A DATABASE SYSTEM FOR SELECTION OF REHABILITATION TECHNIQUES OF SEWER PIPES

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Abstract: Automation in construction gained sizable momentum during the last decade and considerable efforts have been made to benefit from this emerging technology in reducing cost and improving quality of work performed in this industry. This is particularly true in inspection and maintenance tasks of infrastructure facilities. This paper presents an automated system for inspection of sewer pipes. The system can detect, classify and recommend the most suitable rehabilitation techniques for a number of defects that commonly exist in this class of pipes. The system consists of two main sub-systems: detection and rehabilitation. The paper briefly describes the developed automated detection sub-system and focuses primarily on the conceptual design of the rehabilitation sub-system.

Keywords: Rehabilitation, Sewers, Automation, Defect detection, Trenchless technology.

1. INTRODUCTION

Sewer systems are one of the six most capital intensive infrastructure systems in North America [1]. Their poor status has been reported by many researchers [2, 3], revealing the presence of many types of defects that impact their performance. The presence of defects could, generally, be attributed to two main factors: 1) aging of pipes and 2) inadequate preventive maintenance programs. Figure 1 depicts the condition of sewer pipes over time. In this figure, the condition of a pipe is represented on a scale of 1-5, with 5 and 1 indicating superior performance and failure, respectively. It can be noticed that inadequate inspection and maintenance programs accelerate the rate of deterioration until the pipe ultimately fails. But, if regular inspection and maintenance programs are conducted, then the performance and lifetime of the pipes are significantly improved. It should be noted that the rate of pipe deterioration is a function of many factors, such as material and various working conditions, and further research should be carried out to verify the validity of time intervals shown on Figure 1.

Improving the performance of sewer pipes requires regular inspection and implementation of proper rehabilitation techniques. Regular inspections are usually costly to implement. This is due to the fact that their implementation is heavily dependent on manual techniques and more importantly, on the intervention of human experts. The intervention of human experts does not only add to the cost of the inspection process, but may also lead to other problems related to accuracy and speed. If manual inspection process can be replaced by an automated system, then not only time and money can be saved, but higher consistency and reliability can also be achieved.

This paper presents an automated system for rehabilitation of sewer pipes. The developed system performs its task in two stages. The first aims to detect and classify defects, and the second to suggest the most suitable rehabilitation technique for repairing detected defects. The system utilizes image analysis (IA), artificial intelligence (AI), database management system (DBMS), and decision support system (DSS). The paper presents an overview of the system and focuses primarily on the conceptual design of the DBMS and DSS dedicated to support the selection process of rehabilitation techniques.

2. AUTOMATED DETECTION SYSTEM

Automation in construction gained momentum during the last decade and considerable efforts have

been made to benefit from this emerging technology in reducing cost and improving quality of work performed. This is particularly true in inspection and maintenance tasks of infrastructure facilities. Figure 2 depicts the various components of a developed system for detection and classification of defects in sewer pipes. It has the capability to capture, process, detect, analyze and classify various types of defects. These defects are multiple cracks, cracks, joint displacements, cross-sectional reduction, deposits and sign of infiltration [4,5].

