Chapter 8
Case Studies

8.1 Chapter Overview

The previous chapters provided a thorough discussion on the methodologies for asset categorization, risk of failure evaluation, cost estimation, multicriteria decision analysis, and brought all of them into a simulation test to verify their applicability and effectiveness. This chapter presents two case studies based on the real situation. The first case study demonstrates the application of DSS in the real feeder located in industrial estate area where reliability of power supply is regarded as a must to customers. While in the second case study, there has already existed a requirement to underground the overhead distribution facilities, the DSS can be applied to select the most appropriate undergrounding methodology that fits into the context of world heritage site.

8.2 Enhancing the Distribution Feeder in Industrial Estate Area

The distribution feeder operating in the industrial estate area is selected for the first case study. In the industrial estate, there exist many production factories of which the continuity of production processes as well as the quality of products depend seriously on the reliability and quality of power supplied by such feeder. The failure of feeder would result in serious money losses especially to the customers due to several impacts such as:

- Salary, or work or overtime payment without producing any useful products;
- Cost of loss of raw material, cost of re-starting the process, or cost of damaged equipment because of supply interruption; or
- Cost of loss of profit opportunity due to production stoppage.

Because of the nature of an existing overhead system, the feeder has suffered reliability problems caused by various operational and environmental stressors such as weather conditions, tree and animal contacts, accidents, etc. In addition, the feeder is situated in the coastal area in which a large amount of moisture and salt vapor in the air maybe accelerates the deterioration rate of the feeder components. So the selected feeder which characterizes the high stressors and high impact would be an excellent case to demonstrate the applicability and effectiveness of the proposed DSS.

The customers situated in industrial estate area which supplied by Substation KO have been suffering the reliability problems of power supply. The existing feeder is an overhead constructed with insulated conductors (ASC cable). In the previous year, utility staffs had performed a preventive maintenance by line patrolling to examine the weak points in the feeders. The problems found led to the preventive actions either upgrading components design or replacing the defective components with new ones. After the preventive works, the performance of most of feeder was found to improve except there is still high outage number in one feeder. The statistics of outage is shown in table 8.1.

Table 8.1 Outage statistics of Substation KO

Feeder	**2007**	**2008**
KO411	2	0
KO412	13	7
KO413	16	1
KO414	9	1
KO415	9	1
KO421	20	1
KO422	6	0
KO423	7	1
KO424	18	4
KO425	6	1
Total	*106*	*17*

Since all the feeders are installed with ASC conductor, the further reinforcement action would be to underground overhead feeder; so the highest outage feeder (KO412) is taken for analysis and recommended if undergrounding solution is justified. Followings indicate the data of KO412. Also noted that the condition grades of feeder components at present-year are quite good since feeder had just been renovated by preventive maintenance.

