Chapter 7

Novel Decision Support System for Power Distribution Network Asset Management

Decision occurs in people’s everyday lives. They all have concerns for which they have to make decisions and there being very often the case that they will ask help in order to do so, from a good friend, a counselor, or an expert in “something” before making up their mind and do something. In a very simple task like buying a chocolate, people just do a simple cost-benefit analysis by weighing the benefits they will get, e.g., their own satisfactory against the money they have to spend. However, very often that the real-life problems are not such simple, people have to make their decision based on many associated criteria and constraints.

Asset management discipline involves significantly with making a decision on asset spending, i.e. the distribution feeder rehabilitation. That is what investment option that utility shall adopt in order to offer the most benefits to all of its stakeholders. On the other hand, an asset management is a process of making an asset related decision based on the information available to a decision maker. In making such a decision, two main things that asset manager has to consider: what investment option should he select and based on what criteria. Chapter 4 of the thesis has discussed on the knowledge representation of distribution network asset and these information would be later used for determining the risk of feeder failure and its associated costs. The employment of fuzzy logic and Markov chain for quantifying the percentage of feeder failure possibility has been proposed and thoroughly examined in chapter 5. To make the investment option comparable, chapter 6 has investigated the concerning costs in case of feeder failure as well as the costs of preventive measures. The feeder failure possibility previous obtained would be transformed into monetary value while the costs of preventive measures (investment options) have also been quantified. To make a final decision however, not only the cost components are considered, but also another criterion. The main objective of the thesis is to develop the decision support system (DSS) to assist the asset manager in decision making on feeder rehabilitation investment, this chapter will consolidate all the frameworks discussed in the previous chapters and assemble the decision support tool. The technique employed for evaluating the investment alternatives against the preset criteria is the Analytic Hierarchy Process (AHP) which is considered very effective for the qualitative assessment problems of infrastructure investment decision.

DSS is a class of computerized information system that supports decision-making activities. DSS are interactive computer-based systems and subsystems intended to help decision makers use information technologies, data, documents, knowledge and/or models to complete decision process tasks. DSS exists to help people make decision. DSS do not make decision by themselves but attempt to automate several tasks of the decision-making process of which modeling is the core.

This chapter will discuss particularly on the decision support system that is proposed from the research study. However, the principles and methodologies behind the DSS were already addressed in the previous chapter, so this chapter will go right into the architecture and demonstrative example of the proposed system. It should be, however, noted hereby that this thesis does not intend to offer the full range of computerized decision support tool application; it rather recommends the framework for implementing such decision support tool. The data recording/retrieval and computation are thus done manually in order to show the applicability and effectiveness of the proposed framework. Another key point that should be also noted is that DSS does not make any decision on its own; rather it provides all necessary information and knowledge required for making a decision. The final decision making has to be performed by concerned people, i.e. asset managers.

7.1 Chapter Overview

The chapter starts with the discussion of the requirement for distribution network investment; why the distribution network needs to be reinforced. Then the chapter turns to the principle of multicriteria decision analysis in general; followed by thoroughly discussion of AHP in particular, in order to demonstrate its effectiveness in dealing with the problems on multicriteria decision making. Since all the methodologies and techniques discussed in previous chapters will be integrated to form a decision support system, so the chapter turns to the explanation of the architecture of the proposed DSS. After that the simulation to verify the applicability of the system is performed by attempting to determine the possibility of failure on the simulated feeder; followed by the determination of financial impact in case of feeder failure; and then brought into a multicriteria decision analysis process. The results and issues occurred from the simulation will then be discussed in the last section.

7.2 Requirement for Distribution Network Investment

In chapter 2, all the issues related to asset management were discussed. The most prominent aspects in asset management decision include cost, risk and performance. The issues associated with cost and risk had also been thoroughly addressed in chapter 5 and 6. When come to making a decision of asset manager, not only these two aspects are examined but also the others. What utility asset managers usually consider when they are making decisions on asset related spending. Let first take a look on what are the objectives that utility want to achieve in managing its utility infrastructure especially in electric power utility business. The Electric Power Research Institute (EPRI) has published guidebooks [134, 138] for utility line inspection and assessment which indicate a number of goals for performing power line formal inspection program. The goals include:

- Protection of the public interest
- Protection of utility personnel
- Increased service reliability

- Improved economics through calculated maintenance and capital improvements
- Code and regulatory compliance
- Environmental aspects.

This is in conformity with the study of CIGRE Working Group which addresses the value and criteria for investment decision that have been employed by utility through investigative studies of Working Group on investment decision processes and investment selection criteria which include [3]:

- Performance
- Safety
- Reliability
- Flexibility
- Capacity
- Customer importance
- Environmental pressure
- Legal implications
- Integration
- Maintainability
- Quality of supply
- Importance of plant
- Risk and consequences
- Physical condition
- Return on capital employed
- Life cycle cost
- Operational costs
- Capital costs
- Obsolescence
- Corporate image
- Sociological impact.
- Importance of plant

All of these objectives/criteria are the statement that reflected the requirements of all stakeholders. Every course of action adopted in managing distribution system assets shall be done in such a way that meets these requirements. For example, if the reliability of network decreases because of network asset physical condition degradation, utility may need to reinforce the system but the reinforcement shall provide suitable return on investment and create minimal adverse impact to social and environment. However, requirements may contradict each other by nature, asset mangers should have means to deal with this contradiction. The rest of this chapter will provide approaches to handle this situation.

7.3 Multiple Criteria Decision Analysis (MCDA)

Before discussing the design and application of the novel DSS, it would be beneficial to uncover the principle decision making theory especially the multiple criteria decision making process. The usual method to evaluating the candidate projects for making an investment decision is to value each project into monetary term and select the most economic option in terms of money value. The criterion for selection is straightforward but the transformation of each governing criterion into monetary value might be a problem. For example, how the decision maker should generate the money value of technical difficulties, people safety, or city aesthetics is still be a question awaiting the answers. So this thesis offers the methods to tackle these obstacles by establishing the novel DSS to help the decision maker to handle the multiple criteria decision making problem, particularly the distribution feeder rehabilitation investment.

A decision is an allocation of resources [159]. Reference [160] suggests the definitions into twofold: the study of identifying and choosing alternatives based on the values and preferences of the decision maker, and the process of sufficiently reducing uncertainty and doubt about alternatives to allow a reasonable choice to be made from among them. Essentially, decision making [161] is the cognitive process of selecting a course of action from among multiple alternatives. Every decision-making process produces a final choice. It can be an action or an opinion. It begins when people need to do something but they do not know what to do. Therefore decision-making is a reasoning process which can be rational or irrational, and can be based on explicit assumptions or tacit assumptions.

Alternatively, decision making is the study of identifying and choosing alternatives based on the values and preference of the decision maker. Making a decision implies that there are alternative choices to be considered, and in such a case not only to identify as many of these alternatives as possible are required but to choose the one that best fits with intended goals, desires, values, and so on. Hence, decision making is the process of sufficiently reducing uncertainty and doubt about alternatives to allow a reasonable choice to be made from among them. This definition stresses the information gathering function of decision making. It should be noted that uncertainty is reduced rather than eliminated. Very few decisions are made with absolute certainty because complete knowledge about all the alternatives is seldom possible. Thus, every decision involves a certain amount of risk.

7.3.1 Concept of Multicriteria Decision Making

Multi-criteria decision making (MCDM) is the study of methods and procedures by which concerns about multiple conflicting criteria can be formally incorporated into the management planning process. It helps identify the ultimate goal, subgoals or criteria, and alternative choices and then systemically rank the alternatives with regards to the criteria governed. Moreover, if it is to be more than one stakeholder involved in decision making, MCDM helps compromise the preferences or expectations of stakeholders. By using knowledge elicitation techniques, it will help people form and express preferences in terms suited to the decision problem. Elicited preferences, and thus weights, would then be more stable and coherent because they have been arrived through informed and well considered value judgments [162].

There are a number of techniques that decision makers can select to apply in their domain problem, depending on type of problems and stakeholders' concerns. Apart from a prevalent cost-benefit analysis method, the available techniques can range an elementary one, such as *pros and cons analysis, maximin and minimax methods, conjucntive and disjunctive methods,* or *lexicographic method*; to a complex multi attribute utility theory, such as *simple multiattribute rating technique, generalized means*, or *The Analytical Hierarchy Process (AHP)* and an outranking methods, such as *The ELECTRE method*, or *The PROMETHEE method* [163].

MCDA has undergone an impressive development during the last 30 years, in part because it is amenable to handling today's complex problems, in which the level of conflict between multiple evaluation axes is such that intuitive solutions are not satisfactory. MCDA is not a tool providing the 'right' solution in a decision problem, since no such solution exists. The solution provided might be considered best only for the stakeholders who provided their values in the form of weighting factors, while other stakeholders' values may indicate another alternative solution. Instead, it is an aid to decision-making that helps stakeholders organize available information, think on the consequences, explore their own wishes and tolerances and minimize the possibility for a post-decision disappointment [164, 165].

7.3.2 General Process of Multicriteria Decision Making

Various MCDA methods are available, suitable for a wide variety of decision situations. Furthermore, several weighting techniques have been developed to help stakeholders involved in a MCDA procedure become aware and articulate their preferences. However, certain structural processes are common to all decision situations; independent of the MCDA method used. These structural processes are briefly described in the following paragraphs [163].

