Prioritization of Municipal Water Mains Leakages for the Selection of R&R Maintenance Strategies Using Risk Based Multi-Criteria FAHP Model

Thewodros G. Mamo [1], Ilan Juran[2], Isam Shahrour [*3]

[1,2] Department of Civil & Urban Engineering Polytechnic Institute of New York University, 6 Metro Tech Center, Brooklyn, NY
[*3]Laboratoire de mécanique de Lille, University of Sciences and Technologies of Lille, 59650 Villeneuve d'Arcy, France
[1]tgm232@nyu.edu, P.E., Ph.D. Candidate [2]ijurann@poly.edu , Ph.D. [*3]isam.shahrourr@univ-lille1.fr ,Ph.D.

ABSTRACT

Municipal water network systems are composed of a wide range of complex buried Infrastructure. Many of these essential Infrastructures have reached or exceeded their design life cycle and need a sound rehabilitation and replacement (R&R) Maintenance Strategies. However, maintaining and repairing such an aging and complex water pipeline network systems in big urban cities presents a unique decision and management challenges for water utility companies with respect to how to carry out the ranking and evaluation process and decide which of these complex wide ranges of buried Infrastructure from the networks required replacement or rehabilitation in a cost-effective manner. These decision and management challenges of maintaining water distribution pipeline network infrastructures at nearly the intended design condition by investing the minimum amount of money, and allocating limited resources utility companies have among different projects keep the water utility companies actively searching for innovative approaches for decision support methodologies based on analysis of options, that involves evaluation of many criteria and parameters in order to determine the optimal maintenance Strategies for the Prioritization of rehabilitation and replacement.

This paper presents how Risk based Fuzzy Analytic Hierarchy Process (FAHP) decision approach can be used to rank existing or recently detected multiple leakages form WD pipeline networks. And demonstrate how this method can help the decision makers for the selection of which pipeline required urgent action, and prioritize the optimal alternative rehabilitation and replacement (R&R) Maintenance Strategies by integrating value professional judgments and stakeholder preferences with limited annual budget the water utility companies may have. In conclusion, this FAHP approach would benefit the decision-makers of water utility companies where there are currently no structured approach or methods for making a responsible and defendable decision with clearly demonstrated trade-offs between stakeholder investment and water utility agencies service levels standards and objectives.

Keywords: Multi-Criteria Decision support (MCDS), FAHP Model, Infrastructure Rehabilitation, Leakage, Water Loss Reduction, Asset Management, Infrastructure

1. INTRODUCTION

Each water distribution pipeline networks have their own distinct characteristics such as different operating pressure, service location, pipe sizes, material, and deterioration factors. Today, one of the broader challenges water utility companies are facing associated with their infrastructure includes lack of when and how to evaluate, rank, plan and execute maintenance projects that restores or replaces towards to its originally planned capacity or condition in a cost-effective manner those deteriorating water pipeline networks which have multiple leakage, and can cause in the future poorly hydraulic performance, service interruptions, damage of property, and poor water quality. Some of the decision challenges water utility companies are facing involve selecting the optimum possible solution among a number of competing alternatives. However, to select the best solution available in a systematic and innovative way, decision support methodologies with the desired objective in mind that facilitates comparative professional judgments and eventual optimized alternative decision options are needed To demonstrate how risk based Fuzzy Analytic Hierarchy Process (FAHP) decision support approach can be used to rank existing or recently detected municipal water mainline leakages for selecting of which water main pipeline from the networks require urgent action, and to prioritize the optimal alternative rehabilitation and replacement (R&R) Maintenance Strategies with value professional judgments and stakeholder preferences a case study at Lille University has been carried out. The rest of this paper consists of a brief summary of FAHP and detail formulation of the FAHP model as well as a sample calculation to demonstrate model application using the case study of Lille University "Zone- six "water supply pipeline networks.

2. OVERVIEW OF RISK BASED MULTI-CRITERIA FAHP DECISION MAKING MODEL

Risk based multi-criteria decision support (MCDS) methodologies furnish a means of assessing the outcomes of each possible combination of quantifiable and qualitative attributes under the optimization constraints in a decision problem. Saaty L. T. (1990). How to Make a Decision: The Analytical Hierarchy Process. European Journal of Operational Research 48(1990) 9-26.

The Analytical hierarchy process is one of the most widely practiced decision support techniques by research scientists. Baby S. (2013). International Journal of Innovation Management and Technology Vol. 4, No. 2. The most powerful flair that FAHP possess is its ability to elicit both true values of tangible elements and preference scores derived from subjective professional judgments for intangible elements in the form of ratios between absolute levels of performance of attribute pairs. AHP decomposes decision problem and filters out unimportant information. It also allows preference scores to be assigned by decision makers or stakeholders to attributes according to their perceived relative importance weights in a pairwise comparison process. Saaty L. T. (2005), the Analytic Hierarchy and Analytic Network Processes for the Measurement of Intangible Criteria and for Decision-Making Eds. Figueira J, Greco S. & Ehrgott M. Multiple Criteria Decision Analysis: State Of The Art Surveys (pp. 345-382), Springer Science + Business Media, Inc. Publisher, and Tavana M. and Banerjee S. (1995). A multiple Criteria Decision Support System for Evaluation of Strategic Alternative. Journal of Decision Science Volume 26 #1

3. FAHP MODEL FORMULATIONS AND APPLICATION

Several research papers have been published used the FAHP procedure based on extent analysis methods and AHP decision support system in multi-criteria approaches, and demonstrated how it can be applied to different cases. The Extent FAHP which is originally introduced by Chang, D.Y. (1996), Applications of the extent analysis method on fuzzy AHP, European Journal of Operational Research, 95, PP # 649–655, has been used for this research.