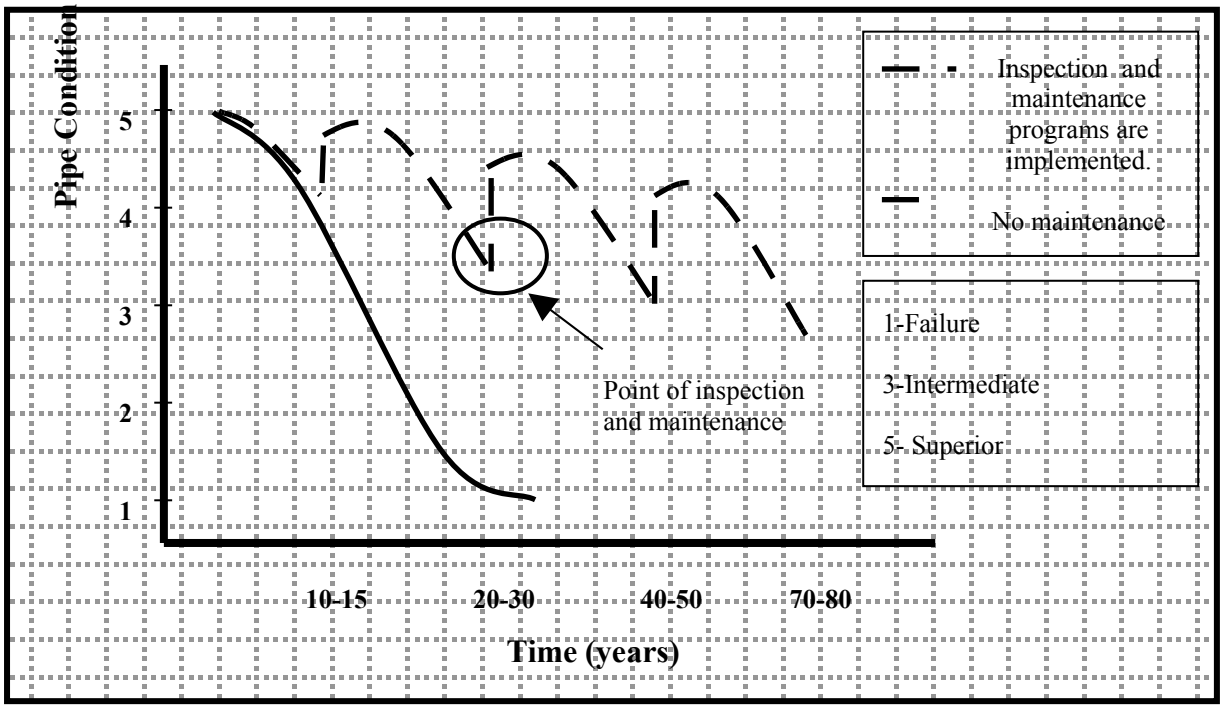
As depicted in Figure 2, the detection system performs its task in three main steps: 1) data acquisition, 2) data preparation and 3) data processing. At each step, the system utilizes a specific module. The system utilizes frame grabber, image analysis (IA), and artificial intelligence (AI) modules at the first, second and third step, respectively. A detailed description of each module and the various capabilities of the developed system have been presented elsewhere [4,5,6] and will be briefly described here for continuity.

In the data acquisition step, a frame grabber is utilized to capture and digitize video images. These digitized images are then utilized as input in the data preparation step, in which image analysis software is utilized for analysis. The result of this analysis is to detect the presence of defects, if any, and to calculate their attributes (i.e. geometry, statistical and gray level value). The calculated attributes are then utilized as input in the third and final step (i.e. data processing), in which neural network software is utilized to design and train different networks for classifying different types of defects. At the end of this three-step process, a report is issued identifying all detected defects and their types (i.e. cracks or sign of infiltration). It should be noted that these trained networks will be utilized by the system, at a later stage, to classify new but similar sets of defects.

3. REHABILITATION SYSTEM

Rehabilitation of sewer pipes posses a major challenge to most municipalities. This challenge is demonstrated by two main tasks. The first is to satisfy all constraints that are imposed by specific job conditions and/or user requirements, and the second is to select the most suitable rehabilitation technique that satisfies those constraints. There are more than 50 different methods of rehabilitation, worldwide, with over 500 contractors providing services for these methods [7]. Given the availability of this large number of methods, the importance of developing a system that eases the challenging task of selecting a suitable rehabilitation technique for specific job conditions and/or user requirements can not be overemphasized.

To assist municipality engineers in overcoming this challenging task, a rehabilitation system, comprising of a DBMS and a DSS, has been developed. The system provides a tool that saves time and effort in selecting the most suitable rehabilitation technique. The system is believed also to help new and less experienced engineers to benefit from the experience gained by others. In so doing, the system suggests the most suitable rehabilitation techniques that satisfy the constraints imposed by job conditions and/or user requirements.



