Design and Algorithm Development of An Expert System for Continuous Health Monitoring of Sewer and Storm Water Pipes

Esmond MOK[1], King WONG[2], Geoffrey SHEA[1], Wu CHEN[1], Lilian PUN[1]

1 Department of Land Surveying and Geo-informatics, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China
2 CEO TUG (The UtilityINFO Group); President, HKIUS; Convenor, IIUS

ABSTRACT

Management and monitoring the health condition of underground utilities are essential in the process of sustainable urbanization development, as our daily necessities such as water, gas and electricity supplies are delivered through very complicated networks of pipes and cables underground. Regarding the management of water pipes, if their health condition is not regularly and properly monitored for preventive measures to be carried out in advance, the leakage of water pipes may cause road and slope collapse and hence lead to traffic jam and inconvenience to public, and more seriously fatality and property loss. However, there are no unified rules in Hong Kong on the interpretation of the health condition of utilities from pipe condition survey data. As the judgment is largely based on experience, it is unavoidable that subjective interpretation, particularly those cases with fuzzy results on for example site inspection, visual assessment based on photos and video recording may lead to different opinions. In this paper, the development of an expert system to enable collective decision making on the fuzzy results, and together with other assessment results to rank the overall health condition of drainage and sewage pipes based on the continuous tracking on the Utility Health Index (UHI) is introduced. The system is being tested in the Utility Info using real project data for further improvement. The long term tracking of the UHI and the site inspection results used for calculating the UHI can provide a fuller picture on the health condition of different sections of the pipe network. With the continuous monitoring of the pipe condition by the expert system, the potential problems of pipes can be continuously analyzed and identified, for the maintenance logistics and precautions to be planned and implemented more effectively.

DESIGN OF THE EXPERT SYSTEM

Figure 1 shows the overall design of the expert system. Spatial information such as position, alignment and gradient of pipes together with condition survey results include, but not limited to for example, CCTV videos, photographs, instrument outputs and site inspection reports can be sent to utility specialists to carry out on-line health assessments via internet. The computer server plays the important roles of managing the assessment rules, collecting and updating the database of assessment results and Utility Health Index (UHI) generated based on a set of rules to define the healthy and unhealthy condition of pipes. The condition survey results can be largely classified into qualitative and quantitative information. Quantitative results such as current measurement and soil corrosivity are numerical data. Qualitative results are descriptions based on on-site observations and interpretation of visual records. Examples of qualitative assessment results are site inspection and interpretation of the pipes' health condition based on photos and CCTV recording. The health condition of pipes is the holistic assessment of all condition survey results, composing both quantitative and qualitative types of assessment. This holistic assessment results is presented with a UHI. A matrix to provide sufficient information for developing the database of the respective assessment rules for storm and sewage pipes, and to convert the assessment results into the common assessment scale, was developed. If all the assessment components are rated as certainly healthy or unhealthy, the information will be directly used for generating the UHI. Any uncertain assessment components leading to uncertain cases will be sent to specialists for deliberating if the uncertain assessment component(s) should be rated healthy or unhealthy, with justifications. Collective assessment results returned to the central computer server will then be used to generate the UHI.