8.2.1 Feeder Data

1) Feeder description

1.1 Feeder no.: KO-412
1.2 Single line diagram:

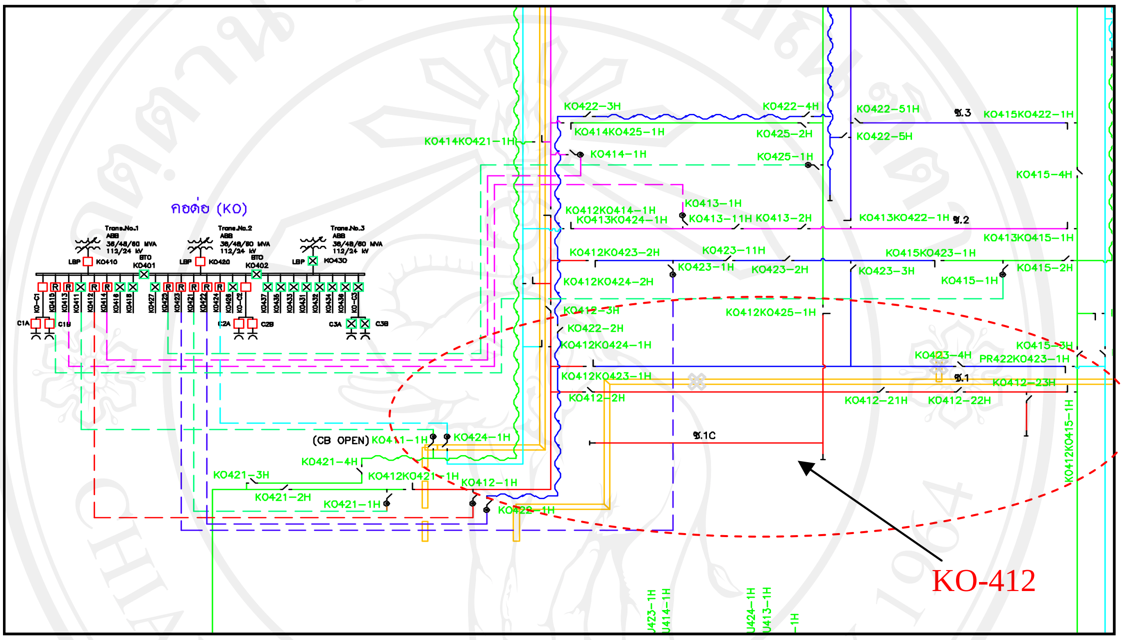


Figure 8.1 Single line diagram of Substation KO feeder

1.3 Geographical layout plan:

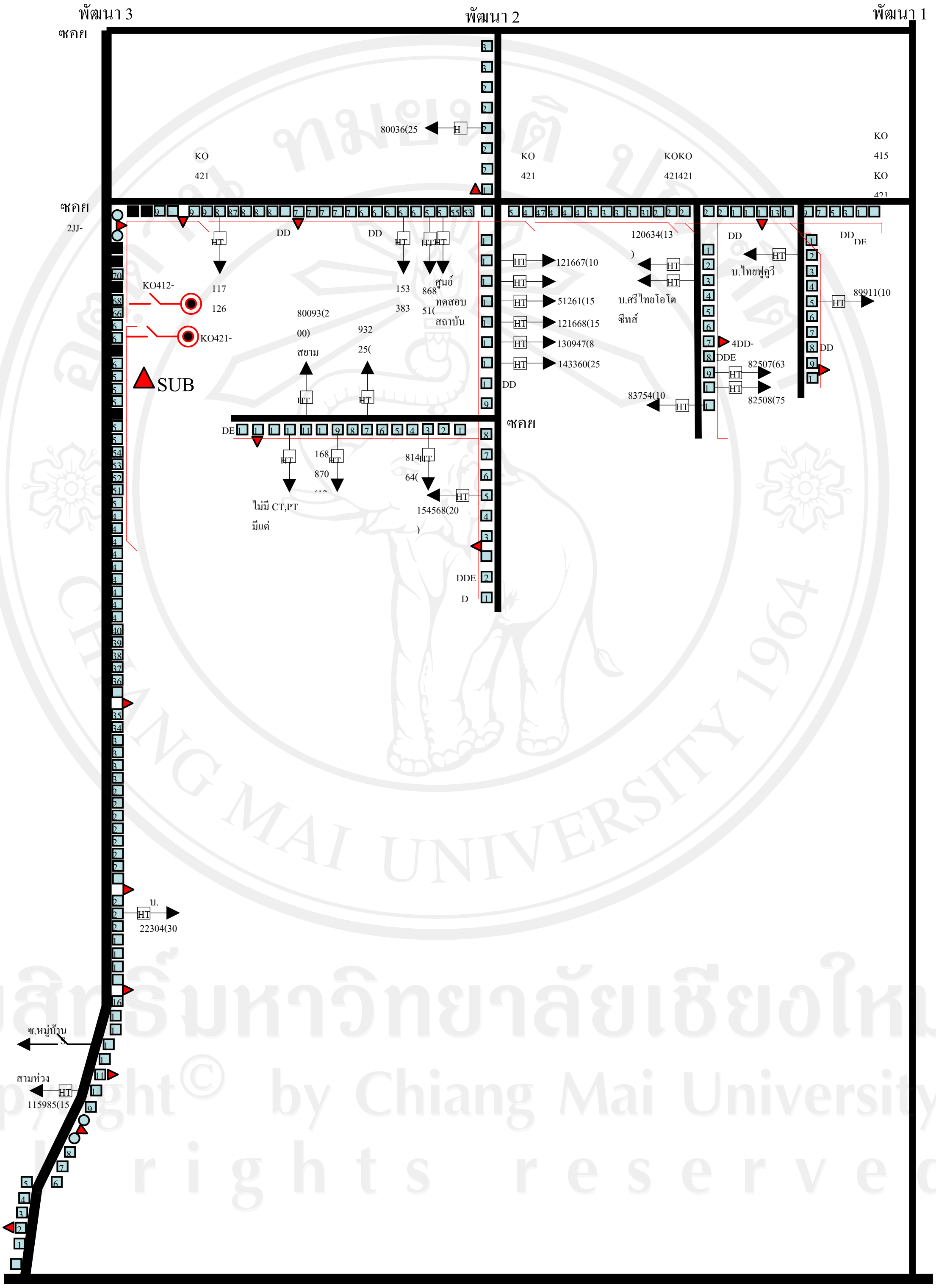


Figure 8.2 Line route of feeder KO412

1.4 Underground construction data
  1.4.1 Rated kV: 24kV
  1.4.2 Rated Ampere: 400 A
  1.4.3 Type of insulation: XLPE
  1.4.4 Conductor material: Copper
  1.4.5 Conductor size: 400 mm^2
  1.4.6 Length: 0.050 cct-km
  1.4.7 Age: 13 years
  1.4.8 Type of Ductbank construction: concrete encased
  1.4.9 Soil condition: wet soft clay
1.5 Overhead construction data
  1.5.1 Type of pole: 12m concrete
  1.5.2 Type of insulator: Pin-post and Pin Type
  1.5.3 Type of conductor: ASC
  1.5.4 Conductor material: aluminum
  1.5.5 Conductor size: 185 mm^2
  1.5.6 Rated Ampere: 400 A
  1.5.7 Length: 2 cct-km
  1.5.8 Age: 13 years
1.6 Connected customers
  1.6.1 Residential customers (kW): none
  1.6.2 Commercial customers (kW): none
  1.6.3 Industrial customers (kW): 12,400 kW
1.7 Reliability index
  1.7.1 SAIFI: 2.0 time/customer/year
  1.7.2 SAIDI: 6 min/customer/year

2) Operational and environmental stressors

Stressors from feeder operation and environment are shown in table 8.2 below.

Table 8.2 Operational and environmental stressors feeder KO412

Stressors	**Category/Value**	**description**
Load current	350A	87 % of normal current
Ambient temperature	39 ^{o}C	Area average temperature in summer
Ventilation degree	2	Normal wind and humid
Lightning exposure	3	Vicinity of trees and construction of same height
Lightning protection	3	Both lightning arrester and OH ground wire installed
