the manhole, generally shaped as a fillet to direct incoming flows to the outlet pipeline and minimize the accumulation of deposits (Hughes 2009). Defects pertinent to the bench component are vertical cracks and fractures, horizontal cracks and fractures, holes, breaks, collapse, surface damage, settled deposits, roots and I/I.
h) Channel: The channel is the flow-shaped way within the bench (Hughes 2009). Defects pertinent to the channel component are vertical cracks and fractures, horizontal cracks and fractures, multiple cracks and fractures, holes, breaks, collapse, surface damage, settled deposits, roots, obstruction and I/I.
i) Steps: The steps are composed of a ladder made of separated parts that are fixed to multiple components in the manhole. Steps allow inspectors to move in and out. Defects pertinent to the steps component are related to corrosion, missing and/or broken individual steps.

Relative Importance Weights

The manhole component weights (relative importance weights) were computed by applying the ANP methodology. As explained earlier, each questionnaire was analyzed separately to ensure reliable consistencies of the responses. More than 115 questionnaires were distributed as a hard copy and a softcopy, with the help of social media engines, in different regions. Fortunately, 27% of the distributed questionnaires were received; in specific, 32 experts from four different areas, North America (Canada and US), Middle East, Europe and China, participated. The highest number of responses were participants having experience between 9 and 15 years. However, the lowest number of responses were participants having experience between 3 and 6 years. In addition, participants from North America were the highest participating region among the other regions; while the Middle East region respondents were the lowest participants. This was expected since sewer condition assessment practice and trenchless technology in the Middle East is not as popular as in the other regions.

The results are shown in Table 4. The table shows the average relative weight of each component, the standard deviation, the minimum and maximum value, the 95% confidence intervals and the percentage difference between the average value and any of the confidence interval bounds. By consulting the table, it can be observed that there are differences between the respondents' opinions. The extreme minimum and maximum values show apparent discrepancies among the experts in signifying the importance of one component to another. This can be observed in the channel and wall components. As per the data collection chapter, the responses were collected from four different regions around the world and therefore, not all experts are homogenous in thinking and judgment.

However, the 95% confidence level ranges are not far from the average value calculated for each component. Based on the difference percentage calculated between the average relative importance weight of each defect and the lower or upper bound of the confidence interval value, it can be observed that the percentage difference ranges between 3% and 18%.

Table 4. Manhole Component Weights and Statistics

Component	Average	Standard Deviation	Min	Max	95% Confidence Interval		Difference% (Average and Bounds)
					Lower Bound	Upper Bound	
Bench	6.21%	0.0283	2.85%	11.23%	5.23%	7.19%	15.81%
Channel	11.10%	0.0529	6.58%	29.94%	9.27%	12.93%	16.52%
Chimney	11.52%	0.0120	9.39%	14.60%	11.10%	11.93%	3.62%
Cone	15.46%	0.0222	11.14%	18.43%	14.69%	16.23%	4.97%
Cover & Frame	15.13%	0.0282	11.08%	20.83%	14.15%	16.10%	6.45%
Pavement	4.70%	0.0241	2.12%	9.64%	3.87%	5.54%	17.75%
Seals	14.44%	0.0274	8.71%	19.03%	13.49%	15.39%	6.57%
Steps	3.83%	0.0068	3.01%	5.78%	3.59%	4.07%	6.17%
Wall	17.61%	0.0308	12.69%	23.73%	16.54%	18.68%	6.07%

Overall Manhole Grade

The overall manhole grade is calculated based on aggregating each grading score with its corresponding importance weight as in equation 3.

$$Overall\ Manhole\ Grade\ = \sum_{i}^{n} w_i C_i \qquad [3]$$

where *w* is the relative importance weight of each component; *C* is the condition index computed for each component; *i* is the component number; and *n* is the total number of components, which are nine.

CONCLUSIONS

Although sewer manholes have an important hydraulic contribution, their assessments are not as popular as pipelines. Recent research and industrial contributions commenced by establishing protocols related to sewer manholes. However, current practices consider equivalent weights for all manhole components which may mislead decision-makers in rehabilitating important components. This research used ANP methodology to distinguish between the components in the manholes. Based on the analysis, wall components had the highest relative importance weights followed by cone, cover and frame and seals. However, the lowest relative importance weights were associated with the pavement and steps. This research provides a methodology to enhance the overall manhole grading calculations, which will improve aid decision makers in their asset management practices.

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