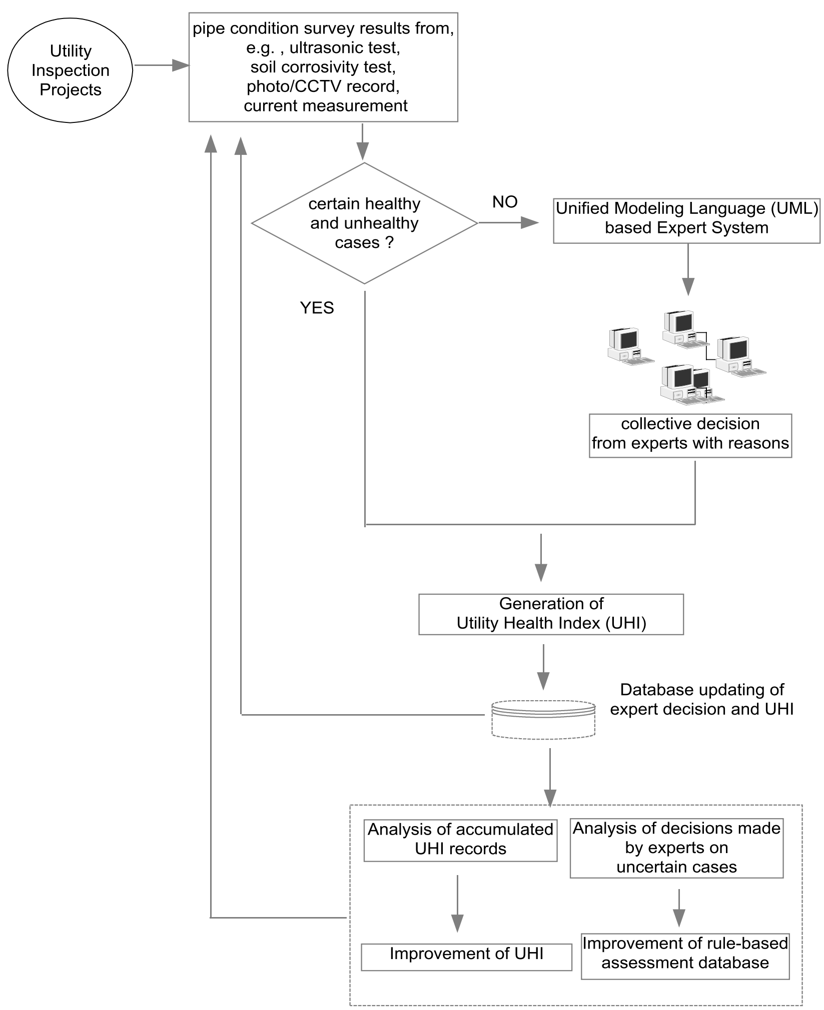

Figure 1: Schematic diagram showing the overall design of the expert system.

ALGORITHM FOR THE DETERMINATION OF UHI

The UHI of the section of pipe under inspection can be expressed mathematically as,

$$\sum_{i=1}^{n} w_i \cdot H_i \cdot S_i$$

where

i = the number of assessment components adopted by the organization
w_i = the weight indicating the relative importance of the assessment components
H_i = 1 for healthy, 0 for unhealthy
S_i = the scale derived from assessment results or inspection reports, rated 1 to 10.

The weight w_i is derived based on the Analytic Hierarchy Process (AHP) algorithm [2]. Implementation of the algorithm into the system is described below.

1. *Decomposing the Complex assessments into hierarchical order*. Each level of AHP consists of independent elements to be considered in the condition assessment process. The process is classified down to the most specific elements of the problem, typically the specific measurements or inspections required in condition survey. These elements are represented at the lowest level of the hierarchy. As an example shown in Table 1, the factors contributing to the deterioration of sewage pipes can be classified as operational, environmental and physical, and each type of classification contains different assessment components.

Table 1: Factors contributing to the deterioration of sewage pipes

Condition Assessment of Sewage pipe			
Level 1	Operational	Environmental	Physical
Level 2	1. Internal Water Volume 2. Leakage 3. Water Quality 4. Flow Velocity 5. Internal Air Pressure Component 6. Operational and Maintenance Practice	7. Pipe Bedding 8. Trench Backfill 9. Soil Type 10. Ground Water 11. Climate 12. Pipe Location 13. Disturbances 14. Seismic Activity	15. Pipe Material 16. Wall Thickness 17. Time to First Installation 18. Pipe Vintage 19. Diameter 20. Type of Joints 21. Thrust restraint 22. Pipe Lining & Coating 23. Dissimilar Material 24. Pipe Installation 25. Pipe Manufacture

2. *Formation of Comparison Matrix*. Comparison matrices A (p,q) for each level p and classification group q are established, with the matrix elements a_{ij} assigned based on their

relative importance. For the number of elements of a comparison matrix A equal n, the dimension of the matrix will be n×n, where

$A = (a_{ij})_{n\times n}$, $a_{ij} > 0$; $a_{ij} = 1/a_{ji}$; and $a_{ii} = 1$

Use Table 1 as an example, Level 1 has one classification group, i.e. operational, environmental and physical, thereof p=1, q=1, and only one comparison matrix is formed. Level 2 has three classification groups, therefore, p=2, q=3. Therefore, level two has three comparison matrices. Table 2 illustrates the comparison matrix established for Level 1

Table 2: An illustrate data collection matrix

	Operational	Environmental	Physical
Operational	1	1/a	1/b
Environmental	a	1	1/c
Physical	b	c	1

The general expression for matrix A with n components $A_1,\ldots, A_n$ and the corresponding weights, $w = (w_1,\ldots,w_n)$ is

$$A = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & \vdots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix}$$

Each pair is evaluated with the question, "which option - Operational factor or Environmental factor or Physical factor - is more important in affecting the condition assessment?" to provide a numerical judgement in making such pairwise comparisons, a workable scale is needed. The 9-point scale used in typical analytic hierarchy studies adopted in this project is illustrated in Table 3.

Table 3: Scale of pair-wise comparison

Scale for indication of relative importance	Level of Importance	Explanation
1	Equal importance	Two activities contribute equally to the objective.
3	Weak importance of one over another	Experience and judgement slightly favour one activity over another.

5	Essential or strong importance	Experience and judgement strongly favour one activity over another.
7	Demonstrated importance	An activity is strongly favoured and its dominance is demonstrated in practice.
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation.
2, 4, 6, 8	Intermediate values between the two adjacent judgements	When compromise is needed.
Reciprocals of above nonzero	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*.	