Pollution existence	4	High accumulation of dust, salt vapor
Tree exposure	2	Some trees presence nearby
Accident exposure	3	Along the public road
Animal involvement	3	Small number of trees nearby as well as pole and wire attracted to birds

3) Feeder component condition grades

Table 8.3 illustrates the condition rating of feeder KO412.

Table 8.3 Condition rating of feeder components

Components	Assessed Condition					Numerical Grade
	good	*adequate*	*fair*	*poor*	*failed*	
Pole	0.1	0.9	0	0	0	1.9
Crossarm	0	0	0.35	.65	0	3.65
Guy	0	0.9	0.1	0	0	2.1
Fittings	0	0.8	0.2	0	0	2.2
Conductor	0	0.9	0.1	0	0	2.1
Insulator	0.05	0.95	0	0	0	1.95
Splice	0	0	0.15	0.85	0	3.85
Overhead ground wire	0	0.95	0.05	0	0	2.05
Lightning arrester	0	0	0.2	0.8	0	3.8
Fuse cutouts	0	0	0.4	0.6	0	3.6
Switch	0	0.6	0.4	0	0	2.3

8.2.2 Determination of Feeder Failure Possibility

The condition grades shown in table 8.3 were assessed before the preventive maintenance actions took place on the feeder. The overall feeder condition after defuzzification and adjustment was $(\frac{0}{good},\frac{0.329}{adequate},\frac{0.671}{fair},\frac{0}{poor},\frac{0}{failed})$ or 2.671 numerically. The deterioration rate assessed by the DSS yields 0.132 membership per year (assume that all components were brand-new at the time of installation). However, the feeder condition grade is improved to $(\frac{0.129}{good},\frac{0.871}{adequate},\frac{0}{fair},\frac{0}{poor},\frac{0}{failed})$ or 1.871 by the measures of preventive maintenance, so this value would be used as a present-year condition for calculating the condition grade of feeder on the remaining years. Figure 8.3 depicts the condition rating of feeder KO412 obtained from DSS.