3.1 GENERAL AHP APPROACH

Let n be the number of criterion and $Z_1, Z_2 \dots Z_n$ be their corresponding relative priority given by the water utility company decision maker. Then the judgment matrix A which contains pair wise comparison value a_{ij} for all $i, j \in \{1,2,\dots,n\}$ is given by: Saaty L. T. (1990). How to Make a Decision: The Analytical hierarchy process. European Journal of Operational Research 48(1990) 9-26. Baby S. (2013). International Journal of Innovation Management and Technology Vol. 4, No. 2

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} = \begin{bmatrix} 1 & \frac{z_1}{z_2} & \cdots & \frac{z_1}{z_n} \\ \frac{z_2}{z_1} & 1 & \cdots & \frac{z_2}{z_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{z_n}{z_1} & \frac{z_n}{z_2} & \cdots & 1 \end{bmatrix} \tag{1}$$

For multiple decision makers, let h be the number of decision maker and $a_{ij}{}^{k}$ be the pair wise comparison value of criteria i and j given by decision maker k, Where: - k=1, 2,…, h Then by using geometric mean of the $a_{ij}{}^{k}$ conducted by each decision maker, we have a new judgment matrix with element given by:

$$a_{ij} = \left[a^1{}_{ij} \times a^2{}_{ij} \times \cdots \times a^k{}_{ij} \times \cdots \times a^h{}_{ij}\right]^{\frac{1}{h}} = \left[\prod_{k=1}^{h} a^k{}_{ij}\right]^{\frac{1}{h}} \tag{2}$$

Now, normalize each column to get a new judgment matrix A'

$$A' = \begin{bmatrix} a'_{11} & a'_{12} & \cdots & a'_{1n} \\ a'_{21} & a'_{22} & \cdots & a'_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a'_{n1} & a'_{n2} & \cdots & a'_{nn} \end{bmatrix} = \begin{bmatrix} \frac{a_{11}}{\sum_{i=1}^{n} a_{i1}} & \frac{a_{12}}{\sum_{i=1}^{n} a_{i2}} & \cdots & \frac{a_{1n}}{\sum_{i=1}^{n} a_{in}} \\ \frac{a_{21}}{\sum_{i=1}^{n} a_{i1}} & \frac{a_{22}}{\sum_{i=1}^{n} a_{i2}} & \cdots & \frac{a_{2n}}{\sum_{i=1}^{n} a_{in}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{a_{n1}}{\sum_{i=1}^{n} a_{i1}} & \frac{a_{n2}}{\sum_{i=1}^{n} a_{i2}} & \cdots & \frac{a_{nn}}{\sum_{i=1}^{n} a_{in}} \end{bmatrix} \tag{3}$$

Where: - $\sum_{i=1}^{n} a_{ij}$ is the sum of column j of judgment matrix A.

To get weight vector V by summing up each row of normalized judgment matrix A' we have

$$V = \begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ v_n \end{bmatrix} = \begin{bmatrix} \sum_{j=1}^{n} a'_{i1} \\ \sum_{j=1}^{n} a'_{21} \\ \vdots \\ \sum_{j=1}^{n} a'_{n1} \end{bmatrix} \tag{4}$$

By defining the final normalization weight vector W , we have

$$W = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} \frac{v_1}{\sum_{i=1}^{n} v_i} \\ \frac{v_2}{\sum_{i=1}^{n} v_i} \\ \vdots \\ \frac{v_n}{\sum_{i=1}^{n} v_i} \end{bmatrix} \tag{5}$$

3.2 THE CHANG'S EXTENT FUZZY AHP (FAHP) APPROACH

Let $\tilde{A}$ represent the $[n \times n]$ judgment matrix containing triangle fuzzy number (TFN) $\tilde{a}_{ij}$ for all $i, j \in \{1,2,\ldots,n\}$ as shown

$$\tilde{A} = \begin{bmatrix} (1,1,1) & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & (1,1,1) & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & (1,1,1) \end{bmatrix} \tag{6}$$

Where: - $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ with l_{ij} is the lower and u_{ij} is the upper limit and m_{ij} is the most likely value, where a fuzzy number is said to be a triangular of its membership function is given as

$$\tilde{m}(x) = \begin{cases} \frac{x-l}{m-l} & l \le x \le m \\ \frac{u-x}{u-m} & m \le x \le u \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

Consider two triangle fuzzy numbers $\tilde{m}_1$ and $\tilde{m}_2$, $\tilde{m}_1 = (l_1, m_1, u_1)$ and $\tilde{m}_2 = (l_2, m_2, u_2)$.

The arithmetic operation between the two triangular fuzzy numbers are defined as Chang, D.Y. (1996)

$$(l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = \tilde{m}_1 \oplus \tilde{m}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{8}$$

$$(l_1, m_1, u_1) \otimes (l_2, m_2, u_2) = \tilde{m}_1 \otimes \tilde{m}_2 = (l_1 l_2, m_1 m_2, u_1 u_2) \tag{9}$$

$$(l_1, m_1, \mu_1)^{-1} = \tilde{m}_1^{-1} = \left[\frac{1}{u_1}, \quad \frac{1}{m_1}, \quad \frac{1}{l_1}\right] \tag{10}$$

The basic procedure of Chang's extent fuzzy AHP approach is given as following Chang, D.Y. (1996)

Step-1- Sum up each row of fuzzy judgment matrix $\tilde{A}$ to get the fuzzy number vector R_s

$$R_s = \begin{bmatrix} rs_1 \\ rs_2 \\ \vdots \\ rs_n \end{bmatrix} = \begin{bmatrix} \sum_{j=1}^{n} \tilde{a}_{1j} \\ \sum_{j=1}^{n} \tilde{a}_{2j} \\ \vdots \\ \sum_{j=1}^{n} \tilde{a}_{nj} \end{bmatrix} = \begin{bmatrix} (\sum_{j=1}^{n} l_{1j}, & \sum_{j=1}^{n} m_{1j}, & \sum_{j=1}^{n} m_{1j}) \\ (\sum_{j=1}^{n} l_{2j}, & \sum_{j=1}^{n} m_{2j}, & \sum_{j=1}^{n} m_{2j}) \\ \vdots & \vdots & \vdots \\ (\sum_{j=1}^{n} l_{nj}, & \sum_{j=1}^{n} m_{nj}, & \sum_{j=1}^{n} m_{nj}) \end{bmatrix} \tag{11}$$