3. *Consistency ratio test.* Consistency is the indication of the relation between the entries of *A*: $a_{ij}/a_{jk}=a_{ik}$, which means that if we have *n* entries that form a spanning tree, the remainder of the matrix can then be generated from them. With matrix A has the maximum eigenvalue λ_{max}, the formula $(\lambda_{max}-n)/(n-1)$ serves as a Consistency Index (CI) indicating the departure from consistency in estimating the ratio w_i/w_j. Consistency is achieved if and only if $\lambda_{max} = n$. The CI is compared with what it would be if the numerical judgements were taken at random from the scale 1/9, 1/8, 1/7, …, 1/2, 1,2,…,9; represented by the Random Consistency Index (RI). (Saaty and Mariano) concluded that the Consistency Ratio (CR) value less than 0.1 is considered to be highly consistent. When the CR is poor, the reformulation of matrix A is needed. The calculations of CI and CR are shown below. The RI table for different n values is shown in Table 4.

$$CR = \frac{CI}{RI},\ \ CI = \frac{\lambda_{\max} - n}{n-1}$$

4. *Calculation of weighting vectors*. In order to assign the weight to each assessment elements under different levels in the hierarchy, the determination of the weighting vector W_i for the classification group (p,q) is required. There are a number of ways in determining W_i. In our algorithm the row averaging standardization method is adopted as follow:

$$W_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}, \qquad i, j = 1,2,...n$$

Table 4: Random Consistency Index (RI) values for different values of *n*.

n	1	2	3	4	5	6	7	8	9	10	11
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

A numerical example is used below to show this AHP based weight determination approch.

Level 1: Comparison matrix for operational, environmental and physical factors

Formation of matrix A

	Operational	Environmental	Physical
Operational	1	3	6
Environmental	1/3	1	3
Physical	1/6	1/3	1

Summation of each column of elements

	Operational	Environmental	Physical
Operational	1.00	3.00	6.00
Environmental	0.33	1.00	3.00
Physical	0.17	0.33	1.00
(sum)	1.50	4.33	10.00

Standardization of each element

	Operational	Environmental	Physical
Operational	0.67	0.69	0.60
Environmental	0.22	0.23	0.30
Physical	0.11	0.08	0.10

Final calculation of weight

	Operational	Weight
Operational	(0.67+0.69+0.60)/3	= 0.653
Environmental	(0.22+0.23+0.30)/3	= 0.250
Physical	(0.11+0.08+0.10)/3	= 0.097

Same procedure is used for calculating the weights of L2: Operational, Environmental and Physical assessment components:

Level 2 : Comparison matrix and computed weight for “Operational” factors

	O1	O2	O3	O4	O5	O6	Weight
O1	1.00	0.11	0.33	1.00	0.20	0.14	0.034
O2	9.00	1.00	7.00	9.00	5.00	3.00	0.462
O3	3.00	0.14	1.00	3.00	0.33	0.20	0.073
O4	1.00	0.11	0.33	1.00	0.20	0.14	0.034
O5	5.00	0.20	3.00	5.00	1.00	0.33	0.140
O6	7.00	0.33	5.00	7.00	3.00	1.00	0.255

O1: internal water volume, O2: leakage, O3: water quality, O4: flow velocity;
O5: internal air pressure, O6: operational maintenance practice.

Level 2: Comparison matrix and computed weight for "Environmental" factors

	E1	E2	E3	E4	E5	E6	E7	E8	Weight
E1	1.00	1.00	0.33	1.00	1.00	0.20	0.33	0.11	0.037
E2	1.00	1.00	0.33	1.00	1.00	0.20	0.33	0.11	0.037
E3	3.00	3.00	1.00	3.00	3.00	0.33	1.00	0.17	0.097
E4	1.00	1.00	0.33	1.00	1.00	0.20	0.33	0.11	0.037
E5	1.00	1.00	0.33	1.00	1.00	0.20	0.33	0.11	0.037
E6	5.00	5.00	3.00	5.00	5.00	1.00	3.00	0.14	0.185
E7	3.00	3.00	1.00	3.00	3.00	0.33	1.00	0.14	0.095
E8	9.00	9.00	6.00	9.00	9.00	7.00	7.00	1.00	0.472

E1: pipe bedding, E2: trench backfill, E3: soil type, E4: ground water, E5: climate;
E6: pipe location, E7: disturbances, E8: seismic activities.

Level 2: Comparison matrix and computed weight for "Physical" factors

	P1	P2	P3	P4	P5	P7	P8	P9	P10	P11	Weight
P1	1.00	1.00	0.33	0.33	1.00	0.20	0.20	1.00	1.00	1.00	0.042
P2	1.00	1.00	0.33	0.33	1.00	0.20	0.20	1.00	1.00	1.00	0.042
P3	3.00	3.00	1.00	1.00	3.00	0.33	0.33	3.00	3.00	3.00	0.114
P4	1.00	3.00	1.00	1.00	3.00	0.33	0.33	3.00	3.00	3.00	0.114
P5	1.00	1.00	0.33	0.33	1.00	0.20	0.20	1.00	1.00	1.00	0.042
P6	5.00	1.00	0.33	0.33	1.00	0.20	0.20	1.00	1.00	1.00	0.042
P7	5.00	5.00	3.00	3.00	5.00	1.00	1.00	5.00	5.00	5.00	0.233
P8	1.00	5.00	3.00	3.00	5.00	1.00	1.00	5.00	5.00	5.00	0.233
P9	1.00	1.00	0.33	0.33	1.00	0.20	0.20	1.00	5.00	1.00	0.055
P10	1.00	1.00	0.33	0.33	1.00	0.20	0.20	1.00	1.00	1.00	0.042
P11	1.00	1.00	0.33	0.33	1.00	0.20	0.20	1.00	1.00	1.00	0.042

P1: pipe material, P2: wall thickness, P3: time to first installation (pipe age);
P4: pipe vintage, P5: diameter, P6: type of joints, P7: thrust restraint;
P8: pipe lining and coating, P9: dissimilar material, P10: pipe installation;
P11: pipe manufacture.