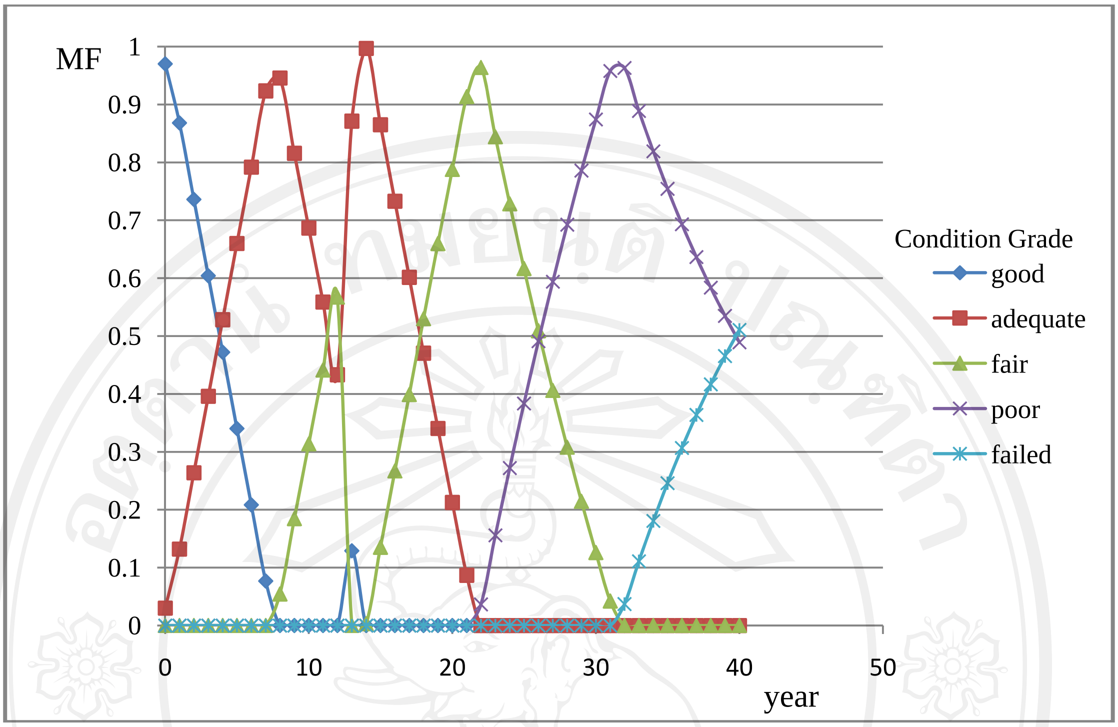


Figure 8.3 Condition rating of feeder KO412

In the assessment of possibility of failure on the feeder KO412, all the driving factors contributing to the failure of KO412 which include condition grade and stressors are taken into account. The result obtained by DSS is shown in figure 8.4. It is evident that the failure possibility in the early years is driven by the external stressors, i.e. pollution and it starts increasing in the late years when severely deterioration of feeder components begins to take place.