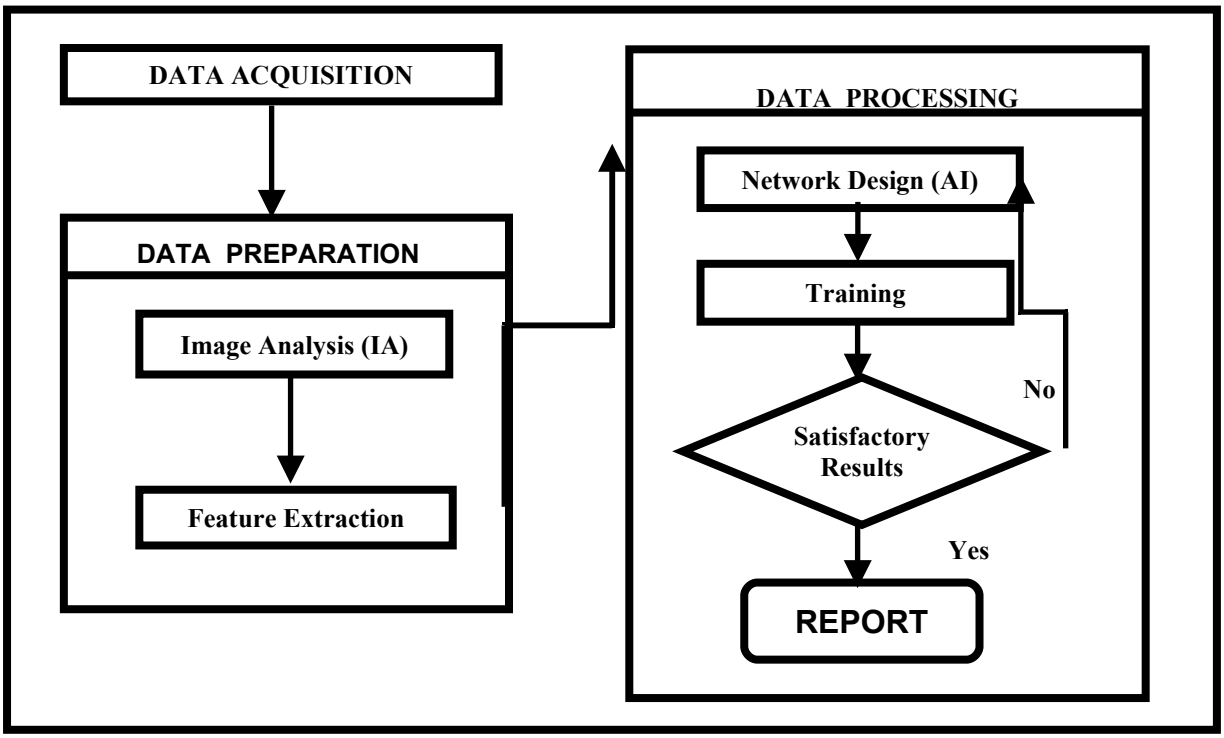


Figure 2. Automated Detection System

The rehabilitation system utilizes two main modules to perform its task. These modules are database management system (DBMS) and decision support system (DSS). The system performs its task in two main steps. First, based on the report generated by the automated detection system and other specified job/user requirements, The DBMS fires its search query to select the most suitable rehabilitation technique(s). Second, if more than one feasible rehabilitation technique is suggested by the first module, then the system activates its DSS to assist the user in selecting the most suitable one that satisfies his preference. The following sections describe the conceptual design of the main modules in this system (i.e. DBMS and DSS).

3.1 DBMS and rehabilitation techniques

Developing a database encompasses the utilization of database management systems (DBMS) to support the process of defining, constructing and manipulating data [8]. Defining a database involves specifying the data types and their associated constraints (i.e. text, number and format). Constructing a database is the process of storing the data itself in a digital format. Manipulating a database includes such functions as querying and retrieving data. There are different database models, and the relational model is the most commonly used [9]. Accordingly, this model will be utilized to design and build the database dedicated to support the rehabilitation system. In this model, the data are organized in tables. These tables are related to each other by different types of relationships such as one-many, many-one and many-many.