Matrix	Eigen value (λ_{max})	CI	RI	CR
Level 1	3.018	0.0092	0.58	0.016
Level 2: O1-O6	5.317	-0.1366	1.24	-0.110
Level 2: E1-E8	8.283	0.0404	1.41	0.029
Level 2: P1-P11	11.440	0.0440	1.51	0.029

The above consistency test shows the overall design is acceptable except for L2:O1-O6 that is slightly deviated from the acceptable threshold may need fine-tuning. By using this result, the final weight to be used for UHI calculation can be determined as shown in the following example. The final weight for the leakage (O2) under “operational” is 0.462×65.3% =30.2%, or 0.302.

Overall Objective	Level 1 : Criteria	Weight (%)	Level 2 : Sub-criteria	Final Weight (%)
Condition Assessment of Sewage pipe and Grade them by Utility Health Index	Operational	65.30%	Internal Water Volume	2.24%
			Leakage	30.20%
			Water Quality	4.81%
			Flow Velocity	2.24%
			Internal Air Pressure Component	9.16%
			Operational & Maintenance Practice	16.65%
	Environmental	25.10%	Pipe Bedding	0.94%
			Trench Backfill	0.94%
			Soil Type	2.44%
			Ground Water	0.94%
			Climate	0.94%
			Pipe Location	4.65%
			Disturbances	2.41%
			Seismic Activity	11.85%
	Physical	9.60%	Pipe Material	0.40%
			Wall Thickness	0.40%
			Time to First Installation (pipe age)	1.09%
			Pipe Vintage	1.09%
			Diameter	0.40%
			Type of Joints	0.40%
			Thrust restraint	2.24%
			Pipe Lining & Coating	2.24%
			Dissimilar Material	0.53%
			Pipe Installation	0.40%
			Pipe Manufacture	0.40%
Total				100%

THE UML BASED EXPERT SYSTEM

Regarding the software development of the expert system, it is developed with the license free open sources as listed below.

	Software
Web Server:	Tomcat 7.0
Database:	PostgreSQL 9.0
Spatial DB:	PostGIS 1.5
Map:	Microsoft Bing Map
Geospatial Server:	GeoServer 2.1.3
Programming Language:	Java+JSP

Data Structure Design of Condition Survey Results

Figure 2 shows the UML diagram of the observation data model. This data model is designed based on the Hong Kong Conduit Condition Evaluation Codes 2009 (HKCCEC 2009), which is widely used in Hong Kong for underground pipeline's inspecting projects. In HKCCEC, there are three mandatory elements that an inspection report should contain: a) written and the computerized operator's report detailing the observations; b) A video record of the entire inspection; c) Photographs of features of interest . Therefore, three objects are used to represent the three assessment elements of *Photograph*, *Video* and *Report*. The *Photograph* object contains a byte stream which is used to represent the image, as well as other attributes that describe it. Because the video and report are submitted in the format of avi or pdf respectively, so we only store the file's path in the object of Video or Report, while the original file is stored in the local disk of the server. In order to facilitate the management and query, the model applies a hierarchical structure. The *Record* object is designed to aggregate all the inspecting data of a pipeline between two manholes. This object not only contains related information of a pipeline such as the diameter, installation date, age and so on, but also holds three collections that contain the pointers linking to the objects of *Photograph*, *Video* and *Report*. Generally, the inspecting operators will make a plan before the inspection. They will define a survey region based on the contract. So the highest object in the hierarchical structure is *Project*. Each project has an attribute of *project_no* for identification and a *date*, *location* for spatio-temporal series.

