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RISK ASSESSMENT OF WATER DISTRIBUTION NETWORK USING FUZZY BASED SYSTEM

RohanDipakkumarKania[1], Sejal S. Bhagat[2]
P.G. Student, Town & Country Planning, Sarvajanik College of Engg & Tech, Surat, Gujarat[1]
Assistant Professor, Civil Engg, College of Engineering and Technology, Surat, Gujarat[2]

Abstract:* *The challenge which is faced by the municipal engineers is to assess risk associated with the buried infrastructure. Assessment of risk associated with water distribution network is most challenging as they are undergrounds, operated under pressure and are inaccessible. The present paper develops a methodology to evaluate the risk associated with each segment of network using fuzzy rule based system (FRBS).Total eight risk of failure parameters are considered which deteriorate the segment and are classified into three main risks of failure factors then a risk of failure model is built which considers the three main factors to evaluate the risk.

Key Words: **Infrastructure; Water distribution network; Risk of Failure; Fuzzy Rule Base System (FRBS); MATLAB R2008a-fuzzy tool box.**

INTRODUCTION

Water distribution networks are those infrastructures which are buried and have received very little attention from the municipalities and decisions makers. Now, with time it is found that the breakage rate as well as the cost which is associated with the failure of the distribution network has led to such a level that has drawn attention of municipalities as well as the decision makers. Now, it is obvious that with increase in breakage rates of the water distribution network will led to decrease in hydraulic capacity as the system starts deteriorating. As a result, dealing with the risk associated with the water distribution network has been enduring a great transformation in concept from reacting to failure events to taking preventive actions which will maintain the water distribution network in good working condition.

The urban water supply is based on a large and complex infrastructure that has been expanded and developed during the last century. While getting older, water supply assets, primarily pipes, are exposed to the deterioration process and consecutive pipe leakage and then failure of that pipe. It is common that for cities there occur hundred and even thousands of water pipelines break in the water distribution network every year. Nowadays, most Indian cities observed high rates of failure in water distribution network. Due to lack of information and data viability, there is no measurement of water leakage from the pipelines in Indian city. It is also found that the water pipeline networks in developing countries are in poor condition. This deterioration not only manifests itself in increased operating operation and maintenance cost, water losses, frequent service disruption, and a reduction in the quality of water supplied but also includes enormous hidden costs.

According to the (InfraGuide, 2006), the risk of failure is defined as the combination of the probability and the impact severity of a particular circumstances that negatively affects the ability of the infrastructure assets to meet the objectives of the municipality. Broadly, one can classify the risk factor for water distribution network into two types: 1) deterioration factors and 2) consequence (post failure) factors. Now, the deterioration factors are those factors which are either responsible for the deterioration of the portable water distribution network or else they are the indicators up to what level the network has deteriorated. Various types of factors which are included in deterioration framework can be classified into major three factors that are physical, operational and environmental factors while the consequences factors are those factors which represent the cost of water distribution network failure.

In order to upgrade their status of water distribution network, municipalities and other authorities should built a long term as well as a short term management plan which can help in prioritizing the rehabilitation of the water works within their limited budgets. Thus, to upgrade, maintain and repair the water distribution network, it is crucial to apply management strategies and such strategies should be built on logical approaches that consider the risk of pipeline failure with all the failure factors.

In the present research, a model is developed using fuzzy rule based system which evaluates the risk of water distribution network failure. Only the deterioration factors are considered in this research and the consequence factors are not considered. This model will act as a guide to municipalities to make their best and effective management plan as the model will propose a risk of failure scale which highlights the risk associated with each segment in the water distribution network.Hence, objectives of the current paper can be abridged as:

1. To frame fuzzy rule based system model for water distribution network failure to evaluate the risk associated with each segment in the network.
2. To frame a risk of failure scale that provides guidance to decision makers.