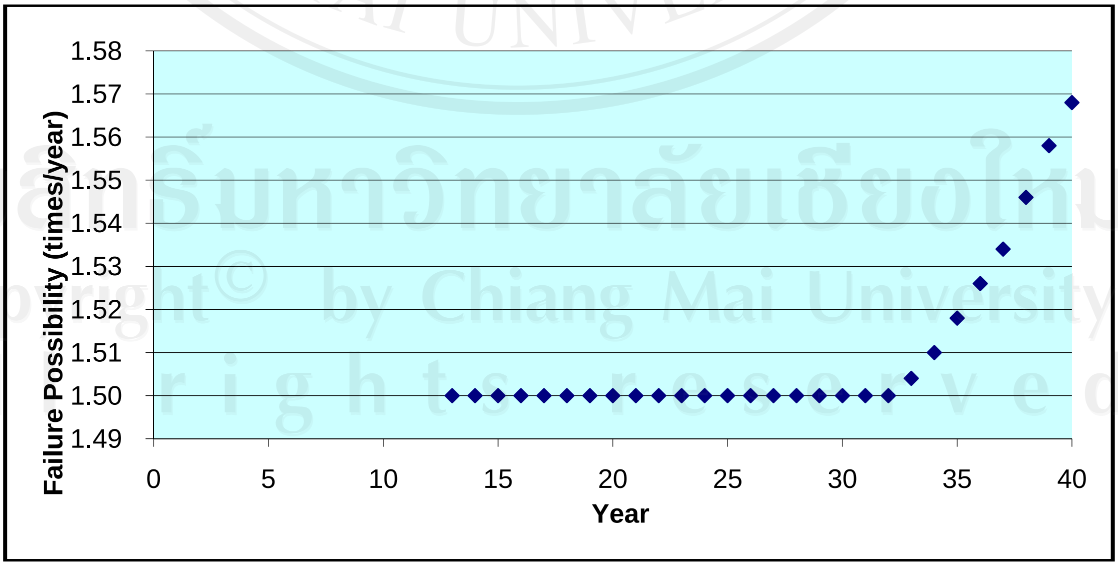


Figure 8.4 Failure possibility of feeder KO412

8.2.3 Determination of Financial Impact

Figure 8.5 illustrates the result of cost-benefit analysis obtained from the DSS. Since the existing feeder is an overhead with ASC conductor, so only underground system is introduced for rehabilitation candidates. From the result, since the outage cost saved by the introduction of underground feeder is very far below its investment cost, so underground feeder will never gain the preference if only considering the financial benefit (it is the same for almost every circumstance).

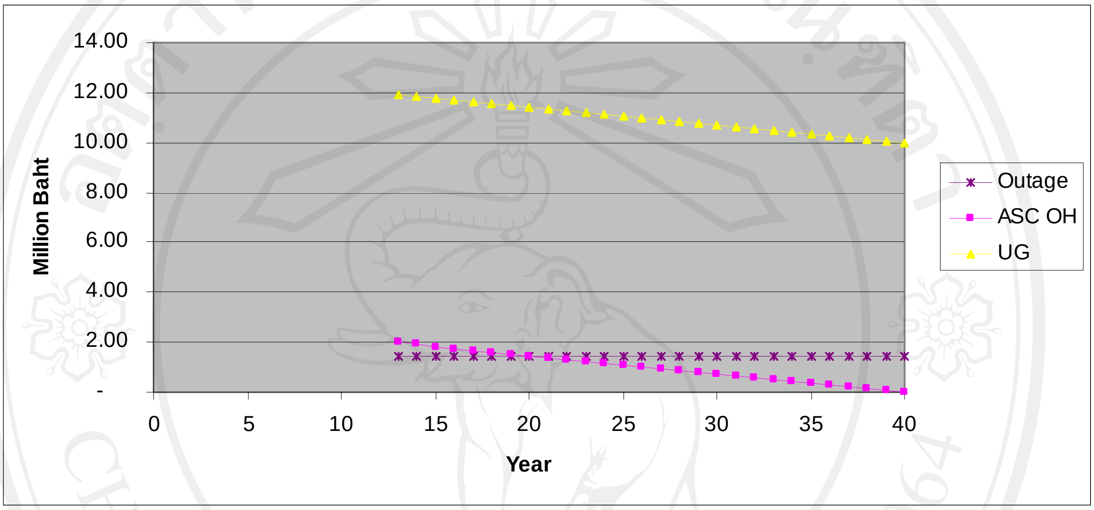


Figure 8.5 Illustration of cost and benefit among options

Another observation should be pointed out from the results is it looks that the outage cost (benefit) overcomes the remaining cost of ASC feeder around year 20. Should it means that it is financially profitable if existing feeder be replaced by the new one of same design? The answer to this question is NO because the failure occurs during these years are caused by external stressors (pollutions) which cannot be eliminated by the features of ASC feeder. Replacement with new ASC feeder is sensible only when component deterioration starts dominating, e.g. around year 33 for this case (see figure 8.4).

8.2.4 Multicriteria Decision Analysis

When coming to the decision whether KO412 should be rehabilitated by underground construction or not, the other perspectives shall be brought into the equation. Technical issues which comprise the reliability, construction, and maintenance of feeder are taken into account. As well, the social agenda such safety and aesthetics are also considered. The decision hierarchical structure is shown in figure 8.5. Table 8.4, 8.5 and 8.6 indicate the ranking of options when assessor put different weight on technical and financial criteria. The results obtained still shows the preference of ASC overhead over underground system except the latest case where weight is significantly stressed on the underground.