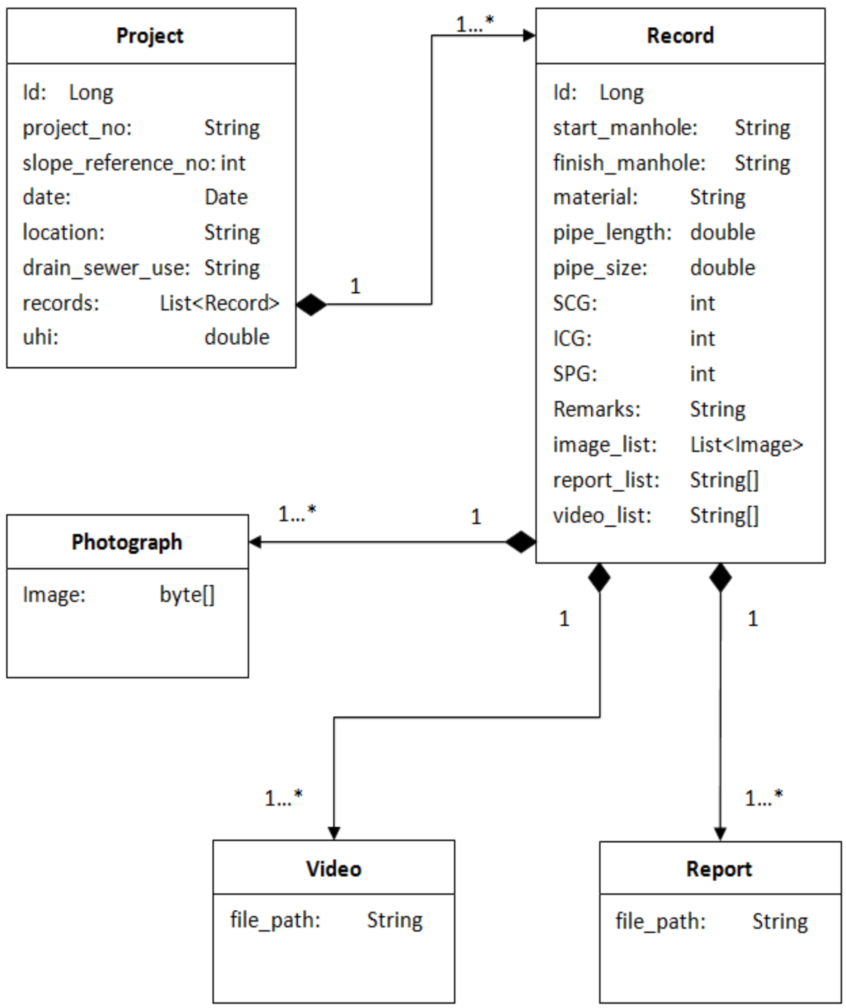

Figure 2. UML diagram of health assessment data model.

Design of the Dynamic AHP Multi-Tree Structure

The core component of the self-improving utilities management system is the development of UHI, which is derived based on a set of rules and conditions about the phenomena indicating the healthy condition of specific type of utility. As shown in Table 1, a series of factors affecting final determination of UHI are weighted by using the AHP algorithm. In order to facilitate the operation of affecting factors in AHP, such as adding and removing factors, adjusting pair-wise comparison matrices and meanwhile updating each factor’s weight, a special data structure, which is called Dynamic AHP Multi-Tree (DAMT), is designed and implemented to represent the overall AHP structure. An example of DAMT structure is shown in Figure 3.

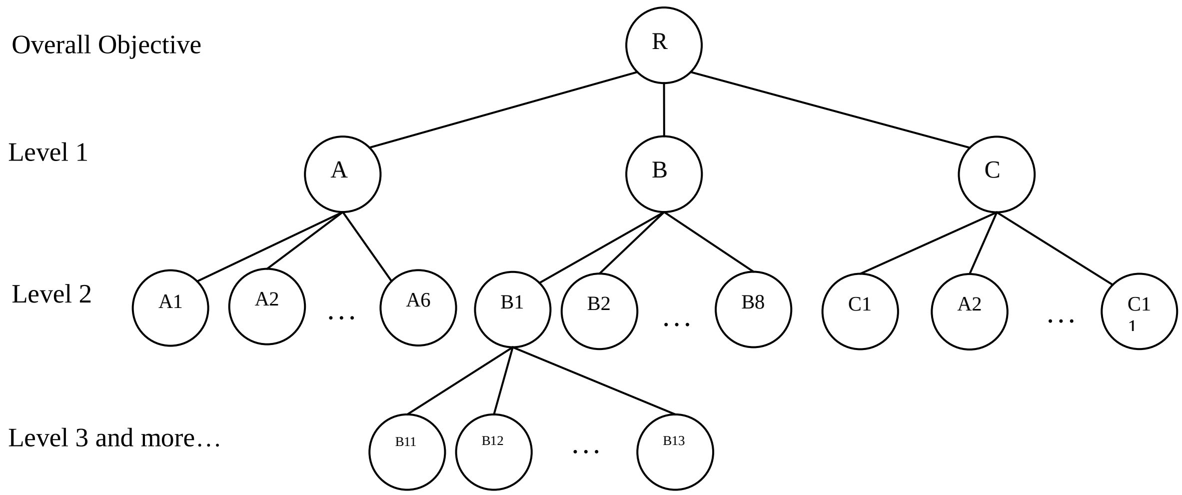

Figure 3. An example of DAMT tree structure.

In DAMT, each factor is represented by an entity called *Node* that owns related attributes such as ID, name, weight and level. A Node holds a collection of references which points to its *children* and a reference of its *parent*, and the overall objective. Moreover, in order to facilitate the calculation of the weights of its children, the *Node* holds a two-dimension array which records the pair-wise comparison matrix. Figure 4 illustrates a Node's structure in UML and its relationship with its parent and children.