LITERATURE REVIEW

It is observed that water distribution networks, accounts up to 80% of the total cost or expenditure involved in water supply system (Kleiner & Rajani, 2000).Now, it is obvious that with increase in breakage rates of the water distribution network will led to decrease in hydraulic capacity as the system starts deteriorating. The pipes and other conveyances that connect treatment plants to consumers tap forms the distribution systems of public drinking water supplies. The distribution system constitutes a significant management challenge from both an operational and public health point of view. Also development of physical infrastructure of water supply is a huge task for the planners. Now a day we can see, poor water quality distribution networks all over the world and the situation is becoming worse day by day due to inefficient design, improper and unqualified material, poor construction work, aged pipelines, poor network management and maintenance, surrounding environment and breaks from unexpected elements.

Failure of Water Distribution Network

Water distribution network failure can be defined as the failure to satisfy the elementary requirements from the distribution system, failure to fulfil customer demand or failure to sustain pressures within specific limits. The water distribution failure can be classified as:Performance failure and Mechanical failure.

Performance failure occurs when the actual demand on the network exceeds the design demand capacity of the network or when the hydraulic capacity of the network is reduced below the actual demand due to deterioration while Mechanical failure is related to the failure of the components of the distribution system like pipelines, control valves, pumps, treatment plants and supervisory and data acquisition systems. Now according to (H. Fares, 2008)the most common type of mechanical failure is pipeline failure when the pipeline bursts resulting in excessive release of water.According to the (InfraGuide, 2006)sources of mechanical failure risks can be classified into five different groups:Natural occurring events, External impacts, Aggressions, Operational risks and Aging Infrastructure and physical deterioration. The Aging Infrastructure and physical deterioration risk factors are further classified asPhysical factors, Operational factors andEnvironmental factors.

Consequences of Failure

In the evaluation of risk, a judgement of the potential consequences is essential, which means answering to questions like: What are the consequences if something goes wrong? The cost of water main failure event may be classified in to three categories: Direct cost, In-direct cost and Social cost.

Direct costs are those costs which include cost of property damage, damages to human condition, environmental damages, loss of manufacture, repairs costs, clean-up and remediation costs while indirect costs are those cost which include cost of litigation and contract violation, customers disappointment, political reactions, loss of market shares,and government fines and penalties(Zayed H. F., 2010)

Direct cost are relatively easy to quantify in monetary terms, indirect costs may require much more effort, and social costs are often the most difficult to describe and assess (Sadiq, Rajani, & Kleiner, 2004). Strictly speaking the magnitude of failure consequence is a random value because no two failures have the same consequences. The failures of small distribution mains are usually repaired with little effort. The failures of large transmission mains are relatively rare, and because only a few water utilities attempt to assess total failure damage. Consequence of failure varies with the time base on the business cycle of a pipeline, its generated revenue, and flow load (Zayed H. F., 2009)

Risks of Water Distribution Network Failure

The section discus contribution of various researches and different efforts put by them related to risk models of water distribution network failure. In efforts put by various researcher to assess risk related to water distribution network various techniques were used, their methodology and work is discussed as follows. Rezaei, Ryan and Stoianov (2015) say atpresent none of the modelling concepts take into consideration dynamic hydraulic condition. But with the development in data management as well as logging technologies, measuring the operational factors with precision and attaining an accurate and deep understanding about hydraulic behaviour of the distribution networks become more feasible. Hence doing this will results in more development to understand the fundamentals of failure mechanisms and finally this will led in reducing the cost of mains failures.Urbanik and Valis (2013)develop an application of fuzzy logic for failure risk assessment in water supply system management determining the failure risk based on defined two parameters: the

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probability that is duration of lack of eater supply and the consequences that is the number of customers without water. The paper leads to exhibit the novel way to deal with risk assessment in blend with failure and result investigation, as to assess the level of waterworks service accessibility.