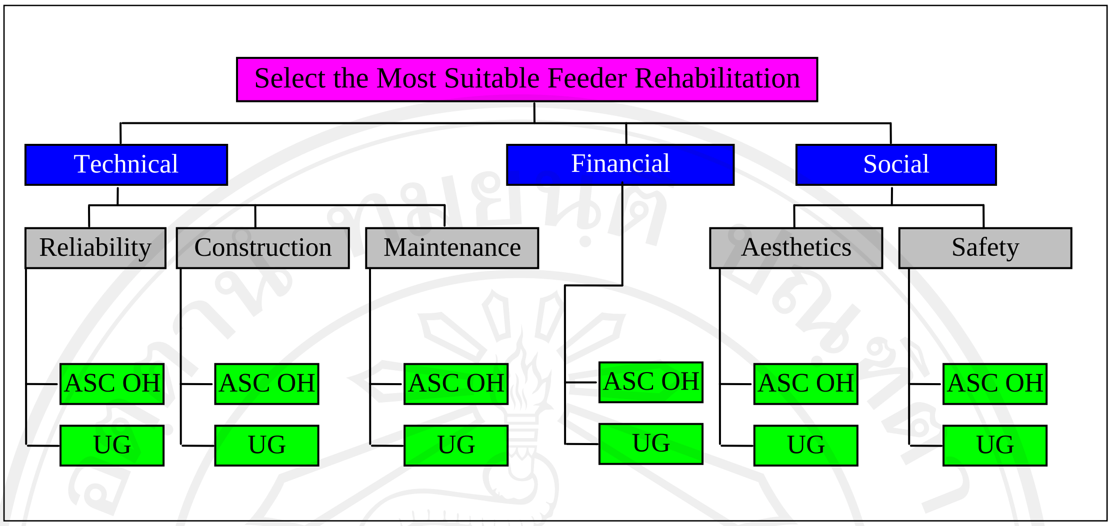


Figure 8.6 Feeder rehabilitation decision hierarchy

Table 8.4 Overall ranking of alternatives when financial criterion is moderately important as compared to technical

Criteria	**Significant Weight**	**ASC OH**	**UG**
Reliability	0.1763	0.1429	0.8571
Construction	0.0215	0.8333	0.1677
Maintenance	0.0537	0.8333	0.1677
Finance	0.5889	0.9000	0.1000
Safety	0.1194	0.1429	0.8571
Aesthetics	0.0398	0.1000	0.9000
Overall marks (%)		63.89	36.11

Table 8.5 Overall ranking of alternatives when technical criterion is equally important as compared to financial

Criteria	**Significant Weight**	**ASC OH**	**UG**
Reliability	0.3227	0.1429	0.8571
Construction	0.0394	0.8333	0.1677
Maintenance	0.0984	0.8333	0.1677
Finance	0.4615	0.9000	0.1000
Safety	0.0577	0.1429	0.8571
Aesthetics	0.0192	0.1000	0.9000
Overall marks (%)		58.66	41.34

Table 8.6 Overall ranking of alternatives when technical criterion is moderately important as compared to financial

Criteria	**Significant Weight**	**ASC OH**	**UG**
Reliability	0.4580	0.1429	0.8571
Construction	0.0557	0.8333	0.1677
Maintenance	0.1392	0.8333	0.1677
Finance	0.2510	0.9000	0.1000
Safety	0.0720	0.1429	0.8571
Aesthetics	0.0420	0.1000	0.9000
Overall marks (%)		46.65	53.35

8.2.5 Discussion and Analysis

Following findings and recommendations have been addressed from the results:

- Failure possibility of 1.5 times/year estimated from DSS is lower when compared to 7 of actual events occurred in feeder KO412 in year 2008. However, this figure looks alright when compared to other feeders operating in neighboring area (see table 8.1). The high number of outage taking place in KO412 must have been influenced by factors particularly inherent to KO412 such as quality of component material, installation workmanship, system design or operation procedure, etc.
- Deterioration of components looks faster than expected; this may be due to components being highly contaminated by pollution as well as the quality of component material and production, system design and installation workmanship.
- Under certain stressors, i.e. pollution, some components such as lightning arrester, fuse cutout, or splice which has connection points deteriorate very much faster than others and consequently leads to failure and eventually causes feeder fail to operate.
- Length of feeder contributes to the failure of feeder since there are more components subjected to failure and it also exposes to more stressors.
- Failure possibility obtained from DSS is dominantly induced by stressors (stressors prevail condition grade) until components become significantly deteriorated in the late years.
- Although ASC conductor is employed in this feeder, but the connection points (splices) are not normally (impractical to) insulated so trees still have an impact on the operation of feeder.
- Undergrounding system cannot compete with overhead counterpart if only financial aspects are considered. It is true for almost any circumstances except there exist particular requirements such as special reliability customers or city aesthetics.

- Although the result from MCDA indicates the underground feeder being preferred in the latest case, but the reliability index (SAIFI, SAIDI, see section 8.2.1) still remain within the guaranteed standard (table 8.7) so utility hesitates to invest due to the high investment costs. However, the customers may push the project to go ahead by provide the money contribution into the project.
- For the case of feeder KO412, the tougher preventive measures such as frequent tree trimming, insulator wash or splice inspection and correction are required to secure feeder performance.
- DSS only provides information to asset manager with every perspective of the problems, not make decision on its own; the decision making has to be perform by asset manager himself.