Step-2- Normalize the row fuzzy number vector R_s to get the fuzzy synthetic extent value vector S.

$$\tilde{S} = \begin{bmatrix} \tilde{S}_1 \\ \tilde{S}_2 \\ \vdots \\ \tilde{S}_n \end{bmatrix} = \begin{bmatrix} rs_1 \otimes \left(\sum_{j=1}^{n} rs_j\right)^{-1} \\ rs_2 \otimes \left(\sum_{j=1}^{n} rs_j\right)^{-1} \\ \vdots \\ rs_n \otimes \left(\sum_{j=1}^{n} rs_j\right)^{-1} \end{bmatrix} \tag{12}$$

Where: - $\left(\sum_{j=1}^{n} rs_j\right)^{-1}$ is the derivative of the sum fuzzy number vector R_s and it is calculated by

$$\left(\sum_{j=1}^{n} rs_j\right)^{-1} = \left(\frac{1}{\sum_{k=1}^{n}\sum_{j=1}^{n} u_{kj}}, \frac{1}{\sum_{k=1}^{n}\sum_{j=1}^{n} m_{kj}}, \frac{1}{\sum_{k=1}^{n}\sum_{j=1}^{n} l_{kj}}\right) \tag{13}$$

Step-3- Compute the degree of possibility to get the non-fuzzy weight vector V.

$$V = \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_n \end{bmatrix} = \begin{bmatrix} \min V(\tilde{S}_1 \geq \tilde{S}_k) \\ \min V(\tilde{S}_2 \geq \tilde{S}_k) \\ \vdots \\ \min V(\tilde{S}_n \geq \tilde{S}_k) \end{bmatrix} \quad (14)$$

Where for element i the subscript $k \in \{1,2,\ldots,n\}$ and $k \neq i$

The degree of possibility of $\tilde{S}_2 = (l_2,\ m_2,\ u_2) \geq \tilde{S}_1 = (l_1, m_1,\ u_1)$ is obtained by

$$V(\tilde{S}_2 \geq \tilde{S}_1) = \begin{cases} 1 & \text{of } m_2 \geq m_1 \\ 0 & \text{of } l_1 \geq l_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{otherwise} \end{cases} \quad (15)$$

Step-4- Define the final non-fuzzy normalization weight vector W .

$$W = \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{bmatrix} = \begin{bmatrix} \dfrac{V_1}{\sum_{i=1}^{n} V_i} \\ \dfrac{V_2}{\sum_{i=1}^{n} V_i} \\ \vdots \\ \dfrac{V_n}{\sum_{i=1}^{n} V_i} \end{bmatrix} \quad (16)$$

Where: - W is a non-fuzzy number.

4. DECISION MAKING UNCERTAINTY

The process of decision making is encounter with uncertainties that can be generated from lack of professional judgments and incomplete knowledge of the consequences of actions that leads to imprecision and inherent randomness. Therefore, the credibility of the decision outcomes determined by MCD methods can be affected by the embedded uncertainty if not stated explicitly or dealt with in the model. Bender, M.J. 2002. Fuzzy Compromise Approach to Water Resources Systems Planning Under Uncertainty. In Risk, Reliability, Uncertainty, and Robustness of Water resources Systems. eds. Bogardi J.J and Kundzewicz Z.W. UNESCO International Hydrology Series. Cambridge, UK: Cambridge University Press. Judgment uncertainties are type of internal uncertainty that deals with imprecision in the assessment of criteria scores for different alternatives and criteria weights. Stewart T. J (2005). Dealing with Uncertainties in MCD. Eds. Figueira J, Greco S. & Ehrgott M. Multiple Criteria Decision Analysis: State Of The Art Surveys (pp. 445-455). Springer Science + Business Media, Inc. Publisher. Therefore, to avoid such uncertainty that could arise because of the external environment which provides insufficient information and forces the DMs to make imprecise judgments during pair wise criteria scoring for different alternatives and Parameter weighing process, interviews of different professional on the field of water supply operations maintenances department of NYC have been conducted to get there outcome for this case study explained in the rest of the paper.

5. LILLE UNIVERSITY ZONE-SIX RESEARCH CASE STUDY

5.1 INTRODUCTION

The University Lille 1 was established 1854 in Lille, although its academic roots extend back to 1562. It later moved to Villeneuve d'Ascq in 1967, with 25,000 full-time students plus 15,000 students in continuing education (2011). 1,310 permanent faculty members plus 1,200 staff and around 140 CNRS researchers work there in the different University Lille 1 institutes and 43 research labs. University Lille 1 is a member of the European Doctoral College Lille-Nord-Pas de Calais, which produces 400 doctorate dissertations every year. The university is ranked in the world top 200 universities in mathematics by the Shanghai ranking. (News on Lille 1's webpage, http://www.univ-lille1.fr/Accueil/Actualites?id=26313). Figure -1- below is the map of general location of the campus and “Zone-6” of the research area.

5.2 LILLE UNIVERSITY’S WATER PIPELINE NETWORKS

Lille University water pipeline network systems are divided into different supply zones Z1, Z2… etc. This case study has been carried out for the so called” Zone-six” project area. Currently, there are approximately 2.8 km of water pipelines within the zone-six (Z6) with diameter of 150mm to 300mm. The aged of the pipe lines ranges from 10-50 years with different materials such as cast iron, ductile iron, and PVC. This network has operating pressure of approximately 4- 5 bars or 58-72 Psi. The breakdown of the type of pipe, length in Km and percentage of pipeline material in service is shown in Table-1- below. Figure -1- is also shows a General map of the Zone-6 location. Figure-2- and Table-2- below explains the overall Pipeline and existing condition.