1) Define the problem

Decision making is a kind of problem solving. This process of problem definition must, as a minimum, identify root causes, limiting assumptions, boundaries and interfaces, and any stakeholder issues. The issue to be solved must be made clear; describing both the initial conditions and the desired conditions. The problem statement must however be a concise and unambiguous agreed by all decision makers and stakeholders.

"The conversion of overhead distribution network to underground system" is one example of problem statement.

2) Determine requirements

Requirements are conditions that any acceptable solution to the problem must meet. They explain what the solution to the problem must do. Requirements may be obtained from the desires of stakeholders. These requirements will determine the goals, establish the choices of acceptable solution and formulate the criteria for solution evaluation. In power distribution business, the requirements associated with network asset related decision have been addressed in the previous section. All these requirements will be used to identify the investment solutions and define the set of decision criteria.

From above problem statement, it can be assumed that the solution to the problem is the underground system. So the requirements that stakeholders require may be the underground system with economic cost, high performance, blended to the local environment.

3) Establish goals

Goals are broad statements of intent and desirable values to achieve. Goal may differ to requirement determine in that express the ultimate level to achieve. It goes beyond the minimum essential must have, want or desire. The goals may be conflicting but this is a natural concomitant of practical decision situations. At the end of the day however, there should be one single ultimate goal to achieve.

The goal of above example might be "obtaining the most suitable underground distribution system for the city of Luang Prabang".

4) Identify alternatives

Alternatives offer different approaches for changing the initial condition into the desired condition. Be it an existing one or only constructed in mind, any alternative must meet the requirements. If there are more than one possible alternative, they have to be checked one by one if it meets the requirements. The infeasible ones must be screened out from the further consideration, and finally the explicit list of the alternatives. Upon the checking of each alternative, there must be performed based on the same criteria. Otherwise the outcome will not be practically relied on.

The examples of alternatives for the distribution network undergrounding problem stated above might be: direct buried cable, cable-in-duct installation, conventional substation, or compact unit substation.

5) Define criteria

Criteria provide discrimination among alternatives. It must be based on the goals. It is necessary to define discriminating criteria as objective measures of the goals to measure how well each alternative achieves the goals. Since the goals will be represented in the form of criteria, every goal must generate at least one criterion but complex goals may be represented only by several criteria. It can be helpful to group together criteria into a series of sets that relate to separate and distinguishable components of the overall objective for the decision. This is particularly helpful if the emerging decision structure contains a relatively large number of criteria. Grouping criteria can help the process of checking whether the set of criteria selected is appropriate to the problem, can ease the process of calculating criteria weights in some methods, and can facilitate the emergence of higher level views of the issues. It is a usual way to arrange the groups of criteria, subcriteria, and sub-subcriteria in a tree-structure. In principle, criteria should be

- able to discriminate among the alternatives and to support the comparison of the performance of the alternatives,
- complete to include all goals,
- operational and meaningful,
- non-redundant,
- few in number.

6) Select a decision making tool

There are several tools for solving a decision problem. Some were mention here in the previous section. There is no single tool that can take care of every problem. Each tool may have pros and cons and may fit to different situation or problems. The selection of an appropriate tool is not an easy task and depends on the concrete decision problem, as well as on the objectives of the decision makers. Sometimes ‘the simpler the method, the better” but complex decision problems may require complex methods, as well.

7) Evaluate alternatives against criteria

Every correct method for decision making needs, as input data, the evaluation of the alternatives against the criteria. Depending on the criterion, the assessment may be objective (factual), with respect to some commonly shared and understood scale of measurement (e.g. money) or can be subjective (judgmental), reflecting the subjective assessment of the evaluator. After the evaluations the selected decision making tool can be applied to rank the alternatives or to choose a subset of the most promising alternatives.

8) Validate solutions against problem statement

The alternatives selected by the applied decision making tools have always to be validated against the requirements and goals of the decision problem. It may happen that the decision making tool was misapplied. In complex problems the selected alternatives may also call the attention of the decision makers and stakeholders that further goals or requirements should be added to the decision model.

The process described above offers a very useful guideline to deal with any kind of MCDM problems. It is however too general to apply in practical situation. The following section will offer more concrete method in dealing with MCDM problems which is called AHP.

7.3.3 Analytical Hierarchy Process

Analytical hierarchy process (AHP) is an approach to decision making that involves structuring multiple choice criteria into a hierarchy, assessing the relative importance of these criteria, comparing alternatives for each criterion, and determining an overall ranking of the alternatives [163]. The output is a ranking which is prioritized indicating the overall preference for each of the alternatives.

AHP, developed by Thomas Saaty [166], allows decision makers to model a complex problem in a hierarchical structure showing the relationships of the goal, criteria, subcriteria (if any), and alternatives. Figure 7.1 illustrates hierarchical structure of AHP decision analysis model. Uncertainty and other influencing factors can also be included. AHP enables decision makers to derive ratio scale priorities or weights as opposed to arbitrarily assigning them. In so doing, AHP not only supports decision makers by enabling them to structure complexity and exercise judgment, but also allows them to incorporate both objective and subjective considerations in the decision process. In fact, AHP is composed of several previously existing but unassociated concepts and techniques such as hierarchical structuring of complexity, pairwise comparisons, redundant judgments, an eigenvector method for deriving weights and consistency considerations. Although each of these concepts and techniques were useful in and of themselves, Saaty’s synergistic combination of the concepts and techniques produced a process whose power is indeed far more than the sum of its parts. Another advantage of AHP is that it is designed to handle situations that subjective personal preference assignment is allowed. This subjective judgment of individuals constitutes an important part of the decision process.

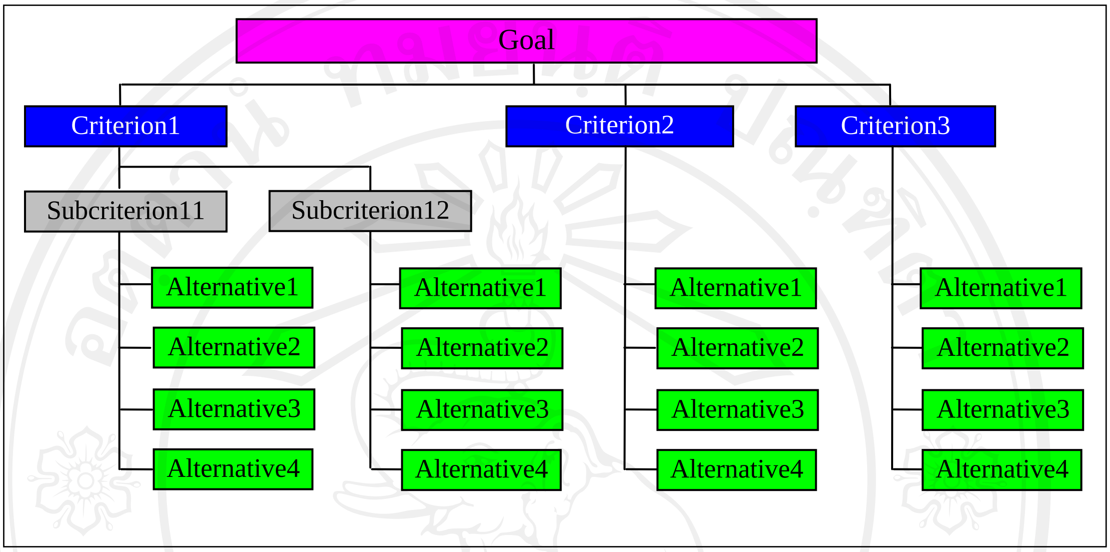


Figure 7.1 The hierarchical structure of AHP decision model

The decision analysis process in AHP involves with the pair-wise comparison of alternatives, comparison matrix, priority vector and consistency. The procedure of employing AHP in facilitating the multicriteria decision making can be described as follows [166, 167, 168, 169, 170].

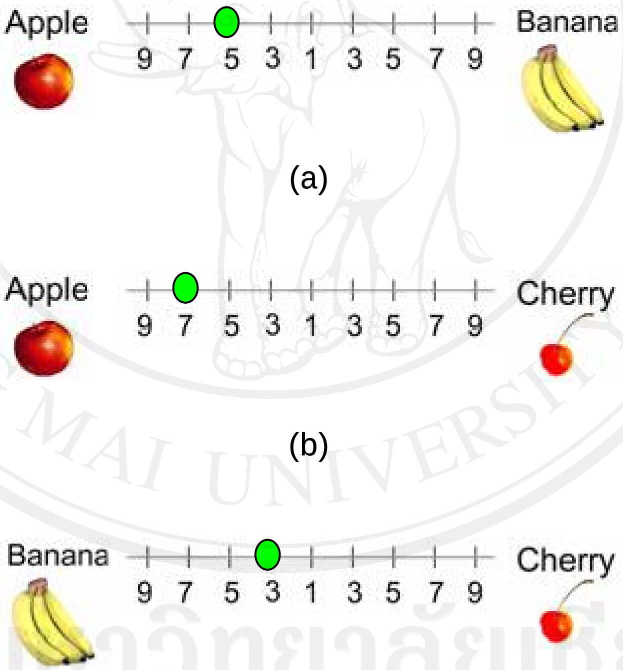
7.3.3.1 Pair-wise Comparison

Table 7.1 Numerical rating and verbal preference

Numerical Scale	Verbal Importance	Explanation
1	Equal importance	Two activities contribute equally to the object
3	Moderate importance	Slightly favors one over another
5	Essential or strong importance	Strongly favors one over another
7	Demonstrated importance	Dominance of the demonstrated in practice
9	Extreme importance	Evidence favoring one over another of highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is needed

Although there are a number of criteria and alternatives in MCDM problems to be compared but AHP allows only two (pair) of them to be made at a time. This is where a term pair-wise comparison is from. Furthermore, AHP provides the numerical rating for decision makers to express their preference of one thing over another. This allows the decision makers to easily translate their subjective opinion into a numerical representation which in turns offer the feasibility for further numerical computation. Table 7.1 indicate those numerical rating and its explanation

The application of numerical rating to perform pair-wise comparison of criteria and alternatives may be intuitively explained by using the following example. Let say there are three kinds of fruits that we would to indicate our preference. In this example, if the evaluator puts a mark on number "5" of the left side of figure 7.2 (a) it means that they strongly have a favor on apple over a banana. It can be done the same way with the other pairs by just expressing the evaluator's preference of one kind of fruit over another in numerical term.