Fares and Zayed (2010) designed a framework to evaluate risk of failure usinghierarchical fuzzy expert system (HFES). They developed HFES the model on data of the city of Mancton, New Brunswick, were used to examine the water networks.. Fares and Zayed (2009) using fuzzy system evaluated risk of failure considering 16 factors that represents both chance of failure and the adverse consequences of failure event further categorized into 4 mains risks of failure factors. The conclusion from the model is that the age of pipe has the highest effect on risk of failure and the other major factors that effects are the pipe material and breakage rate. Al-Barqawi and Zayed (2008) developed a two conditional rating model for water mains using ANN/AHP. Eleven sub-factors within three main factors were considered and results obtained were that the pipe age has maximum impact followed by pipe material and breakage rate on condition assessment.Sadiq, Najjaran and Rajani (2008) proposed an approach based on hierarchical evidential reasoning (HER) for the conditional assessment of the buried pipes and concluded that the HER model can be modified without changing the combination algorithm.Fares and Zayed (2008) evaluated risk of failure by designing a framework using hierarchical fuzzy expert system concluding that the age of high has the highest effect on risk of failure scale followed by pipe material and breakage rate.

Mamlook and Al-Jayyousi (2009) proposed a technique known as fuzzy set technique for determining problems related to infrastructure system and environmental system and was applied to various case studies in Jordan for water distribution system. It was found that the pipe age, operational aspects, pipe material and demand pattern play a major role and affects the leakages. Kleiner, Rajani and Sadiq (2006) discussed about the use of fuzzy-based techniques which helps to incorporate inherent imprecision, uncertainties and subjectivity of available data, as well as to propagate these attributes throughout the model leading to more realistic results. A risk of failure value is used to make a decision about the scheduling of the next inspection. If renewal action is required, the decision maker uses a structured process to make an educated guess about the performance of the renewal alternatives to be considered. Al-Barqawi and Zayed (2006) developed a model using artificial neural network (ANN) approach with result showing that the highest factor that contributes more to pipe condition is the breakage rate.

Yam and Vairavrmoothy (2004) proposed a methodology to assess the pipe condition using multi-criteria decision making technique with fuzzy set theory. The fuzzy set theory is used to convert linguistic descriptions of pipe conditions into crisp value.A screening model is developed, which according to the condition ranks pipes using composite program technique. 6 factors (pipe age, pipe diameter, pipe material, road loading, soil condition and surrounding) all are first level indicators. Composite programming was used successively to aggregate first level indicators to obtain a final pipe condition indicator. Fuzzy ranking method was then used to rank the fuzzy number, corresponding to rank the pipe condition. Limitation of the developed model was it covers only factors like physical and environmental and also only cast iron pipes are considered and only one type of soil is taken into consideration. Kleiner, Sadiq and Rajani (2004) use fuzzy technique for the assessment of pipe conditions due lack of data about the rate at which deterioration of buried pipes occur and also with the imprecise nature of assessment of pipe condition. For the assessment fuzzy-rule based Markovian deterioration process (FR-MDP) is applied in two stages: First step: from the age and condition state the deterioration rate at a specific time is concluded using fuzzy-rule based algorithm and Second step: the condition state of the pipe is calculated from present condition state and deterioration rate. The conclusion was that using fuzzy rule base on can determine the level of risk which is defined on a nine grade scale from extremely low to extremely high.