Table 8.7 Reliability standard in MEA area

Service Area	**SAIFI**	**SAIDI**
City/Business	2.46	54.86
Industrial	2.63	54.23
Suburb	4.32	100.37
Overall MEA	2.79	62.07

8.3 Conversion of Overhead Distribution Feeders in World Heritage Site

The second case study is presented to demonstrate the applicability of DSS to develop the types of undergrounding, formulate the decision hierarchy, evaluate the options, and select the most appropriate undergrounding methodology for the feeder of which there exist needs from stakeholders to purposely underground distribution network. *This case study differs from the first one in the sense that the decision of whether or not the overhead feeder should be undergrounded was already made but why and how to do it is the question the asset manager seeks the answer. So this case is intended to demonstrate the employment of multicriteria decision analysis methodology to bring about the final decision on what option of underground system is the most suitable in the context of World Heritage Site where there are quite a number of criteria to consider and some of them are difficult to quantify.* The case would reveal the undergrounding techniques employed for distribution network, criteria for option evaluation, how the changes in assessor's preference impact the outcomes as well as the cost figure of each option.

The city of temples has been recognized as a World Heritage Site due to its architectural and cultural richness. All its traditional constructions that exist in the city are registered and recorded with every detail of structure and architecture for the purpose of preservation. Because of its cultural richness, the city has to accommodate a large number of tourists pouring into the city. The number increases sharply every year. This requires the electric utility to expand its network to cope with such increasing demand. Apart from enhancing the distribution network to meet the drastically increase in power demand, it is also required by world heritage regulation to keep the world heritage scenery unintact which in turns required to underground all existing overhead infrastructures. This is a challenge for the city’s electric utility.

It is obvious that the ultimate goal of the electric utility to manage this challenge is to underground all its power distribution network that run throughout the city. However, there are many factors and alternative choices that have to be taken into account in the decision making process of selection the undergrounding methodologies. This problem hence falls into the multicriteria decision making process which suit the framework proposed in this thesis.

The followings will discuss in details to show how effective the framework is how the solution to the problem is obtained. The explanation is given step by step of procedure which stated in the previous chapters.

8.3.1 Definition of Problem and Goal

As stated above, the problem is how to convert an overhead power distribution network to underground system. However, there are a numbers of ways to underground the overhead distribution facility, so the ultimate goal of tackling this problem is to select the most appropriate methods of undergrounding in the context of world heritage site.

8.3.2 Analysis of Requirement and Constraints

The infrastructure business involves with various stakeholders. As having been discussed in the previous chapter, the utility, customers, employees, or investors are the kinds of stakeholders. In addition, since the utility has to run their network throughout the service area via the public properties such as roads, railways, canal, etc; the local community also plays an important role in the implementation of utility network. Different stakeholder calls for different requirement.

For the undergrounding project of the city of temples, the key stakeholders include the electric utility, customers, and local community. During the first stage of project feasibility study, each stakeholder group was enquired to view their requirements toward the implementation of underground distribution network in the city. The requirement statements that have been given by each stakeholder group are listed as follows.

Utility

- Cost of implementation shall be cheap.
- Construction and installation work shall be simple.
- Operation and maintenance of the network shall be easily made.
- There shall be fewer complaints during the construction of the network.
- The conversion process from existing overhead to new underground shall be less complicated.
- Underground feeder portion that already existed in the system shall be included in the new feeder.

Customer

- Electricity shall be supplied continuously and undistortedly.
- Electricity price shall be cheap.
- Service from the utility shall be good.
- New connection can be made anytime.

Community

- Aesthetic of the city shall be kept intact.
- Regulation of world heritage shall be followed.
- Safety of public lives and properties shall be guaranteed.

All these requirements lay down the criteria for implementing the underground distribution network in the city of temples. The criteria and subcriteria can then be formulated as shown in table 8.8 below.