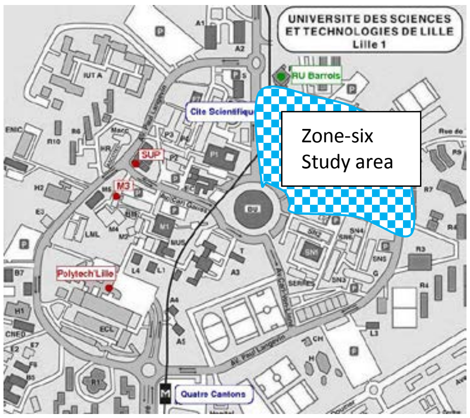

Table -1 -

Pipeline Code	Length in km	Type of material	Diameter	% of pipe in service
P-1	0.622	CI	150	22.76
P-2	0.517	CI	150	18.92
P-3	0.494	PVC	150	18.08
P-4	0.635	DC	300	23.24
P-5	0.465	DC	300	17.00

Figure -1-general location of the campus and “Zone-6” of the research area & Table-1- breakdown of the type of pipe

Table-2-

Existing Condition of the Z6 Pipeline Network				
Pipe -1	Pipe-2	Pipe-3	Pipe-4	Pipe-5
10 Years PVC Pipe Good Hydraulic, structure and water quality condition No breaking history, unavoidable Leakage, Shallow depth Located at normal not busy street.	15 Years of DC Pipe Good Hydraulic, structure and water quality condition, No breaking history, Shallow depth Located at normal not busy street. Minimum Leakage with normal connection	25 Years Ductile Cast Iron Pipe Fair Hydraulic, structure and water quality condition, 1X breaking history, Fairly leakage, Shallow depth, Located at normal street with normal	40 Years Ductile Iron Pipe, Badly deteriorated with junction fittings lost, lots of breaking history, Moderate leaks, Poor Hydraulics Located at very busy street. Bad or risky	50 Years Ductile cast Iron Pipe Moderately deteriorated 2x breaking history Moderate leaks, Poor Hydraulics and water Quality, deeply trenched Located at busy street with fair connection

Table -2 Existing condition of “Zone-six” pipe line network

The Pipelines data from the university database and from technical personnel feedback are used for parameters and criteria formulation required to develop FAHP approach. This includes structural data for the pipes (e.g. diameter, length of pipe, material, laying year, and soil conditions, co-ordinates, joint type...etc.).

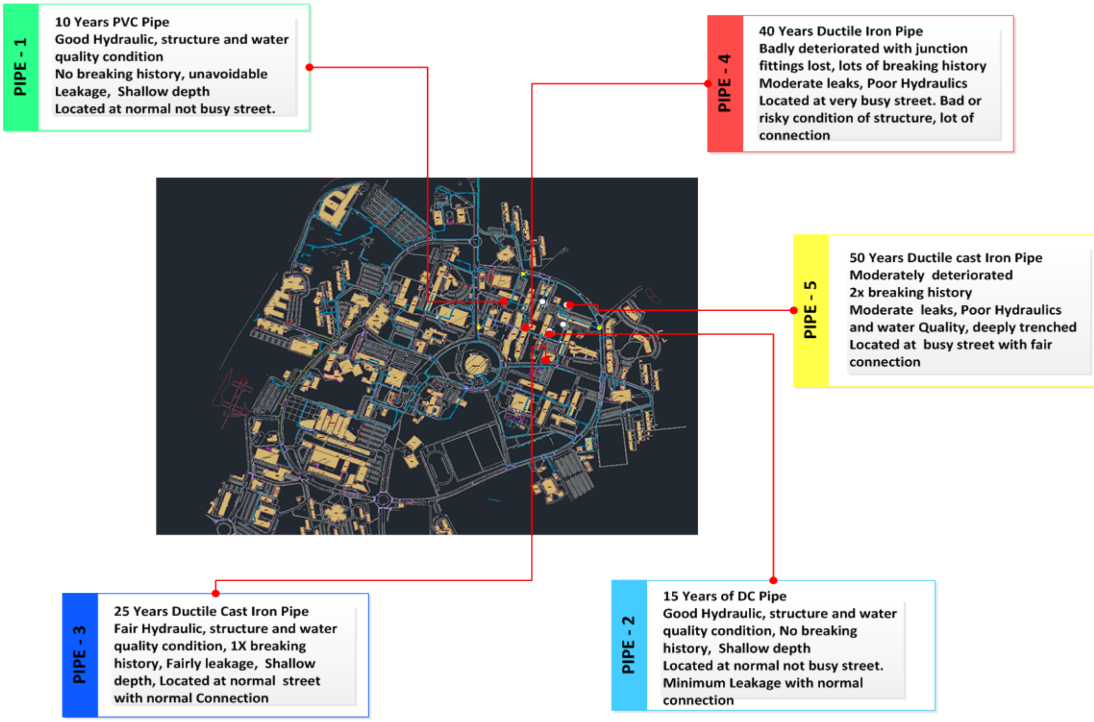

Figure -2- location of all Pipeline mains and existing condition Zone-6

6. MODEL FORMULATION APPROACH FOR MAINTENANCE STRATEGIES

The model formulation approach to rank multiple pipeline leakages to determine the optimal Maintenance Strategies for Prioritization of rehabilitation or replacement is based on the severity of the identified leakage and the potential damage that can cause to the overall reliability of the system, the utility company's goals, performance objectives and target service levels standards. For the purpose of developing FAHP, and to establish risk based pair-wise comparison, the "Zone-6" water pipelines networks system were broken down in to five main groups namely Physical, Environmental, Operational, Post leakage and Economic effect. Each characteristic have sub attributes listed below.