(a)

(b)

(c)

Figure 7.2 Pair-wise comparison of three fruits [170]

The number of comparisons is a combination of the number of things to be compared. In the above example, there are 3 objects (Apple, Banana and Cheery), so there are 3 comparisons. Table 7.2 below shows the number of comparisons.

Table 7.2 Number of alternatives and comparison

Number of things	1	2	3	4	5	6	7	n
Number of comparison	0	1	3	6	10	15	21	$\frac{n(n-1)}{2}$

7.3.3.2 Comparison Matrix

The pair-wise comparison of *n* alternatives can be formed as a square matrix with dimension of *n*. The number located in any element a_{ij} indicates the relative preference of decision maker on alternative *j* as compared to alternative *i*. The elements in diagonal are a comparison of an alternative with itself and must be equal to 1. As stated before the number allowed for assigning to a_{ij} is 1-9 and conversely a_{ji} must be equal to $1/a_{ij}$. The pairwise comparison matrix formation can be explained by the table 7.3 below.

Table 7.3 Formation of comparison matrix

	Criterion (Alternative) 1	Criterion (Alternative) 2	Criterion (Alternative) 3	…..	Criterion (Alternative) *n*
Criterion (Alternative) 1	1	a_{12}	a_{13}	…	a_{1n}
Criterion (Alternative) 2	a_{21}	1	a_{23}	…	a_{2n}
Criterion (Alternative) 3	a_{31}	a_{31}	1	…	a_{3n}
…..	…	…	…	1	…
Criterion (Alternative) *n*	a_{n1}	a_{n2}	a_{n3}	…	1

To gain more understanding, let try an example of pair-wise comparison of fruits from above. Because there are three comparisons, thus a 3 by 3 matrix is to be formed. The diagonal elements of the matrix are always 1 and the evaluators only need to fill up the upper triangular matrix. How to fill up the upper triangular matrix is using the following rules:

- If the judgment value is on the left side of 1 (figure 7.2), then put the actual *judgment* value.
- If the judgment value is on the right side of 1 (figure 7.2), then put the *reciprocal* value.

In comparing apple and banana, if an apple is strongly favored, then put 5 in the row 1 column 2 of the matrix. If comparing apple and cherry and apple is dominant, then put actual judgment 7 on the first row, last column of the matrix. Comparing banana and cherry and banana is slightly favored then put actual judgment of 3 on the second row, last column of the matrix. Then based on the evaluators' preference values above, a reciprocal matrix from the above comparison will look like:

$$A = \begin{vmatrix} 1 & 5 & 7 \\ & 1 & 3 \\ & & 1 \end{vmatrix}$$

To fill the lower triangular matrix, the reciprocal values of the upper diagonal will be used. That is if a_{ij} is the element of row i column j of the matrix, then the lower diagonal is filled using the formula:

$$a_{ji} = \frac{1}{a_{ij}}$$

Finally, the complete comparison matrix will be obtained as:

$$A = \begin{vmatrix} 1 & 5 & 7 \\ \frac{1}{5} & 1 & 3 \\ \frac{1}{7} & \frac{1}{3} & 1 \end{vmatrix}$$

Notice that all the element in the comparison matrix are positive, or $a_{ij} > 0$.

7.3.3.3 Priority Vector

Once the comparison matrix has been developed the calculation of what is called the priority of each of the elements being compared can be made. In the above example the evaluators may now wish to estimate the relative priority for each fruit in terms of their preference. This is referred to as synthesisation. The exact mathematical procedure used Eigen Values and Eigen Vectors but with using a simplified version which was proved by Saaty [166] that a good approximation is still obtained.

Procedure for synthesizing judgments can be made as follows.

- Sum the values in each column of the pairwise comparison matrix
- Divide each element in the pairwise comparison matrix by its column total. The resulting matrix is referred to as the normalized pairwise comparison matrix.
- Compute the average of the elements in each row of the normalized matrix. These averages provide an estimate of the relative priorities of the elements being compared.

Note all column totals in the normalized pairwise comparison matrix sum to one.

Now let take a look on numerical example. If each column of the matrix is summed up, then we get

$$A = \begin{array}{|ccc|} 1 & 5 & 7 \\ \frac{1}{5} & 1 & 3 \\ \frac{1}{7} & \frac{1}{3} & 1 \\ \hline \frac{47}{35} & \frac{19}{3} & 11 \end{array}$$

Then divide each element of the matrix with the sum of its column, we have normalized relative weight. The sum of each column is 1.

$$A = \begin{array}{|ccc|} \frac{35}{47} & \frac{15}{19} & \frac{7}{11} \\ \frac{7}{47} & \frac{3}{19} & \frac{3}{11} \\ \frac{5}{47} & \frac{1}{19} & \frac{1}{11} \\ \hline 1 & 1 & 1 \end{array}$$

The normalized principal Eigen vector can be obtained by averaging across the rows

$$A = \begin{array}{|ccc|} \frac{35}{47} & \frac{15}{19} & \frac{7}{11} \\ \frac{7}{47} & \frac{3}{19} & \frac{3}{11} \\ \frac{5}{47} & \frac{1}{19} & \frac{1}{11} \\ \hline 1 & 1 & 1 \end{array} = \begin{array}{|c|} 0.7235 \\ 0.1932 \\ 0.0833 \\ \hline 1 \end{array}$$

The normalized principal Eigen vector is also called **priority vector**. Since it is normalized, the sum of all elements in priority vector is 1. The priority vector shows relative weights among the things that have been compared. In an example above, Apple is 72.35% preference whereas banana is 19.32% and cherry is 8.33%. That means the evaluators like the banana most, followed by apple and cherry. In this case, it can tell more than just the fruit preference; in fact, the relative weight is a ratio scale that can be divided among them. For example, it can be said that the evaluators like apple 3.75 (=72.35/19.32) times more than banana and they also like apple so much 8.68 (=72.35/8.33) times more than cheery.

7.3.3.4 Consistency

The establishment of priorities through the use of the pairwise comparison procedure above is a key step for AHP. Another important consideration of AHP is the consistence of the judgments made by the decision-maker. What is meant by consistency can be explained as: if an object 1 is more preferable when compared with object 2 and an object 2 is more preferable when compared with object 3, then it should be concluded that an object 1 shall definitely more preferable than object 3. This is called *transitive* property. If the consequence turns out to be opposite then it can be claimed that the comparison is not consistent.

Perfect consistency is however practically not possible to achieve. So it needs a method to measure the degree of consistency among the pairwise judgments provided by the decision-maker. If the degree is acceptable then the decision process continues or else the decision-maker should reconsider and possibly revise the pairwise judgments before proceeding with the analysis. A measure of consistency used by the AHP that can be computed is known as the consistency ratio. This ratio is designed so that values of the ratio exceeding 0.1 are indicative of inconsistent judgments indicating that the decision maker would probably want to revise the original values in the pairwise comparison matrix. The determination of consistency ratio will use an approximation in stead of the exact mathematical calculations which are very complex to achieve.

The following steps are employed to estimate the consistency ratio.

1) Determine the principal Eigen value by summation of products between each element of Eigen vector and the sum of columns of the comparison matrix and denote it by $\lambda_{\max}$.

2) Compute the consistency index (*CI*) which is defined as follows:

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

where n is the number of items being compared.

3) Compute the consistency ration (*CR*) which is defined as:

$$CR = \frac{CI}{RI}$$

Where RI, the random index, is the consistency index of a randomly generated pairwise comparison matrix. It can be shown that *RI* depends on the number of elements being compared and takes on the following values:

Table 7.4 Random consistency index

Number of things	1	2	3	4	5	6	7	8	9
Number of comparison	0	0	.58	.9	1.12	1.24	1.32	1.41	1.45

In AHP problem if the consistency ratio is less than 0.1 it is considered acceptable.

Now let have a look if the above example has a consistency or not. First compute the $\lambda_{\max}$ which yields

$$\lambda_{\max} = \frac{47}{35}(0.7235) + \frac{19}{3}(0.1932) + 11(0.0833) = 3.1115$$

Then the consistency index can be obtained as

$$CI = \frac{3.1115-3}{3-1} = 0.0557$$

Finally the consistency ratio can be obtained as

$$CR = \frac{0.0557}{0.58} = 0.0961 = 9.61\%$$

which can be concluded that the above example is deemed consistent since the consistency ration (*CR*) is less than 10%.