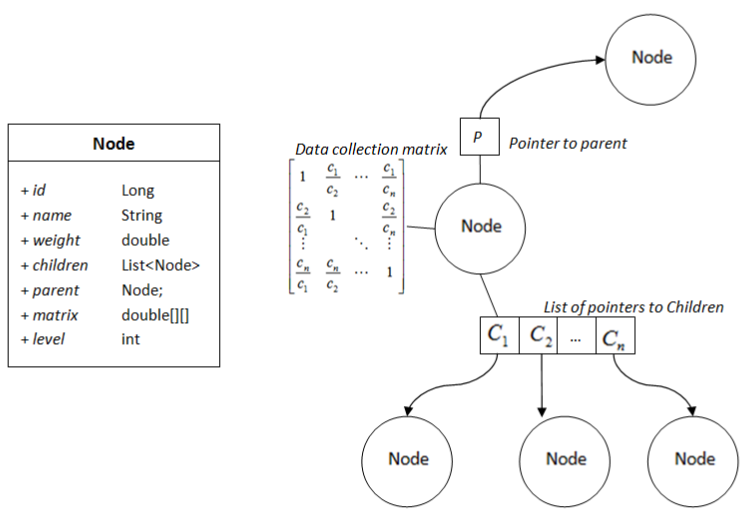

Figure 4. UML structure of a node and its relationship with its parent and children.

The DAMT Editing Structure

1. Add Factor

   Because every factor holds a pair-wise comparison matrix, even though the matrix may be empty (leaf node), it is necessary to update both the collection of children and matrix when we need to add or delete a *Node* of DAMT (refer to Figure 5).

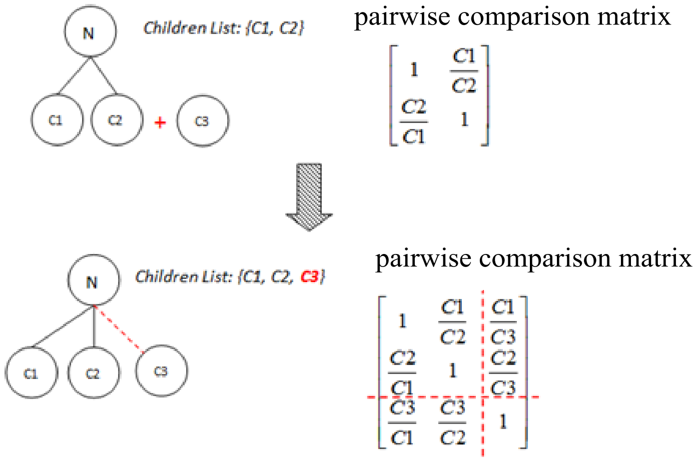

Figure 5. Illustration of addition and removal of nodes.

2. Delete Factor

The Delete operation is similar to Add operation, that both the Children List and Matrix are needed to update when the node is removed. The matrix is a two-dimensional array of which elements are allocated according to the sequence of the children list. Once a node is removed, the index of this node needs to be identified for deleting the corresponding rows and columns of the matrix. Figure 6 on the removal of the child C2 is used as an example. Firstly, C2 is removed from N's children list. Secondly, C2's index in the children list is identified as 2. Finally, all elements belonging to the second row and second column are deleted.

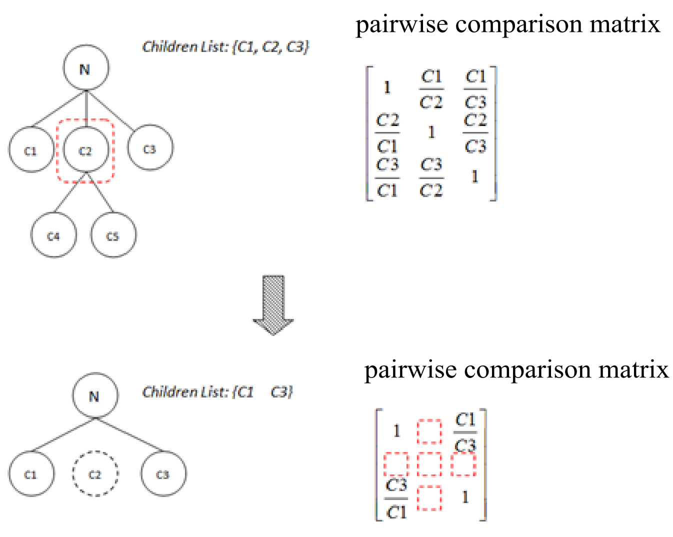

Figure 6. Removal of the matrix elements of node C2.

3. Update Factor
   When the pair-wise comparison matrix of a *Node* needs to be adjusted, there is no need to change the DAMT's structure. It is only required to change the value of the corresponding elements in the matrix.