1. *Physical characteristics* i.e., pipe size, pipe age, material type, depth of cover, and status of appurtenances.
2. *Environmental characteristics* i.e., soil type location information such as proximity to highways and railroads, Daily traffic.
3. *Operational characteristics* i.e., pipe break and leak history, repair records, leak detection reports, and water quality complaint records
4. *Post leakage detection Characteristics* i.e., *S*afety implications, Damage to property, Number / type of premises without water, Volume of water leaking, Traffic implications.
5. *Economic Assessment* i.e., in cases where more than one alternative is feasible, an economic evaluation is applied to select the best course of action from an economic standpoint

The model formulation also consists of different stages, start with a full literature reviews of the risk of water distribution main failure and maintenance strategies followed by data collection to build the model and applied the model to zone-six (Z6) case study. Each of these pipelines were represented by multi-criteria parameter profile mentioned above and coded as Pipe-1, 2, 3, 4, and 5 respectively, See figures -2- above. For each of pipelines the importance parameters according to different attributes were evaluated by professional expertise and the relative weights were given. These weights are characterized by fuzzy number using table -2. Due to lack of pipe inventory and failure data availability, the following assumptions were made: the pipe age is ranging from 10-50 years, leakage and breakage is assumed once in 10-15 years, some of the pipelines are deteriorated because of their exceeding their design life cycle.

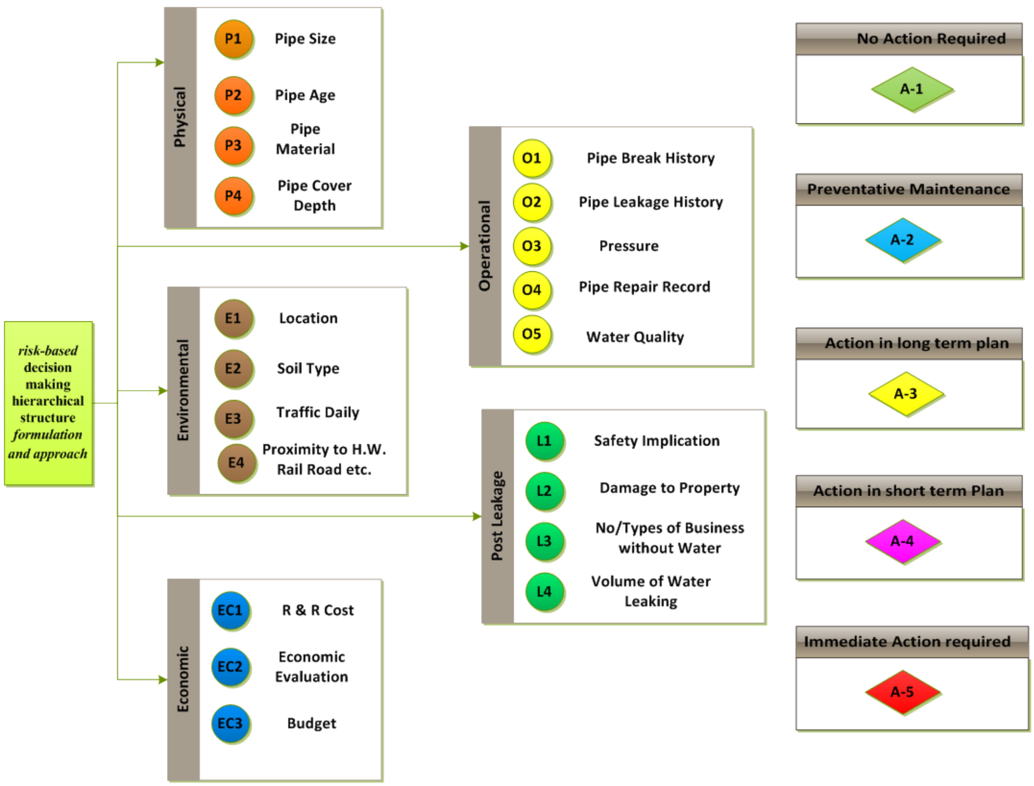

Figure-3- risk-based decision making hierarchical structure *formulation & approach*

These Fuzzy Pair-wise comparisons matrixes and decision making hierarchical structure is shown on figure-3- and table 4 to 8. After the formation of fuzzy pair-wise comparisons matrix, criteria and alternatives weight are determined by fuzzy AHP. According to fuzzy AHP method, combined weights must be calculated first. Refer to table 4 to 8. By using the related equations, combined values are calculated and the related calculation for each matrix is given below.

7. DEMONSTRATED SAMPLE CALCULATIONS AND PROCEDURE

Sample of mathematical calculation of FAHP and pairwise comparisons are demonstrated below *Table -3- The fundamental scale of Fuzzy AHP from Saaty (1994), and Lootsma F.A., Multi-criteria Decision Analysis via Ratio and Difference Judgments, Kluwer Academic Publisher, USA, 1999, pp. 76-81.*

Table-3

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance	Experience and judgment slightly favor one activity over another.
5	Strong Importance	Experience and judgment strongly favor one activity over another.
7	Very Strong Importance	An activity is favored very strongly over another, its dominance demonstrated in practice.
9	Extreme Importance	The evidence favoring one activity over another is of the highest possible order of affirmation.
2, 4, 6, 8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it.
1.1-1.9	For tied activities	When elements are close and nearly indistinguishable; moderate is 1.3 and extreme is 1.9.
Reciprocals of above	If activity A has one of the above numbers assigned to it when compared with activity B, then B has the reciprocal value when compared to A	For example, if the pairwise comparison of A to B is 3.0, then the pairwise comparison of B to A is 1/3.

Table-3- characteristics of the triangular Fuzzy Number

The pair-wise comparison matrix for the main attributes is built and illustrated in the following table and other matrices are constructed in the same manner.