7.4 Decision Support System Architecture

The frameworks for the asset categorization, the feeder failure risk assessment, the failure and prevention costs evaluation, as well as the multicriteria decision making process have been thoroughly proposed and investigated previously in the thesis. However, in order to bring about the final decision the aforementioned frameworks have to be consolidated to form a single system. The novel DSS is thus assembled. The proposed DSS is composed of four different modules: risk module, cost module decision module and asset categorization module. Each module perform different task but related to one another. An output from one module would become an input for another module. This thus makes the complete system robust, comprehensive and effective. The architecture of proposed DSS is illustrated in figure 7.3 and the detail description of each module is provided in the following sections.

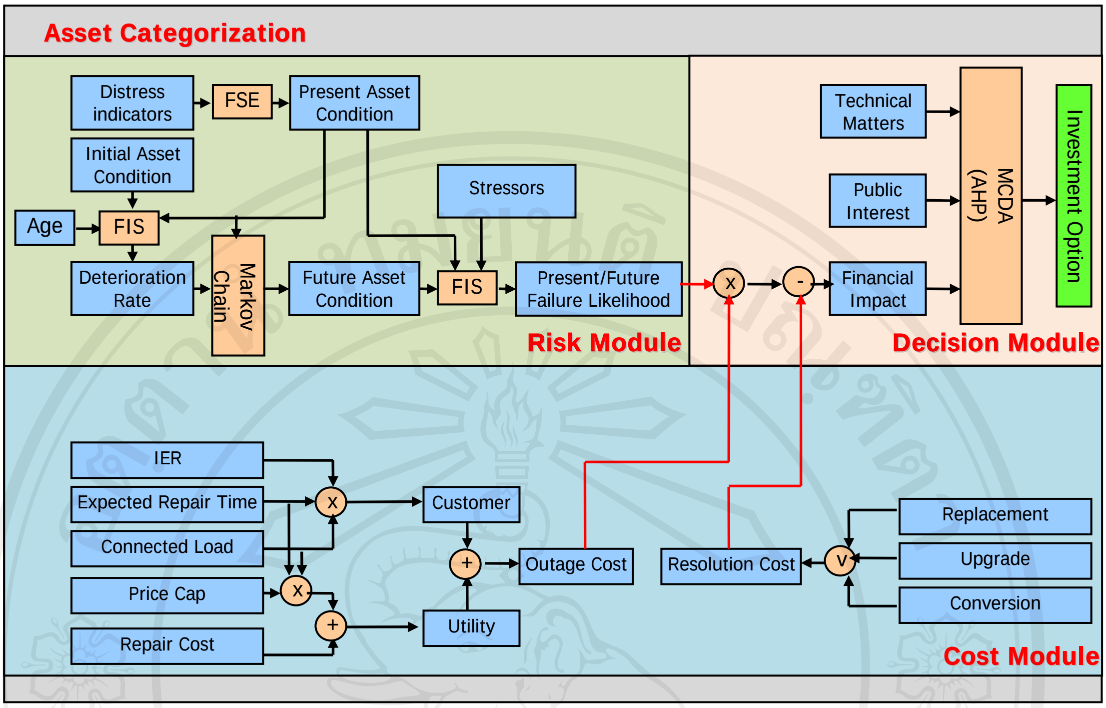


Figure 7.3 The overall architecture of DSS for power distribution network asset management

7.4.1 Risk Module

The main function of risk module is to determine the possibility of feeder failure. The prominence of the risk module is twofold: the exploitation of an already available data and the employment of fuzzy reasoning process. Fuzzy reasoning process is very similar to the reasoning process of human expert. Most of information used in evaluation process is somewhat vague and imprecise whereas the fuzzy technique is immune to these obstacles. Besides, the Markov chain technique is employed to predict the possibility of failure that may occur in the near future. Markov chain makes it possible to predict the future asset condition based on the known present condition without regard to how the system reached its current state.

Before reaching the final output, there are several steps that have been processed in risk module. It starts with the assessment of feeder condition rating or grade. This is done by examining the distress indicators shown on each feeder component. Distress indicator is a sign of deterioration that component has undergone during year-long operation of feeder which in turn indicate the condition grade of such individual component. Using the method of fuzzy synthetic evaluation (FSE), the overall feeder condition grade can eventually concluded. The risk module is however designed to predict the feeder condition rating along its operating life by employing the Markovian deterioration process. In doing that the deterioration rate of feeder asset needs to be evaluated first. This can be achieved through fuzzy inference system (FIS) taking into account known asset condition rating of different time instance to train the FIS. The deterioration rate represents the degree that asset loses its membership of current state to next contiguous state per year. It will then be used to formulate a transition matrix which in turn used to calculate the future grade of the remaining years.

The failure of distribution feeder depends on two main driving factors: feeder asset condition grade and operation and environmental stressors. Condition grades are derived from distress indicators as mentioned above while stressors are derived from the contributing factors that cause feeder to thermally overload, electrically (voltage) breakdown or mechanically collapse. If the feeder is highly deteriorating, it is likely to fail even though the stressors are not taking parts. Conversely, although the feeder is brand new but if stressors are extremely high, the feeder would be likely to fail as well. The crisp value of risk module output indicates the failure rate per km length per year per km length of the feeder.

Details of each evaluation step processed in the risk module have been thoroughly discussed in chapter 5 of this thesis.

7.4.2 Cost Module

Costs are monetary losses and spendings that produced by feeder failure impacting to stakeholders, namely customers and utility. On the other hand, costs comprise of two main components that is losses suffered by both customers and utility and expenses that utility spends for preventing or mitigating such losses.

Loss occurred to customers in the event of feeder failure can be described by salary or work payment, cost of loss of profit opportunity, overtime payment, cost of loss of raw material, cost of re-starting the process, and cost of damaged equipment. This loss figure can be derived by manipulating kW of customer’s unserved loads, expected restoration (repair) time and interrupted energy rate (IER). At the same time when feeder fails to deliver power to users, utility also loses revenue from energy sale. This figure can be obtained by estimating the units expected to be sold to customers multiplied by price cab. Furthermore, utility also needs to dispatch its resources to repair the broken components and restore the power back to the users; this would cost some money to utility.

In order to prevent or mitigate the loss impact from feeder failure, utility needs to formulate the resolution actions. These actions are introduced by utility to reduce the possibility of feeder failure. The usual resolution actions employed by utility to improve the feeder performance might be defective component replacement, network component upgrade or the entire network conversion (overhead to underground system conversion).

Finally, the total financial impact feeder failure can be obtained by performing a cost-benefit analysis on monetary value of losses to be saved and spendings on resolution action. The details concerning the cost evaluation have been considered in chapter 6.

7.4.3 Decision Module

In the final decision process, the multicriteria decision making technique called analytic hierarch process (AHP) is used. The advantage of this technique is it involves in structuring multiple choice criteria into a hierarchy, assessing the relative importance of these criteria, comparing alternatives for each criterion, and determining an overall ranking of the alternatives. By using the AHP, all key factors associated with power distribution network asset management such as technical, financial, social and environmental aspects are taken into account; it thus makes the proposed DSS comprehensive and rigorous.

The prior sections of this chapter have addressed all the issues related to multicriteria decision making and AHP.

7.4.4 Asset Categorization Module

Underpinning the previous three assessment modules is the information and knowledge utilized in assessment process. By using the knowledge engineering methodology together with the modeling technique, the asset categorization of the distribution network asset is hence established. The asset categorization module provides all key attributes of the network assets, either concrete or abstract, operational stresses and external environments of power distribution system implementation. This information is modeled into classes and attributes using the common information model (CIM) specification. The CIM bases itself on the renowned technology of resource description framework (RDF) which allows both the syntax and semantic modeling. Apart from its interchangeability, the CIM also allows expressivity, reusability, extensibility and integratability of the models. When applying in distribution network modeling, the use of CIM facilitates the possibility of existing ontologies reuse and of model extension and integration.

7.5 Simulation Test

7.5.1 Test Feeder

In order to test the applicability of DSS, the simulated feeder needs to be developed. Although there is an IEEE radial test feeder proposed for testing and evaluation on distribution feeder [171], but it is primarily designed for the purpose of distribution system analysis and control, it may not be applicable to the concerned problem. Therefore, the test feeder dedicated for risk-cost evaluation is formed. It is an overhead feeder of about 1 km length running along the road. There are three types of customers connected to this feeder, via 6 distribution transformers; they include residential, medium service and large service business. The far end of feeder is connected to other feeder via the normally-open disconnecting switch. Figure 7.4 shows the single line diagram of this feeder and figure 7.5 depicts its route located with pole and transformer position. Using feeder operational and environmental stressors evaluation form as formulated in appendix A3, the test feeder can be described as follows.