4. Traversal
   In processing the UHI, all the nodes in DAMT need to be traced. A computer algorithm called Traversal is needed to process the above operations. Tree Traversal is used for tracing the nodes of a tree hierarchy in a specified order. Each node is processed only once (although it may be visited more than once). Traversal is like searching except that Traversal is used to move through all the nodes in the tree in some particular orders but the searching process ceases when the required node is found. The programming method for Traversal is shown in Figure 7.

Algorithm: Traversal

```
Initialize:  AHP_tree    //an AHP tree which contains all the factors and corresponding weight;
Initialize:  Stack       // a Stack which used to store the nodes of the AHP tree;
Root ← AHP_tree.getRoot()
Stack.push(Root)
while Stack is not NULL
    Node ← Stack.pop()
    if Node has children
        Collection<Node> ← Node.children
        for all Node_child ∈ Collection<Node>
            Stack.push(Node_child)
        end for
    else
        process(Node)
    end if
end while
```

Figure 7. The programming method for Traversal.

Integration of DAMT into the Expert System

DAMT is saved in a XML-based configuration file (refer to Fig. 8) that describes a DAMT instance in a structured way. The file records the name, matrix, children list of a node. Figure 8 shows the structure of the DAMT configuration file. A special component called *AHP Engine* is designed to facilitate the system to manage DAMT and coordinate its inter-operation with the whole self-improving expert system. The AHP Engine can read the DAMT configuration file and automatically transform it into an Object-Oriented structure which can integrate with the expert system based UML. It also includes DAMT editing operations such as addition, deletion, updating, checking and traversing the nodes. Figure 9 illustrates the architecture of the AHP engine. When the specialists access the server, the *AHP Engine* will first read the configuration file and initialise the DAMT, including the calculation of weight for each factor. It will then gather all the specialists' comments and scores for the considering factors, and notify the specialists which factors have not been assessed. After all the affecting factors have been scored, the AHP Engine will calculate the UHI value and submit it to server for further processing.


```
- <node name="AHP">
  - <matrix>
      {{1, 3, 6}, {0.333, 1, 3}, {0.17, 0.33, 1}}
    </matrix>
  - <chidren>
    - <node name="Operational">
      - <matrix>
          { {1, 0.11, 0.3333, 1, 0.2, 0.14}, {9, 1, 7, 9, 5, 3}, {3, 0.14, 1, 3, 0.3333, 0.2}, {1, 0.11, 0.33, 1, 0.2, 0.14},
          {5, 0.2, 3, 5, 1, 0.3333}, {7, 0.3333, 5, 7, 3, 1} }
        </matrix>
      - <children>
          <node name="Internal Water Volume"/>
          <node name="Leakage"/>
          <node name=" Quality"/>
          <node name="Flow Velocity"/>
          <node name="Internal Air Pressure Component"/>
          <node name="Operational and Maintenance Practice"/>
        </children>
      </node>
    - <node name="Environmental">
      - <matrix>
          { {1, 1, 0.33, 1, 1, 0.2, 0.33, 0.11}, {1, 1, 0.33, 1, 1, 0.2, 0.33, 0.11}, {3, 3, 1, 3, 3, 0.33, 1, 0.17}, {1, 1,
          0.33, 1, 1, 0.2, 0.33, 0.11}, {1, 1, 0.33, 1, 1, 0.2, 0.33, 0.11}, {5, 5, 3, 5, 5, 1, 3, 0.14}, {3, 3, 1, 3, 3, 0.33,
          1, 0.14}, {9, 9, 6, 9, 9, 7, 7, 1}}
        </matrix>
      - <children>
          <node name="Pipe Bedding"/>
          <node name="Trench Backfill"/>
          <node name="Soil Type"/>
          <node name="Ground Water"/>
          <node name="Climate"/>
          <node name="Pipe Location"/>
          <node name="Disturbances"/>
          <node name="Seismic Activity"/>
        </children>
      </node>
    - <node name="Physical">
      - <matrix>
          { {1, 1, 0.33, 0.33, 1, 1, 0.2, 0.2, 1, 1, 1}, {1, 1, 0.33, 0.33, 1, 1, 0.2, 0.2, 1, 1, 1}, {3, 3, 1, 1, 3, 3, 0.33,
          0.33, 3, 3, 3}, {3, 3, 1, 1, 3, 3, 0.33, 0.33, 3, 3, 3}, {1, 1, 0.33, 0.33, 1, 1, 0.2, 0.2, 1, 1, 1}, {1, 1, 0.33,
          0.33, 1, 1, 0.2, 0.2, 1, 1, 1}, {5, 5, 3, 3, 5, 5, 1, 1, 5, 5, 5}, {5, 5, 3, 3, 5, 5, 1, 1, 5, 5, 5}, {1, 1, 0.33,
          0.33, 1, 1, 0.2, 0.2, 1, 5, 1}, {1, 1, 0.33, 0.33, 1, 1, 0.2, 0.2, 1, 1, 1}, {1, 1, 0.33, 0.33, 1, 1, 0.2, 0.2, 1, 1,
          1}}
        </matrix>
      - <children>
          <node name="Pipe Material"/>
          <node name="Wall Thickness"/>
          <node name="Time to First Installation"/>
          <node name="Pipe Vintage"/>
          <node name="Diameter"/>
          <node name="Type of Joints"/>
          <node name="Thrust Restraint"/>
          <node name="Pipe Lining and Coating"/>
          <node name="Dissimilar Material"/>
          <node name="Pipe Installation"/>
          <node name="Pipe Manufacture"/>
        </children>
      </node>
    </chidren>
  </node>
```


Figure 8: Structure of a DAMT configuration file.