STUDY FRAMEWORK

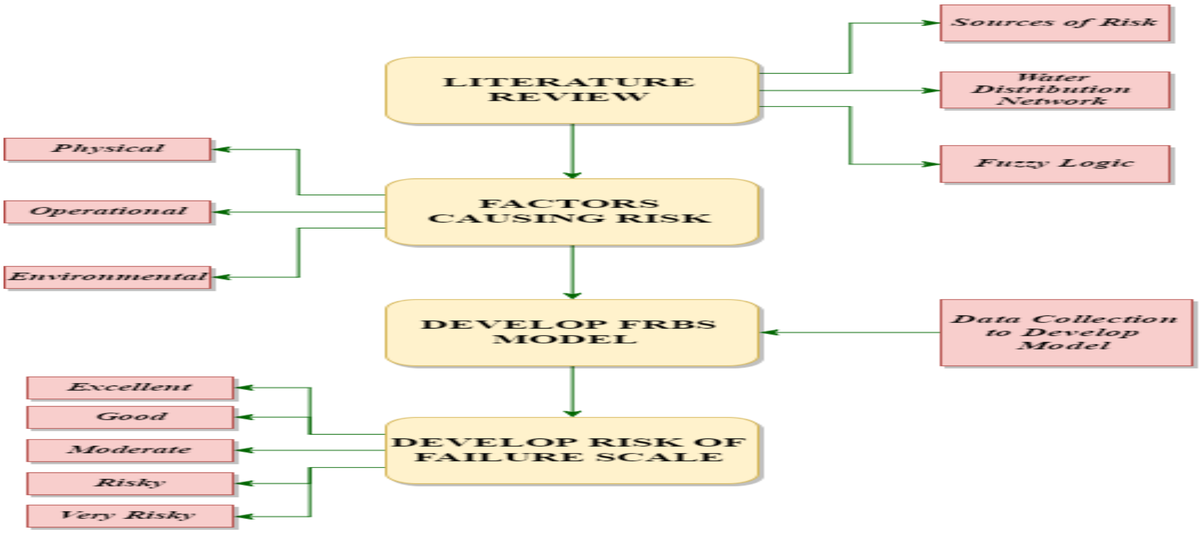

Figure 1Study Framework

The present research focuses on many stages for the study framework. The research starts with the full review of the literature which leads to the risk of failure of water distribution network in which various sources of risk, fuzzy logic and its application in risk of failure for water distribution network is studied. The literature review leads to finding out the factors which leads to deterioration and then failure of the segments of water distribution network. The fuzzy rule based system (FRBS) model is developed by collecting data which helps in developing the model. The last stage of the study framework is to develop a risk of failure scale which would be helpful to the municipalities as well as decision makers for best managing their water distribution networks. The scale ranges from Excellent to Very Risky. Detailed study framework in shown in figure1.

DATA COLLECTION

For the development of fuzzy rule based system model data were needed which were gathered from the available literature review and the data which were not available were gathered through a questionnaire. The factors which impact the performance of the network were obtained from the literature review while information needed for the performance assessment of different factors were obtained through a questionnaire which was in the form of IF….THEN statements. The questionnaire was sent to 50 experts from various fields and feedback was obtained from 40 of them.

DEVELOPMENT OF HIERARCHAL FUZZY RULE BASED SYSTEM FOR DETERMINING RISK OF FAILURE

The model is developed using MATLAB R2008a-fuzzy tool box. For the development of the model the first step is to find out the failure risk parameters. In this paper eight such parameters which leads to risk of water distribution network are work out which represent deterioration. It should be noted that the factors are selected in such a manner that their data is available with the managers or municipalities. Such data can be obtained from the Auto Cad drawings, from hydraulic experts or with visualinspection of reports. After selecting the parameters the next step is the hierarchical division of the model. The model is divided into three branches which represent three main factors that are physical, operational and environmental factors. These three factors result later combine to give risk of failure value. Now, it should be noted that the fuzzy structure of each factor is identical and only the membership function of each of each factor and the rule base of each model changes. The full view of themodel is shown in figure 2 which shows how the whole model for evaluation of water distribution network