Feeder description

1) Feeder name: Fdr_001
2) Single line diagram: As shown in figure 8.1
3) Geographical layout plan: As shown in figure 8.2
4) Overhead construction data

- 4.1 Type of pole: 12m and 12.35m concrete pole
- 4.2 Type of insulator: Pin-post and suspension
- 4.3 Type of conductor: Bare
- 4.4 Conductor material: Aluminum
- 4.5 Conductor size: 185 mm^2
- 4.6 Rated Ampere: 400 A
- 4.7 Length: 1 cct-km
- 4.8 Life expectancy: 40 years
- 4.9 Age: 10 years
- 4.10 Investment cost: 692,735.87 baht

5) Connected customers

- 5.1 Residential customers: 3,400 kW
- 5.2 Commercial customers (medium service business): 4,400 kW
- 5.3 Industrial customers (large service business): 6,500 kW

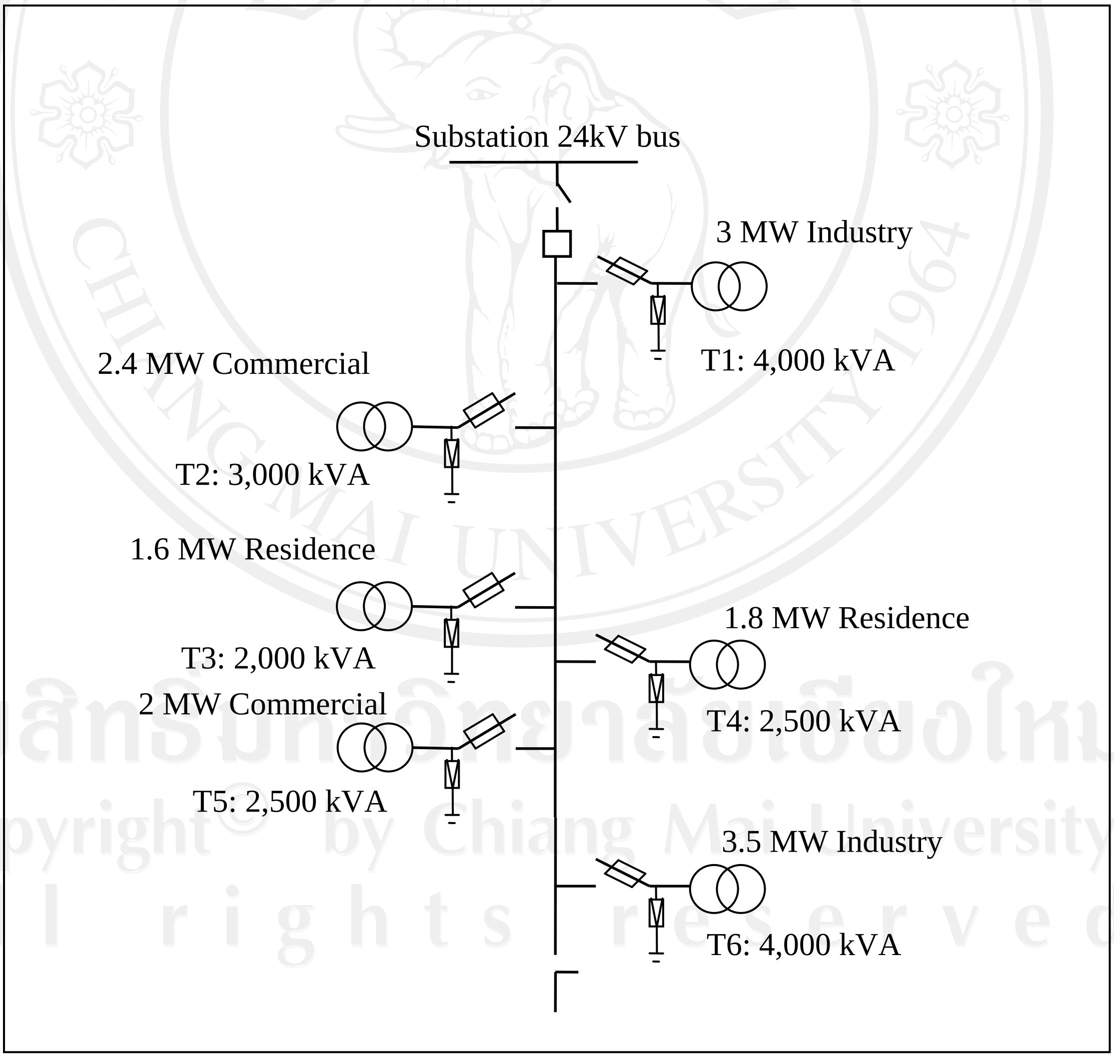


Figure 7.4 Single line diagram of simulated feeder

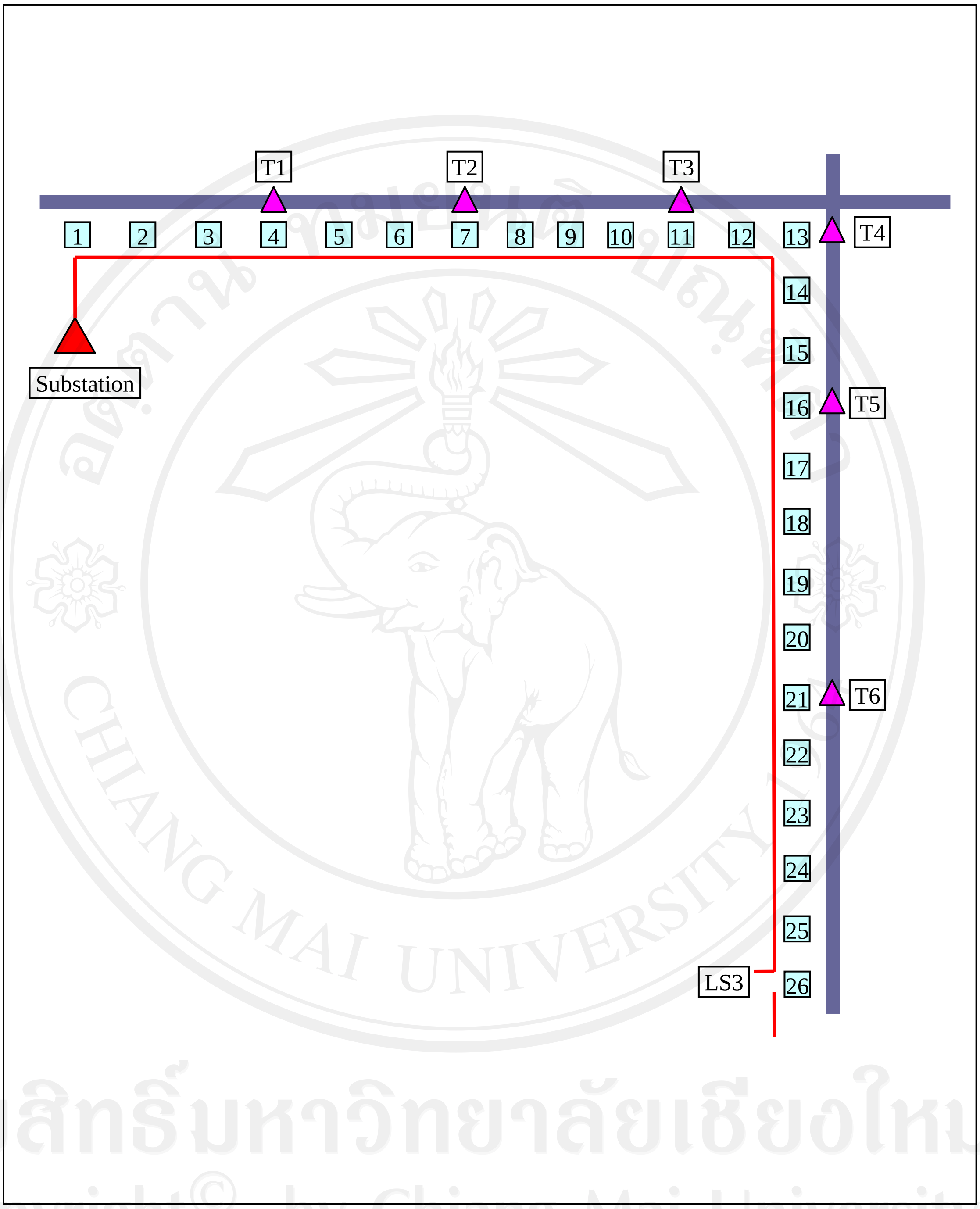
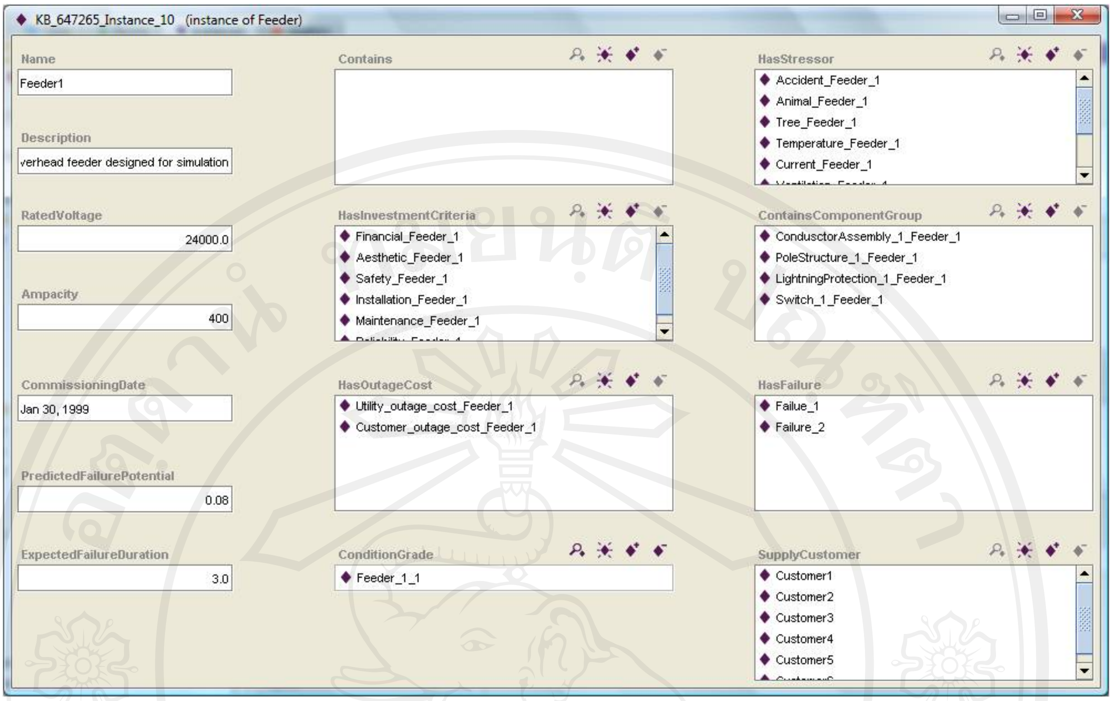


Figure 7.5 Route and equipment location of simulated feeder

The knowledge representation discussed in chapter 4 is used to describe the feeder and Protégé 2000 is used to model the feeder asset. Figure 7.6 is the screenshot of feeder instance.