Building a database involves five main steps: 1) to define and acquire all information or attributes needed to be stored in the database, 2) to build a conceptual model showing all entities and attributes, 3) to transfer the conceptual model to a physical one (i.e. tables and relationships), 4) to populate the database tables with all acquired information and define relationships between them, and 5) to design and build a supporting search system (i.e. query) that retrieves specific information based on user needs. In this paper, only the first two tasks (i.e. defining the required information and building the conceptual model) will be described.

Various rehabilitation techniques are available in the market, each of which is considered suitable for certain job/user requirements. To suggest a suitable rehabilitation technique, it is necessary to consider all contributing attributes that help in performing the selection process. Based on literature review and interviews with various experts, a number of contributing attributes were selected [7,10,11,12]. These attributes are diameter and degree of bends of the original pipe (i.e. 45o or 90o), type of repair that each method can deal with and its associated cost, type of access to the original pipe (i.e. manhole, excavation pits or both), distance between access points, effect of rehabilitation methods on hydraulic characteristics of the original pipe, by-pass requirements, duration of installation, reliability of company, reliability of product, design life, locality

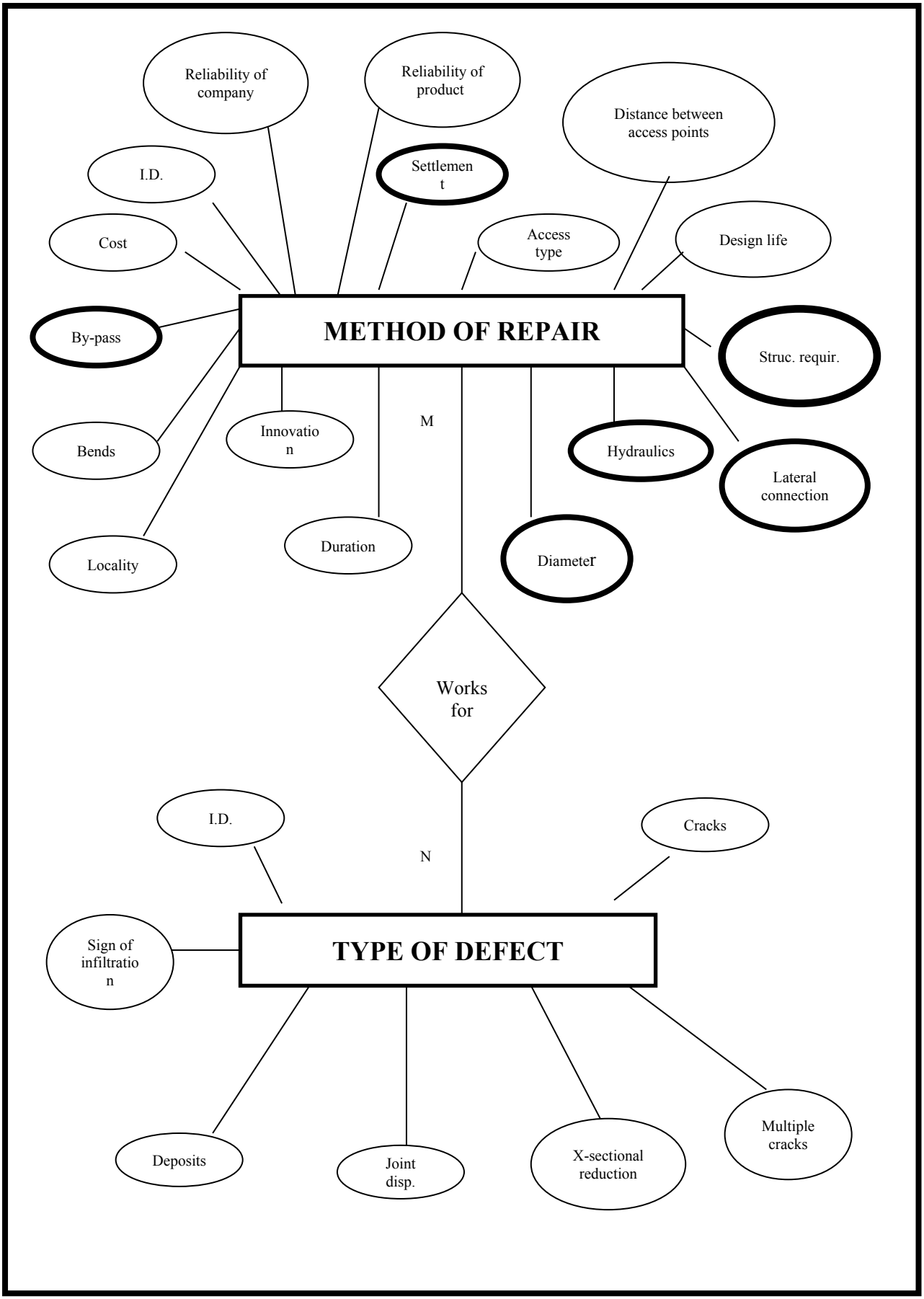


Figure 3. Entity Relationship Diagram

and innovation of suppliers, ability to accommodate differential settlements, method of lateral reconnection.

The conceptual design of a database is usually represented utilizing an entity relationship diagram (ER), as shown in Figure 3. It provides a comprehensive description of the database structure, highlighting its entities and attributes. The method of drawing the ER diagram and its different notations are described in a number of textbooks [8]. As depicted in Figure 3, the ER diagram consists of two main entities: 1) method of repair and 2) type of defect. Each entity is connected to a number of attributes. The attributes associated with the first entity (method of repair) are basically all factors that should be considered when deciding on the suitability of a certain method to fulfill the job/user requirements. The attributes associated with the second entity are all groups of defects that are detected by the developed automated detection system. It should be noted that these entities and attributes, with their associated relationships, will be further processed, grouped and classified when developing the physical model. This will involve creating tables and defining relationships (i.e. one-many, many-one and many-many) between all entities and attributes.

3.2 Decision Support System (DSS)