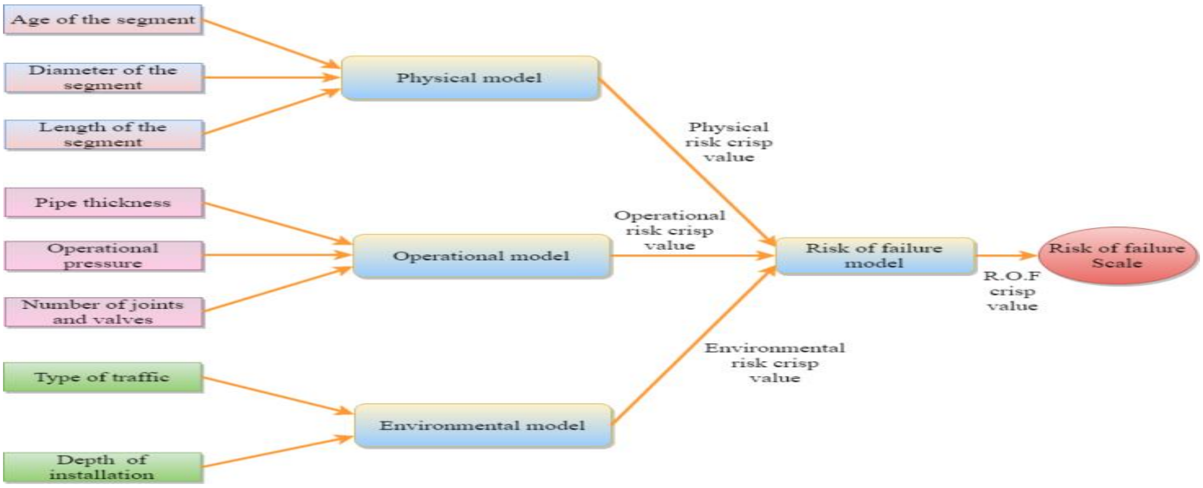

Figure 2Hierarchical Fuzzy Model

The membership function for all the factors are different and are generated based on the information which is obtained from the literature review also the type of membership function for each factor depends on the characteristic of each factor and its effect on risk of failure of the water distribution network. The final risk of failure value is evaluated on a scale of 0-10. After the membership functions are generated for each factor the next step is the fuzzy inference system in which the knowledge base is developed to obtain the risk of failure value for the water distribution network this is done through the knowledge acquisition method in which information is obtained through questionnaire asked to expert in form of IF…THEN statements. In the developed model Mamdani inference method is used which is available in MATLAB R-2008a-fuzzy tool box(Zayed H. F., 2009)

R^j: If $x_1$is$A_1^j$and $x_2$is$A_2^j$and $x_3$isA_3^j and……$x_n$isA_n^j then y is B^j (1)

Here B is the consequent linguistic variable in standardized form of very low, low, medium, high and very high. This is applicable to all the four models that are Physical, Operational, Environmental and Risk of Failure models. The next step is the consequents aggregation for each membership function done using the maximum operator available in MATLAB R-2008a-fuzzy tool box.

The final step in the model development is the defuzzification process which converts the fuzzy consequents into a crisp value. The method used here for defuzzification process is the centre of sum method as shown in Eq. (2). The defuzzification process is applied to all the four models and the crisp output obtained from the risk of failure model represents risk of failure value.

$$\text{Crisp output}=\frac{\sum_{extremely\ low}^{extremely\ high}\text{Truncated area}*\text{Centroid}}{\sum_{extremely\ low}^{extremely\ high}\text{Truncated area}} \qquad (2)$$

PROPOSED RISK OF FAILURE SCALE

Once the model is developed, taking into consideration the crisp output value from the model a risk of failure scale is developed which helps decision makers to assess the condition of the distribution network. The scale ranges from 0-10 where 0 indicated excellent condition while 10 indicates very risky condition of the water distribution network segment. The scale is divided into 5 parts from excellent, good, moderate, risky and very risky.

SUMMARY AND CONCLUSION

With respect to the above research one can say that a model can be developed using fuzzy rule based system for the risk assessment of the water distribution networks and by doing so the challenges which are faced by the municipalities for the assessment of the water distribution segments pipes in the network can be solved and they can prioritize the rehabilitation and maintenance of each water distribution segment. The total of 8 parameters was selected for developing the model but this is not fix one can take as much parameters required in developing the model. Also in this research only deteriorating factors are considered but one can also consider the post-deterioration factors. Municipal managers, contractors and consultants can use the developed model to maintain their rehabilitation plan and assess the risk associated with the network of each segment.

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