Name: Feeder1

Description: verhead feeder designed for simulation

RatedVoltage: 24000.0

Ampacity: 400

CommissioningDate: Jan 30, 1999

PredictedFailurePotential: 0.08

ExpectedFailureDuration: 3.0

Contains

HasInvestmentCriteria: Financial_Feeder_1, Aesthetic_Feeder_1, Safety_Feeder_1, Installation_Feeder_1, Maintenance_Feeder_1

HasOutageCost: Utility_outage_cost_Feeder_1, Customer_outage_cost_Feeder_1

ConditionGrade: Feeder_1_1

HasStressor: Accident_Feeder_1, Animal_Feeder_1, Tree_Feeder_1, Temperature_Feeder_1, Current_Feeder_1

ContainsComponentGroup: ConductorAssembly_1_Feeder_1, PoleStructure_1_Feeder_1, LightningProtection_1_Feeder_1, Switch_1_Feeder_1

HasFailure: Failue_1, Failure_2

SupplyCustomer: Customer1, Customer2, Customer3, Customer4, Customer5

Figure 7.6 Instance of test feeder modeled by Protégé 2000

7.5.2 Determination of Feeder Failure Possibility

Determination of Feeder Condition

Suppose that after line inspection utility engineers have graded the condition of feeder components as shown in table 7.5, the overall condition rating of test feeder can then be determined using the methods discussed in chapter 5 which yields $(\frac{0.19}{good},\frac{0.687}{adequate},\frac{0.250}{fair},\frac{0.044}{poor},\frac{0}{failed})$. The results obtained contradict to intuitive expert opinion which stated that the value shall not support (non-zero membership values) to more than two contiguous states. In this case, defuzzification and adjustment are needed. The condition grade of test feeder after defuzzification and adjustment would be $(\frac{0}{good},\frac{0.681}{adequate},\frac{0.319}{fair},\frac{0}{poor},\frac{0}{failed})$ or 2.319 numerically.

Table 7.5 Condition rating of feeder components

Components	**Assessed Condition**					**Numerical Grade**
	good	*adequate*	*fair*	*poor*	*failed*	
Pole	0	0.5	0.5	0	0	2.5
Crossarm	0	0.75	0.25	0	0	2.25
Guy	0	0.25	0.75	0	0	2.75
Fittings	0	0.9	0.1	0	0	2.1
Conductor	0.1	0.9	0	0	0	1.9
Insulator	0	0.8	0.2	0	0	2.2
Splice	0	0.95	0.05	0	0	2.05
Overhead ground wire	0.1	0.9	0	0	0	1.9
Lightning arrester	0	0.9	0.1	0	0	2.1
Fuse cutouts	0	0	0.6	0.4	0	3.4
Switch	0	0.7	0.3	0	0	2.3
Recloser	0.05	0.95	0	0	0	1.95

Since the feeder has been in use for 10 years, the condition rating at commissioning is assumed to be $(\frac{0.970}{good}, \frac{0.030}{adequate}, \frac{0}{fair}, \frac{0}{poor}, \frac{0}{failed})$ and the present condition rating is obtained as mentioned above, by taking these two conditions into account the yearly deterioration rate of feeder as a whole can then be determined using Fuzzy inference system for Markov deterioration model proposed in chapter 5. The deterioration rate (D) would be $1.16d_0$ or 0.116 membership per year. The Markovian deterioration matrix as formulated in equation (5.33) then becomes

$$\begin{bmatrix} 0.884 & 0.116 & 0 & 0 & 0 \\ 0 & 0.884 & 0.116 & 0 & 0 \\ 0 & 0 & 0.884 & 0.116 & 0 \\ 0 & 0 & 0 & 0.884 & 0.116 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

The condition rating of the test feeder as computed by Fuzzy – Markov process would be obtained as shown in figure 7.7.

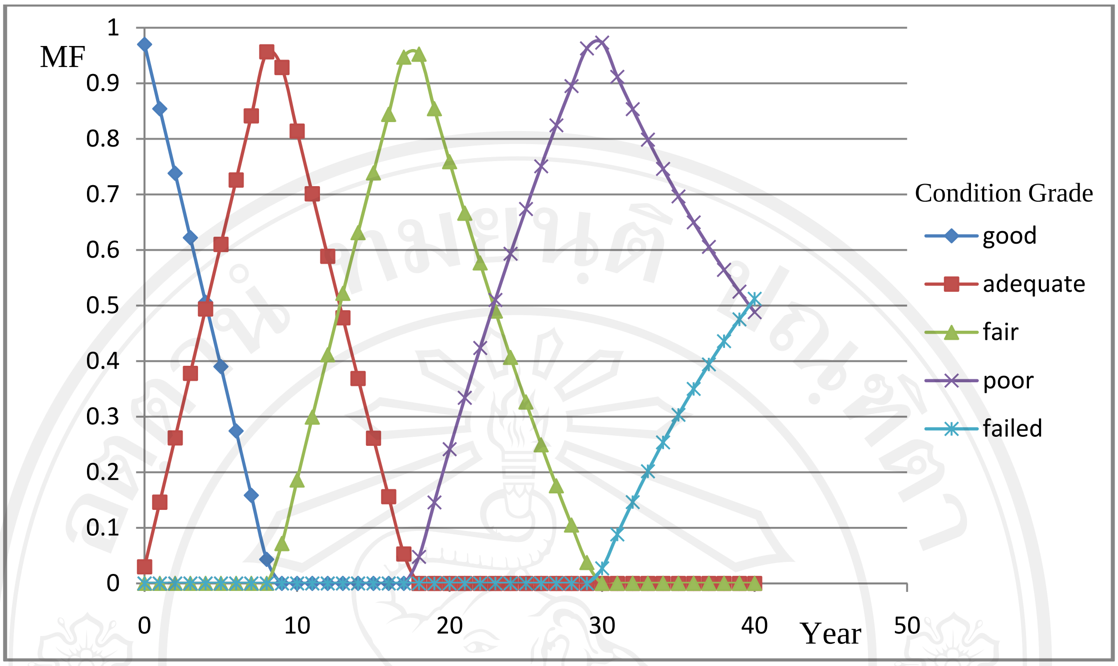


Figure 7.7 Condition rating of test feeder

Determination of Feeder Failure

Although the condition grade of feeder assets at any time instance may imply how such asset would perform, but the condition grade alone does not indicate how likely the feeder would fail. The stressors from feeder operation and its surrounding environments also contribute to feeder failure. The degree of contribution depends on the level of existence, deduction rules and stage of assessment. The stressors used for feeder failure possibility evaluation consists of:

- Load current
- Ambient temperature
- Ventilation or heat dissipation capability of surroundings
- Lightning exposure degree
- Lightning protection degree
- Pollution existence degree
- Tree exposure degree
- Accident exposure degree
- Animal involvement degree

The level of existence and degree of influence of each stressor are thoroughly discussed in chapter 5.

Now let consider the contribution of asset condition rating to feeder failure. To evaluate the contributions from the stressor has to be kept at minimum level in order to prevent dominance of such stressor. Figure 7.8 shows the percentage of failure possibility along with the degradation of components of test feeder. The result shows that failure possibility remains constant until the year 30 when feeder emerges the *failed* state.

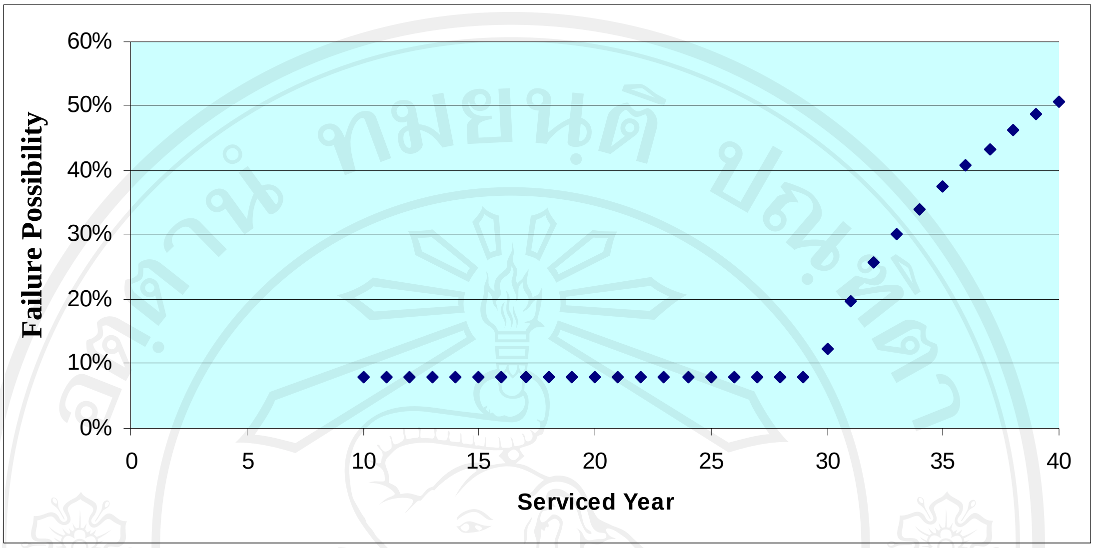


Figure 7.8 Failure possibility contributed from feeder condition rating

However, when taking into account the stressors they would take part in deducing the failure possibility. For example, if the feeder is around 130% overloaded, under the present feeder condition grade the possibility of failure will increase to 50% as compared to 8% of normal load current. The situation is even worse if this feeder is running across a bush of tall tree; the failure possibility goes up to 75% for this case. Hence in some circumstance where the stressors dominate, the condition grade cannot be regarded as an implication for predicting the failure.