In case more than one rehabilitation method will be suggested by the DBMS, the DSS will be activated. The DSS utilizes multi attribute utility theory (MAUT), which proved its effectiveness in comparing alternatives in a multi attribute decision environment [7,13]. The mathematical background of this method and the various steps required to implement it are described in a number of textbooks [14]. In this method, the over all utility value of an alternative is expressed as follows:

$$U_i = \sum_{j=1}^{n} W_j \times U_{ij} \qquad (1)$$

In which

W_j = The relative weight assigned to the jth attribute
U_{ij} = The value of the jth attribute utility function (i.e. the utility value) associated with the ith method of rehabilitation (i.e. the alternative being considered).

The DSS system performs its task by getting into an interactive dialog with the user, asking a number of questions to define the user's preference (i.e. level of satisfaction over a range that each attribute can take). These attributes are cost, duration, reliability of company, reliability of product, design life of the product and innovation. The purpose of these questions is to construct the utility function associated with each attribute. In so doing, utility values of 1.0 and 0.0 are assigned to the maximum and minimum desirable values for each attribute. Other intermediate utility values are given to values between the most and least desirable extremes. The process leads to a set of scattered data points expressing the degree of the decision-maker satisfaction as the attribute takes values between the most and least desirable extremes. Curves with functions such as linear, logarithmic, exponential, power and polynomial functions with second, third, fourth, fifth and sixth degree are then fitted to represent the scattered data. These fitted curves are then compared based on the coefficient of multiple determination (R2), identifying which function is the most representative. The selected function is retained for further processing.

4. CONCLUSION

A comprehensive system for rehabilitation of sewer pipes has been presented. The system can detect and classify a number of defects that commonly exist in sewer pipes and recommend the most suitable rehabilitation technique. The system consists of two main sub-systems: 1) an automated detection system, and 2) a rehabilitation system to suggest the most suitable rehabilitation technique based on various job/user requirements. The developed automated detection sub-system has been briefly described and its capabilities outlined. The conceptual design of the rehabilitation sub-system has also been presented. Further development will be carried out to build the physical model of the database and the DSS utilizing MAUT.

Acknowledgement

The authors wish to acknowledge the cooperation of Mr. Gilles St Denis, consultant specialized in rehabilitation of sewer and water networks. The financial support provided by the National Science and Engineering Research Council of Canada is greatly acknowledged.

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