Table -4-						
Criteria	Physical	Operational	Environmt.	Post Leakage	Economic	Priority Vector
Physical	(1,1,1)	(5,7,9)	(1/5,1/3,1/2)	(3,5,7)	(5,7,9)	0.154
Operational	(1/9,1/7,1/5)	(1,1,1)	(1/9,1/9,1/7)	(5,7,9)	(1/9,1/9,1/7)	0.202
Environment	(1,3,5)	(7,9,9)	(1,1,1)	(5,7,9)	(5,7,9)	0.01
Post Leakage	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1,1,1)	(7,9,9)	0.26
Economic	(1/9,1/7,1/5)	(7,9,9)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1,1,1)	0.231

Table -5-					
Pipe Network	Pipe -1	Pipe-2	Pipe-3	Pipe-4	Pipe-5
Pipe-1	(1,1,1)	(1,2,3)	(3,5,7)	(5,7,9)	(7,9,9)
Pipe-2	(1/3,1/2,1)	(1,1,1)	(1,3,5)	(5,7,9)	(1,3,5)
Pipe-3	(1/7,1/5,1/2)	(1/5,1/3,1)	(1,1,1)	(7,9,9)	(5,7,9)
Pipe-4	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1/9/1/9,1/7)	(1,1,1)	(5,7,9)
Pipe-5	(1/9,1/9,1/7)	(1/5,1/3,1)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1,1,1)

*Table -4- and -5- Fuzzy Paired Wised Comparison matrix total criteria and **Physical characteristics** i.e., pipe size, pipe age, material type, depth of cover, and status of appurtenances*

Table -6-					
Pipe Network	Pipe -1	Pipe-2	Pipe-3	Pipe-4	Pipe-5
Pipe-1	(1,1,1)	(1,3,5)	(3,5,7)	(5,7,9)	(7,9,9)
Pipe-2	(1/5,1/3,1)	(1,1,1)	(3,5,7)	(3,5,7)	(7,9,9)
Pipe-3	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(5,7,9)	(3,5,7)
Pipe-4	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1,1,1)	(7,9,9)
Pipe-5	(1/9,1/9,1/7)	(1/9,1/9,1/7)	(1/7,1/5,1/3)	(1/9,1/9,1/7)	(1,1,1)

Table -7-					
Pipe Network	Pipe -1	Pipe-2	Pipe-3	Pipe-4	Pipe-5
Pipe-1	(1,1,1)	(1,1,1)	(1,3,5)	(3,5,7)	(5,7,9)
Pipe-2	(1,1,1)	(1,1,1)	(1,2,4)	(2,4,6)	(4,6,8)
Pipe-3	(1/5,1/3,1)	(1/4,1/2,1)	(1,1,1)	(5,7,9)	(1,3,5)
Pipe-4	(1/7,1/5,1/3)	(1/6,1/4,1/2)	(1/9,1/7,1/5)	(1,1,1)	(5,7,9)
Pipe-5	(1/9,1/7,1/5)	(1/8,1/6,1/4)	(1/5,1/3,1)	(1/5,1/3,1)	(1,1,1)

*Table -6- and -7- Fuzzy Paired Wised Comparison matrix according to **Operational characteristics** i.e., pipe break and leak history, repair records, leak detection reports, and water quality complaint records and **Environmental characteristics** i.e., soil type location information such as proximity to highways and railroads, Daily traffic.*

Table -8-					
Pipe Network	Pipe -1	Pipe-2	Pipe-3	Pipe-4	Pipe-5
Pipe-1	(1,1,1)	(2,4,6)	(3,5,7)	(1,3,5)	(7,9,9)
Pipe-2	(1/6,1/4,1/2)	(1,1,1)	(5,7,9)	(3,5,7)	(7,9,9)
Pipe-3	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(7,9,9)	(3,5,7)
Pipe-4	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/9,1/9,1/7)	(1,1,1)	(2,4,6)
Pipe-5	(1/9,1/9,1/7)	(1/9,1/9,1/7)	(1/7,1/5,1/3)	(1/6,1/4,1/2)	(1,1,1)

Table -9-					
Pipe Network	Pipe -1	Pipe-2	Pipe-3	Pipe-4	Pipe-5
Pipe-1	(1,1,1)	(1,2,4)	(1,3,5)	(3,5,7)	(7,9,9)
Pipe-2	(1/4,1/2,1)	(1,1,1)	(3,5,7)	(1,3,5)	(3,5,7)
Pipe-3	(1/5,1/3,1)	(1/7,1/5,1/3)	(1,1,1)	(5,7,9)	(7,9,9)
Pipe-4	(1/7,1/5,1/3)	(1/5,1/3,1)	(1/9,1/7,1/5)	(1,1,1)	(5,7,9)
Pipe-5	(1/9,1/9,1/7)	(1/7,1/5,1/3)	(1/9,1/9,1/7)	(1/9,1/7,1/5)	(1,1,1)

*Table -8- and 9 Fuzzy Paired Wised Comparison matrixes according to **Post leakage detection** Characteristics i.e., Safety implications, Damage to property, Number / type of premises without water, Volume of water leaking, Traffic implications. **Economic Assessment** i.e., in cases where more than one alternative is feasible, an economic evaluation is applied to select the best course of action from an economic standpoint. Sample calculation for **Post leakage characteristics matrix***

$$R_s = \begin{bmatrix} rs_1 \\ rs_2 \\ \vdots \\ rs_n \end{bmatrix} = \begin{bmatrix} \sum_{j=1}^{n} \tilde{a}_{1j} \\ \sum_{j=1}^{n} \tilde{a}_{2j} \\ \vdots \\ \sum_{j=1}^{n} \tilde{a}_{nj} \end{bmatrix} = \begin{bmatrix} (\sum_{j=1}^{n} l_{1j}, & \sum_{j=1}^{n} m_{1j}, & \sum_{j=1}^{n} m_{1j}) \\ (\sum_{j=1}^{n} l_{2j}, & \sum_{j=1}^{n} m_{2j}, & \sum_{j=1}^{n} m_{2j}) \\ \vdots & \vdots & \vdots \\ (\sum_{j=1}^{n} l_{nj}, & \sum_{j=1}^{n} m_{nj}, & \sum_{j=1}^{n} m_{nj}) \end{bmatrix} =$$