7.5.3 Determination of Financial Impact

Determination of Outage Cost

Outage cost comprises two components: *customer* and *utility* cost. Customer outage cost depends on type of customer, kW of load as well as expected interruption duration and interrupted energy rate (IER). Utility outage cost can be estimated from loss of energy sale and repair cost. The service quality standard of Thai power distribution utility [172] states that the guaranteed power recovery duration from outage is 3 hours. This figure will be considered as expected interruption duration.

There are three types of customers connected to the test feeder. They include 3,400kW of residential load, 4,400kW of commercial load and 6,500kW of industrial load. Using 3-hour IER provided in chapter 6, the total customer outage cost for this case is 1,543,813.39 baht. The price cap for above customer types occurring during peak period are 1.5289, 0.5993 and 0.5993 baht per kWh respectively [173], so the loss of energy sale occurs to utility would be 35,191.89 baht. In general, repair costs differ significantly depending on type of breakdown; for sake of evaluation the repair cost borne by utility is arbitrarily set to 20,000 baht for each repair. Hence the total outage cost if feeder actually fails would be 1,599,005.28 baht.

Determination of Resolution Cost

In order alleviate or prevent the occurrence of feeder failure, the resolution measures need to be introduced. Based on the fact that the existing system is an overhead construction with bare conductor, so the resolution would be:

- Upgrade of all bare conductors with insulate cables (spaced aerial cables-ASC) or
- Conversion of overhead system to underground system.

Using WBS approach, the costs of obtaining above systems are as follows.

- Overhead feeder with bare conductor: 1,240,584.44 Baht
- Overhead feeder with spaced aerial cable: 1,504,028.84 Baht
- Underground feeder with XLPE cable installed in duct: 6,450,433.44 Baht

The prices indicated above are calculated based on 1 km length of distribution feeder.

Determination of Total Financial Impact

Before determining the total financial impact, three assumptions shall be made. First the stressors stressing the operation of feeder remain unchanged along its operating life. Second the upgrade of overhead system components may reduce the failure possibility down to some extent. And third the underground system can prevent the occurrence of feeder failure. Based on the above assumption, the total financial impact at present year can be illustrated as follows.

Suppose there is no influence from operational and environmental stressors. So at present year, the outage cost supposed to occur when carrying on running the current feeder is around 127,920.42 baht (outage cost of feeder failure multiplying failure possibility). This figure can be considered as the benefit since it can be mitigated by the introduction of resolution action. Let assume that utility employ a linear depreciation policy, so the remaining value of existing feeder will be reduced by amount of 173,18.40 baht each year; and this amount will be added to resolution cost to provide the total cost. For the simulated case however, the resolution measure viable for this case is underground feeder because new overhead feeder with either bare or spaced aerial cable still presents the same risk figure as before. The cost of obtaining underground feeder of 5,729,400.90 (investment cost of underground less investment cost of bare conductor overhead plus the remaining value of existing bare conductor overhead feeder) baht is much more than the benefit of 127,920.42 baht, so it is still worth operating the existing feeder. However, if the feeder keeps running, the benefit and costs obtained from various resolution options can be evaluated and shown in figure 7.9. It can be clearly seen that costs are decreasing but benefit remain constant and starts increasing when feeder components begins to deteriorate.

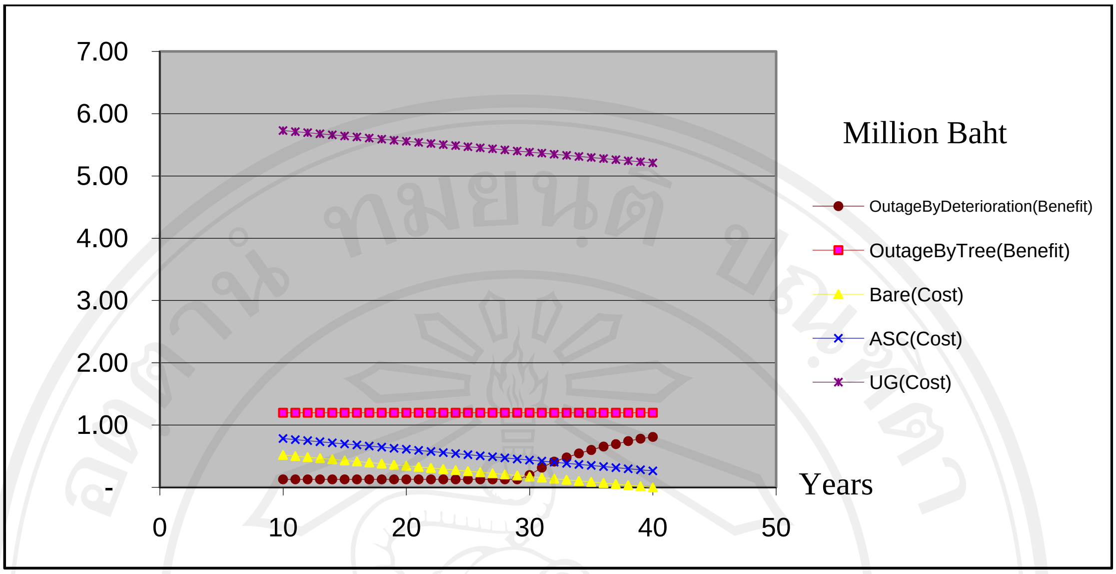


Figure 7.9 Illustration of cost and benefit among options

If the feeder is operating in situation where stressors play significant roles such as polluted area, trees, or heavy load the possibility of feeder failure may increase depending on how significant such stressor contribute as formulated in form of knowledge rules. Therefore the expected outage costs will also increase proportionally. For example, if feeder is 130% overloaded the outage cost would increase to 799,502.64 baht as compared to 126,320.42 baht in case of normal load. Furthermore, the outage cost may go up to 1,199,253.96 baht (shown as red line in figure 7.9) if involved with densely vegetated location. In the latter case, replacement of existing feeder with spaced aerial (insulated) cable (shown as blue line in figure 7.9) is already financially preferable.

7.5.4 Performing Multicriteria Decision Analysis

As already stated several times in the thesis that the financial consideration alone is not adequate for making a decision on what asset management strategy the utility shall adopt in securing the performance of asset. The decision making on feeder rehabilitation of simulated case also needs to consider, apart from financial aspect, other issues that really impacts to the stakeholders.

Formation of Decision Hierarchy

Based on the stakeholder's requirements (utility, customers and local community for this case), the criteria that needed to be evaluated consisting of three main categories: technical, financial and social. Technical aspect is further broken down into reliability, construction and maintenance of the feeder whereas social matter takes safety of people as well as aesthetical landscape in to consideration. The rehabilitation option composes of carrying on using existing bare conductor overhead feeder, replacing by ASC overhead feeder or converting to underground cable. Figure

7.10 below depicts the graphical illustration feeder investment decision hierarchy using AHP methodology.

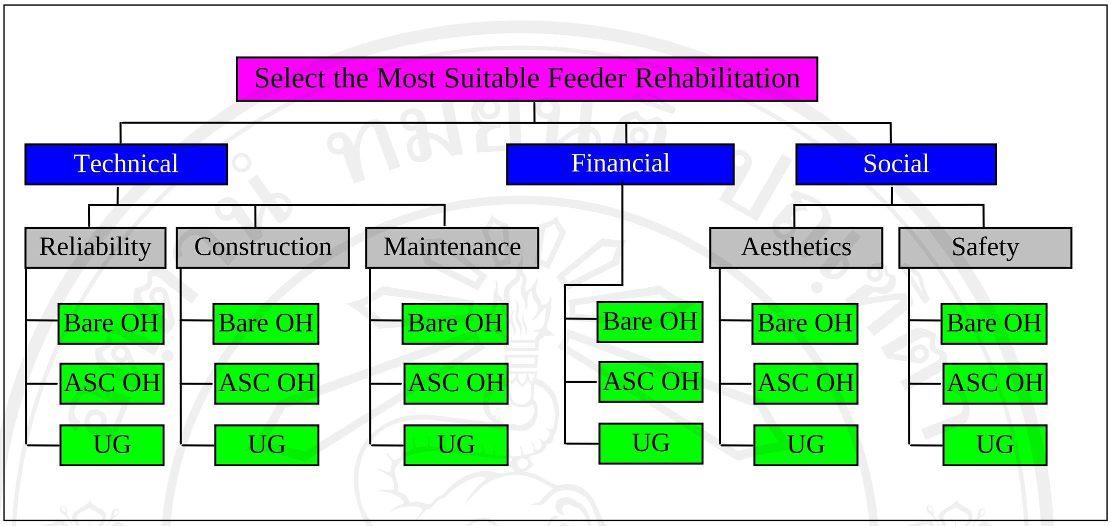


Figure 7.10 Investment decision hierarchy

Evaluation of Options

The following tables illustrate the evaluation of each feeder rehabilitation implementation options against governed criteria.