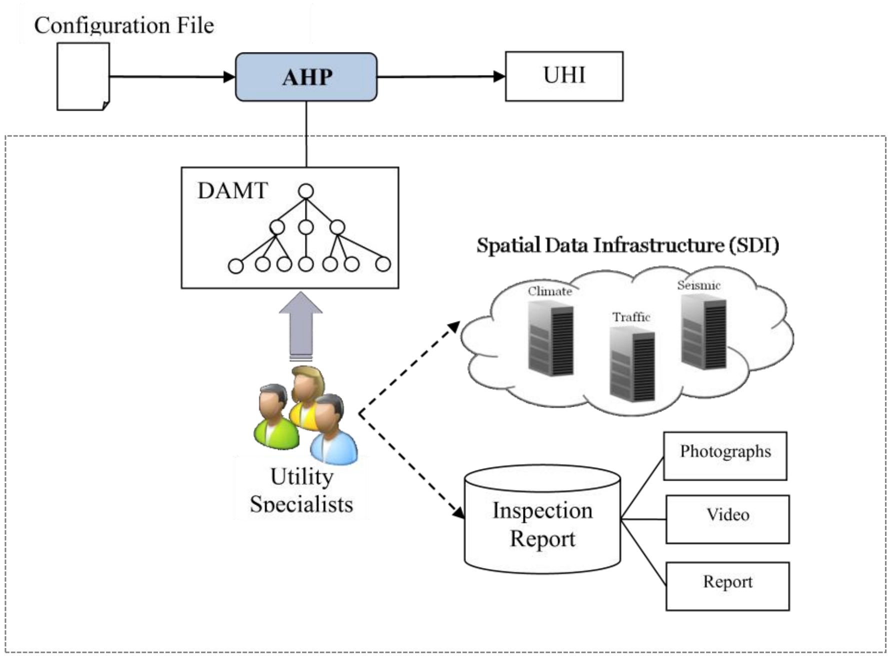

Figure 9: Architecture of the AHP engine.

CONCLUSIONS

The UML based expert system incorporating the AHP based UHI for indicating the overall health condition of the pipes under inspection, and capable of continuously improving the UHI based on experts' advice on cases with fuzzy results is believed to be the first development in the Asian Region, and in the world. Assessing the overall health condition of underground utilities is important for designing appropriate and effective maintenance plans to sustain the cost-effective urbanization development. The condition survey results of underground utilities can be largely classified into qualitative and quantitative information. Quantitative results such as current measurement and soil corrosivity are numerical data. Qualitative results are descriptions based on on-site observations and interpretation of visual records. The mixture of different quantitative and qualitative condition survey results contributing to the overall assessment of underground utilities makes the development of a reliable UHI much more challenging, since qualitative assessments are largely based on experience. Subjective interpretation of peculiar cases may lead to different opinions that would affect reliability of the assessment. In this research, a AHP algorithm is developed to determine the relative importance of each quantitative or qualitative assessment component contributing to overall health condition, leading to the development of a representative UHI with support of scientific theory. Moreover, the UML based expert system is able to disseminate the uncertain cases for assessment by different experts, for the generation of UHIs based on collective wisdom of experts. The continuous monitoring of the UHI profile of the pipe network would greatly help the profession to consider necessary precaution measures and design suitable maintenance logistics. Moreover, the DAMT structure in the system has the flexibility of adding, deleting and changing the database structure of the assessment components for UHI development, hence the system can be easily set up to cater for the assessment methods and standards adopted in different particular cities, regions and countries.

ACKNOWLEDGEMENT:

This research is fully supported by the Hong Kong Polytechnic University Research Fund 1-ZV4U, Investigation of a Self-improving System to Facilitate the Continuous Process of Management, Inspection and Health Monitoring of Underground Utilities.

REFERENCES

1. Mok, E., Chen, W., Shea, G., et.al., 2010. “A Self-improving System to Facilitate the Continuous Process of Health Monitoring of Sewage Pipes in Hong Kong”. Proceedings, First International Conference on Sustainable Urbanization, 15-17 December 2010, Hong Kong.
2. Mok, E., Wong, K., Zhai, G.N., 2011. “Analytic Hierarchy Process Method for Utility Health Index Development”. Proceedings, The 2nd International Conference on Utility Management and Safety, 7-8 March 2011, Hong Kong.
3. Saaty, T.L. (1979). “Rationing Energy to Industries: Priorities and Input-output dependence”. Energy Systems and Policy.
4. Saaty, T.L. (1980). “The Analytic Hierarchy Process”. McGraw-Hill, New York.