$$\begin{bmatrix} (1,1,1) & (1,2,4) & (3,5,7) & (5,7,9) & (7,9,9) \\ (1/3,1/2,1) & (1,1,1) & (1,3,5) & (5,7,9) & (1,3,5) \\ (1/7,1/5,1/2) & (1/5,1/3,1) & (1,1,1) & (7,9,9) & (5,7,9) \\ (1/9,1/7,1/5) & (1/9,1/7,1/5) & (1/9,1/9,1/7) & (1,1,1) & (5,7,9) \\ (1/9,1/9,1/7) & (1/5,1/3,1) & (1/9,1/7,1/5) & (1/9,1/7,1/5) & (1,1,1) \end{bmatrix} = \begin{bmatrix} 17.00 & 24.00 & 38.00 \\ 8.33 & 14.50 & 21.00 \\ 13.34 & 17.53 & 20.50 \\ 7.33 & 9.40 & 10.54 \\ 1.53 & 1.72 & 2.54 \end{bmatrix}$$

$$\left(\sum_{j=1}^{n} rs_j\right)^{-1} = \left(\frac{1}{\sum_{k=1}^{n}\sum_{j=1}^{n} u_{kj}}, \frac{1}{\sum_{k=1}^{n}\sum_{j=1}^{n} m_{kj}}, \frac{1}{\sum_{k=1}^{n}\sum_{j=1}^{n} l_{kj}} \right) = \left(\frac{1}{82.76}, \frac{1}{66..96}, \frac{1}{46.44}\right) = [0.012, 0.015, 0.022]$$

$$\tilde{S} = \begin{bmatrix} \tilde{S}_1 \\ \tilde{S}_2 \\ \vdots \\ \tilde{S}_n \end{bmatrix} = \begin{bmatrix} rs_1 \otimes \left(\sum_{j=1}^{n} rs_j\right)^{-1} \\ rs_2 \otimes \left(\sum_{j=1}^{n} rs_j\right)^{-1} \\ \vdots \\ rs_n \otimes \left(\sum_{j=1}^{n} rs_j\right)^{-1} \end{bmatrix} = \begin{bmatrix} 0.168 & 0.330 & 0.616 \\ 0.194 & 0.334 & 0.583 \\ 0.135 & 0.231 & 0.389 \\ 0.041 & 0.085 & 0.186 \\ 0.018 & 0.025 & 0.467 \end{bmatrix}$$

$$V(\tilde{S}_2 \geq \tilde{S}_1) = \begin{cases} 1 & \text{of } m_2 \geq m_1 \\ 0 & \text{of } l_1 \geq l_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{otherwise} \end{cases}$$

$$\begin{bmatrix} S_1 \geq S_2 = 1 & S_2 \geq S_1 = 1 & S_3 \geq S_1 = 0.05 & S_4 \geq S_1 = 0.00 & S_5 \geq S_1 = 0.41 \\ S_1 \geq S_3 = 1 & S_2 \geq S_3 = 0.65 & S_3 \geq S_1 = 0.65 & S_4 \geq S_2 = 0.00 & S_5 \geq S_2 = 0.47 \\ S_1 \geq S_4 = 1 & S_2 \geq S_4 = 0.03 & S_3 \geq S_1 = 1 & S_4 \geq S_3 = 0.00 & S_5 \geq S_3 = 0.62 \\ S_1 \geq S_5 = 1 & S_2 \geq S_5 = 0.47 & S_3 \geq S_1 = 1 & S_4 \geq S_4 = 0.00 & S_5 \geq S_4 = 0.88 \end{bmatrix}$$

$$V = \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_n \end{bmatrix} = \begin{bmatrix} \min V(\tilde{S}_1 \geq \tilde{S}_k) \\ \min V(\tilde{S}_2 \geq \tilde{S}_k) \\ \vdots \\ \min V(\tilde{S}_n \geq \tilde{S}_k) \end{bmatrix} = V_{\min}(1, \quad 0.03 \quad 0.05 \quad 0.00 \quad 0.41)$$

$$W = \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{bmatrix} = \begin{bmatrix} \dfrac{V_1}{\sum_{i=1}^{n} V_i} \\ \dfrac{V_2}{\sum_{i=1}^{n} V_i} \\ \vdots \\ \dfrac{V_n}{\sum_{i=1}^{n} V_i} \end{bmatrix} = \begin{bmatrix} 0.68 \\ 0.02 \\ 0.04 \\ 0.00 \\ 0.28 \end{bmatrix}$$

Similar Calculation has been performed for the rest of the matrix and summarized and the result are recorded on see table –10- below, and the final ranking is calculated as shown below

Table -10 -

	Physical	Operational	Envirt.	Post Leakage	Economic
P-1	0.38	0.43	0.32	0.68	0.19
P-2	0.22	0.35	0.28	0.02	0.41
P-3	0.27	0.2	0.24	0.04	0.22
P-4	0.07	0.02	0.16	0	0.18
P-5	0.08	0	0	0.28	0

$$\begin{bmatrix} 0.38 & 0.22 & 0.27 & 0.07 & 0.08 \\ 0.43 & 0.35 & 0.20 & 0.02 & 0.00 \\ 0.32 & 0.28 & 0.24 & 0.16 & 0.00 \\ 0.68 & 0.02 & 0.04 & 0.00 & 0.28 \\ 0.19 & 0.41 & 0.22 & 0.18 & 0.00 \end{bmatrix} \otimes \begin{bmatrix} 0.151 \\ 0.202 \\ 0.01 \\ 0.26 \\ 0.23 \end{bmatrix} = \begin{matrix} 0.141 = 14.1\% = 5th = A-1 \\ 0.143 = 14.3\% = 4th = A-2 \\ 0.151 = 15.1\% = 3rd = A-3 \\ 0.172 = 17.2\% = 1st = A-4 \\ 0.161 = 16.1\% = 2nd = A-5 \end{matrix}$$

8. RESULT ANALYSIS, DISCUSSIONS AND CONCLUSION

The results from the case study for Lille University water pipeline networks indicated that the FAHP methodology could support the water utility company in decision making process to present credible evidence and maintenance