Table 7.6 Comparison matrix and priority vector of main criteria

Criteria	Technical	Financial	Social	Weight
Technical	1.00	0.20	0.50	12.85%
Financial	5.00	1.00	2.00	59.49%
Social	2.00	0.50	1.00	27.66%
Sum	8.00	1.70	3.50	100%

CR = 0.64%

Table 7.7 Comparison matrix and priority vector of subcriteria under technical matter

Criteria	Reliability	Construction	Maintenance	Weight	Weighted Weight
Reliability	1.00	7.00	4.00	70.14%	9.01%
Construction	0.14	1.00	0.33	8.53%	1.10%
Maintenance	0.25	3.00	1.00	21.32%	2.74%
Sum	1.39	11.00	5.33	100%	16.38%

CR = 4.56%

Table 7.8 Comparison matrix and priority vector of subcriteria under social matter

Criteria	Safety	Aesthetic	Weight	Weighted Weight
Safety	1.00	3.00	75.00%	20.75%
Aesthetic	0.33	1.00	25.00%	6.92%
Sum	1.33	4.00	100%	27.66%

CR = 0%

Table 7.9 Comparison matrix of implementation options against reliability subcriteria

Reliability	Bare OH	ASC OH	UG	Rank
Bare OH	1.00	0.13	0.11	5.48%
ASC OH	8.00	1.00	0.50	35.83%
UG	9.00	2.00	1.00	58.69%
Sum	18.00	3.13	1.61	100%

CR = 4.50%

Table 7.10 Comparison matrix of implementation options against construction subcriteria

Construction	Bare OH	ASC OH	UG	Rank
Bare OH	1.00	1.00	5.00	45.45%
ASC OH	1.00	1.00	5.00	45.45%
UG	0.20	0.20	1.00	9.09%
Sum	2.20	2.20	11.00	100%

CR = 0%

Table 7.11 Comparison matrix of implementation options against maintenance subcriteria

Maintenance	Bare OH	ASC OH	UG	Rank
Bare OH	1.00	1.00	5.00	45.45%
ASC OH	1.00	1.00	5.00	45.45%
UG	0.20	0.20	1.00	9.09%
Sum	2.20	2.20	11.00	100%

CR = 0%

Table 7.12 Comparison matrix of implementation options against financial criteria

Financial	Bare OH	ASC OH	UG	Rank
Bare OH	1.00	1.00	9.00	48.99%
ASC OH	1.00	1.00	7.00	45.07%
UG	0.11	0.14	1.00	5.94%
Sum	2.11	2.14	177.00	100%

CR = 0.81%

Table 7.13 Comparison matrix of implementation options against safety subcriteria

Safety	Bare OH	ASC OH	UG	Rank
Bare OH	1.00	0.33	0.11	6.98%
ASC OH	3.00	1.00	0.17	16.59%
UG	9.00	6.00	1.00	76.44%
Sum	13.00	7.33	1.28	100%

CR = 8.63%

Table 7.14 Comparison matrix of implementation options against safety subcriteria

Aesthetic	Bare OH	ASC OH	UG	Rank
Bare OH	1.00	1.00	0.11	9.09%
ASC OH	1.00	1.00	0.11	9.09%
UG	9.00	9.00	1.00	81.82%
Sum	11.00	11.00	1.22	100%

CR = 0%

Table 7.15 Overall ranking of alternatives

Criteria	**Significant Weight**	**Bare OH**	**ASC OH**	**UG**
Reliability	0.0901	0.0548	0.3583	0.5869
Construction	0.0110	0.4545	0.4545	0.0909
Maintenance	0.0274	0.4545	0.4545	0.0909
Finance	0.5949	0.4899	0.4507	0.0594
Safety	0.2075	0.0698	0.1659	0.7644
Aesthetics	0.0692	0.0909	0.0909	0.8182
Overall marks (%)		33.46	35.85	30.69

CR = 1.84 %

The results from evaluation of options show that the most suitable solution for feeder rehabilitation in this simulation case is to replace a bare conductor with spaced aerial conductor but still using overhead construction. However, if take a closer look into the results, it can be seen that the overall mark of each option is not much different. Underground feeder is only about 5% behind ASC overhead even though, for this evaluation, assessors rate the financial aspect as *strong importance* as compared to technical criteria. This is because when all the requirements from stakeholders are really taken into account while considering the options, other criteria would also contribute in the decision, it is not trapped by de facto importance of financial aspect. Again in this simulation, if the importance of technical aspect is leveled up to financial one or even slightly less important, the underground construction would prevail the overhead counterparts. The result from the latter evaluation is shown in table 7.16.

Table 7.16 Overall ranking of alternatives when technical criterion is equally important as compared to financial

Criteria	**Significant Weight**	**Bare OH**	**ASC OH**	**UG**
Reliability	0.1854	0.0548	0.3583	0.5869
Construction	0.0226	0.4545	0.4545	0.0909
Maintenance	0.0564	0.4545	0.4545	0.0909
Finance	0.4071	0.4899	0.4507	0.0594
Safety	0.2464	0.0698	0.1659	0.7644
Aesthetics	0.0821	0.0909	0.0909	0.8182
Overall marks (%)		27.02	33.41	39.57

7.6 Discussion on the Performance of Decision Support System

Data modeling

The asset categorization which employs RDF and CIM for asset modeling, apart from its distinctive features of expressivity, reusability, extensibility interchangeability, and integratability, can offer necessary data required for decision making on distribution asset management. For example, the data model has attributes that provide information on asset condition rating and its degree of importance, operational and environmental stressors, as well as costs of material and installation; these information are necessary for decision making. Furthermore, the employment of RDF in asset categorization makes the knowledge on the network asset representable; not only attributes mentioned above are presented but also the relationships among assets. This would enable asset manager or his staffs possess all the knowledge about their assets. For example, if asset manager picks up one feeder to study he would find what asset groups compose the feeder, what components belong to such group, where the transformer is installed, when it is commissioned, what is the length of R-phase conductor, which splice connects Y-phase cable section 1 with section 2 and where it is located, etc.; all these knowledge are available in the asset models.

Data Availability and Acquisition

DSS is designed to employ the data already available in-house. However, if more field data are required, it can be done with less effort to obtain those data since criteria and inspection forms are prepared; only simple visual inspection would be carried out. Furthermore, the data required do not need to be precise (of course the more precise the better), the method applied for evaluation process, i.e. FIS, is immune to data vagueness.

Accuracy of Output Results

Accuracy of the results obtained from risk assessment module greatly depends on several factors. The followings illustrate the major aspects contributing to the results accuracy.

- The inclusion of all impacted factors which in turn translate into inputs of DSS.
- Fuzzification of inputs and outputs
    - How would expert translate linguistic values of *very low* or *low* failure possibility into numerical (percentage) values is very subjective. Even though failure statistics of feeder operating in normal stressors may be used but what *very low* or *low* mean
    - From conversations with utility engineers it was found that the performance of distribution components deteriorate as they approach thirty years of age, this concept is therefore included in the fuzzy model.
    - Rules that deducing the failure in DSS are based on the knowledge that the feeder components usually start deteriorating at age of 30 years.
- Knowledge rules which have been introduced to replicate the assessment and decision making tasks of human experts.

The latter two depends solely on expert's judgment.

It was also found that the failure possibility of OH feeder obtained from DSS are in conformity with EPRI work of reviewing the reliability of electric distribution system components [174] which indicates the failure rate of overhead distribution conductor in the range from 0.0076 to 1.125 failures/km/year (0.0122 – 1.8 failures/mile/year)

The accuracy of cost quantification usually depends on the unit cost of cost components that assemble the entire figure. Since the unavailability of updated data on the damage costs which are based on study conducted in year 2004, the figures obtained may not reflect the real situation at present.

Overall Performance

If taking into account only the reliability issue, underground distribution network cannot compete with overhead counterpart due to its very high investment cost. UG may be preferable only in the place where extreme stressors such as frequent thunder storms, hurricanes, etc. exist. The usual reasons for implementing UG are lack of right of ways and aesthetics. And these figures are usually difficult to quantify in money terms. Furthermore, the decision makers may sometimes want their subjective opinion to be included into the decision making equation. That is why the AHP is suitable for handling this situation. The AHP is able to transform subjective judgment such as aesthetic and safety issues into quantifiable form hence make alternative options easily comparable. However, to make an effective use of the AHP, it needs a consensus on opinion of assessors (if more than one assessor) and it also requires consistency on criteria/option comparison. Ranking the options with the AHP is also sensitive to which criterion assessor put weight on. From above evaluation example if assessor only put little change on signification of criterion, e.g. change the preference of financial over technical from 3:1 to 2:1 (from slightly favors on financial over technical to extremely slightly favors), the ranking would be reverse. However, one of the advantages of the proposed DSS is that whatever the final decision is, asset manager still has knowledge on the failure rate and associated costs which he can use for budgeting purpose.