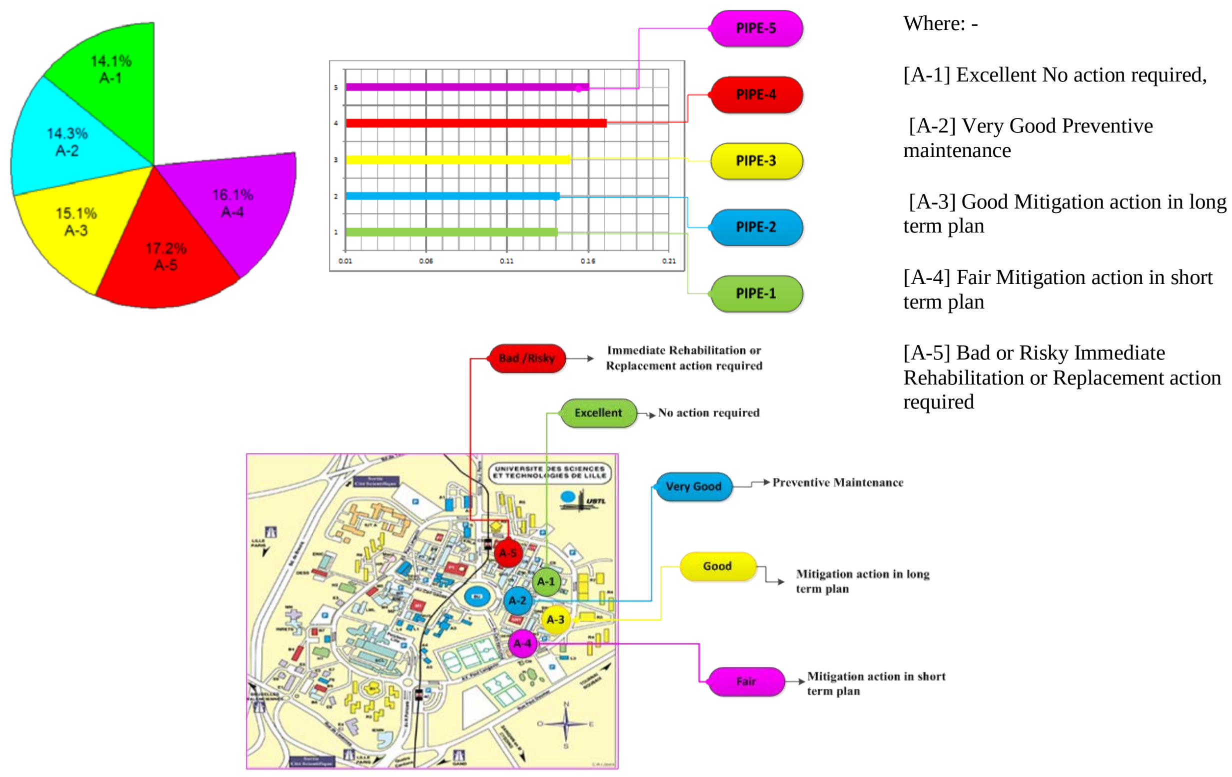

Figure-4-Decision making & priority listing

strategies. For setting priorities which pipelines from the networks or sub network systems required replacement or rehabilitated (R&R), the system is categorized by five different actions namely, A-1. Excellent -No action required, A-2. Very Good - Preventive Maintenance action, A-3. Good -Mitigation action in long term plan, A-4. Fair-Mitigation action in short term plan, and A-5. Bad or Risky-Immediate Rehabilitation or Replacement action required. This allows the water utility companies to better understand the components that are economically feasible and critical to the overall reliability of the system and make a decision for the most feasible method of water main rehabilitation or maintenance strategies. In conclusion, this FAHP approach would benefit the decision-makers of water utility companies where there are currently no structured approach or methods for making responsible and defendable decision with clearly demonstrated trade-offs between stakeholder investment and water utility agencies service level standard and objectives.

REFERENCE

[1] Baby S. (2013). International Journal of Innovation Management and Technology Vol. 4, No. 2

[2] Bender, M.J. 2002. Fuzzy compromise approach to water resources systems planning under uncertainty. In Risk, Reliability, Uncertainty, and Robustness of Water resources Systems. Eds. Bogardi J.J and Kundzewicz Z.W. UNESCO International Hydrology Series. Cambridge, UK: Cambridge University Press

[3] Chang, D.Y. (1996), Applications of the extent analysis method on fuzzy AHP, European Journal of Operational Research, 95, PP # 649–655

[4] Cheng, C. H. (1999). Evaluating weapon systems using ranking fuzzy numbers, Fuzzy Sets and Systems, 107(1), 25-35.

[5] Lee A.H.I., Kang, H.Y., Wang W.P., Analysis of Priority Mix Planning for Semiconductor Fabrication under Uncertainty, International Journal of Advanced Manufacturing Technology, 28, 2006, pp. 351–361.

[6] Lootsma F.A., Multi-criteria Decision Analysis via Ratio and Difference Judgments, Kluwer Academic Publisher, USA, 1999, pp. 76-81.

[7] (News on Lille 1's webpage, http://www.univ-lille1.fr/Accueil/Actualites?id=26313).

[8] Saaty (1994), and Lootsma F.A., Multi-criteria Decision Analysis via Ratio and Difference Judgments, Kluwer Academic Publisher, USA, 1999, pp. 76-81.

[9] Saaty L. T. (1990). How to make a decision: The Analytical hierarchy process. European Journal of Operational Research 48(1990) 9-26.

[10] Saaty L. T. (2005), the Analytic Hierarchy and Analytic Network Processes for the Measurement of Intangible Criteria and for Decision-Making Eds. Figueira J, Greco S. & Ehrgott M. Multiple Criteria Decision Analysis: State Of The Art Surveys (pp. 345-382), Springer Science + Business Media, Inc. Publisher

[11] Stewart T. J (2005). Dealing with Uncertainties in MCDA. Eds. Figueira J, Greco S. & Ehrgott M. Multiple Criteria Decision Analysis: State Of The Art Surveys (pp. 445-455). Springer Science + Business Media, Inc. Publisher

[12] Tavana M. and Banerjee S. (1995). A multiple Criteria Decision Support System for Evaluation of Strategic Alternative. Journal of Decision Science Volume 26 #1