Table 8.8 Set of criteria of undergrounding project

Criteria	**Subcriteria**	**Description**
Technical	Reliability	well protection and well performance of network equipment
	Installation	Simplicity of construction and installation of duct, cable, switchgear and transformer including less adverse effect to public sector
	Maintenance	Convenience of underground network maintenance (inspection, repair, replacement) and operation
	Extension	Network expansion (new substation connected) and new customer connection can be achieved with ease
	Conversion process	Simplicity of conversion step from existing overhead to underground) as well as including less adverse effect to customers
Aesthetic		The network shall be in harmony with the cityscape and existing construction
Safety		Safety to employees and public community
Cost		Cost of implementation; this cost will eventually be borne by every stakeholder

8.3.3 Identification of Alternative Choices

From chapter 4, it is evident that the underground feeder comprises four main parts: cable container, cable assembly, switches, and transformers. For sake of effectiveness in forming alternatives, such four parts can be recombined into two groups. Those are the cable system which grouping cable container and cable assembly together, and the distribution substation which comprises the switches and transformers.

Now take a closer look on the methodology that utility adopt to achieve the underground distribution cable system and substation. The methods the utility employs to build underground cable system include the direct burial and cable-in-duct installation. Furthermore, the construction of duct can be categorized into an open-cut ductbank, the horizontal directional drilled duct, the pipe-jacking ductbank, or even the tunnel. Followings are the short description of each method.

Direct Burial Cable Installation

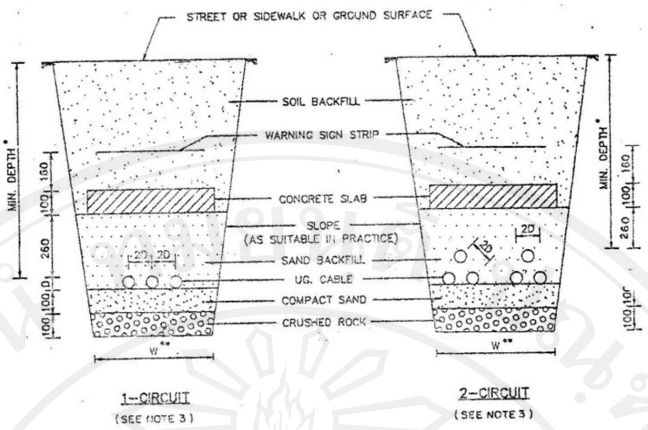
Direct burial is the simplest and cheapest way to construct the underground power system. After the ground is excavated, cable will be just laid down in the groove and then backfilled with the soil. To enhance cable protection, trough and concrete slap may be put on top of the cables. Joint bays are required when two or more sections of cable are to be jointed. From the perspective of the cable mechanical protection and the cable maintenance, this method may not be a preferred choice. It is usually employed when construction is made within the utility or customer property. However, this method is still a preferable option in case that earth digging activity in the public space can be totally controlled.

(a) cable laid in groove

(b) concrete encased ductbank

(c) joint bay located under road surface

(d) internal view of joint bay



CABLE LAYING	MIN. DEPTH* (MM.)	W (MM.)**	
		1–CIRCUIT	2–CIRCUIT
UNDER ROAD OR STREET	1200	500	800
UNDER SIDEWALK	900	500	800
CUSTOMER AREA	900	AS REQ'D	

(f) arrangement of cables and refill

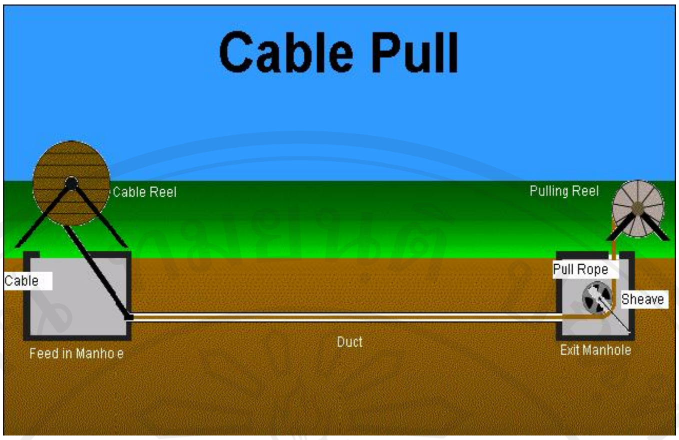
Figure 8.7 Direct buried cable installation

Cable Installation in Duct

In this case, the ducts or pipes must be placed underground in advance, during the construction of road for instance. Then the cables will be pulled and placed in ducts anytime required afterwards. The methods of duct construction will be described in the section. Since the cable is installed inside ductbank, it will be protected from any external forces that may be accidentally applied to such cable. In addition, cable maintenance such as fault locating, cable repair or replacement is more convenient than direct burial.

(a) internal view of manhole and duct

(b) pulling of cable in duct



(c) Pulling of cables between manholes

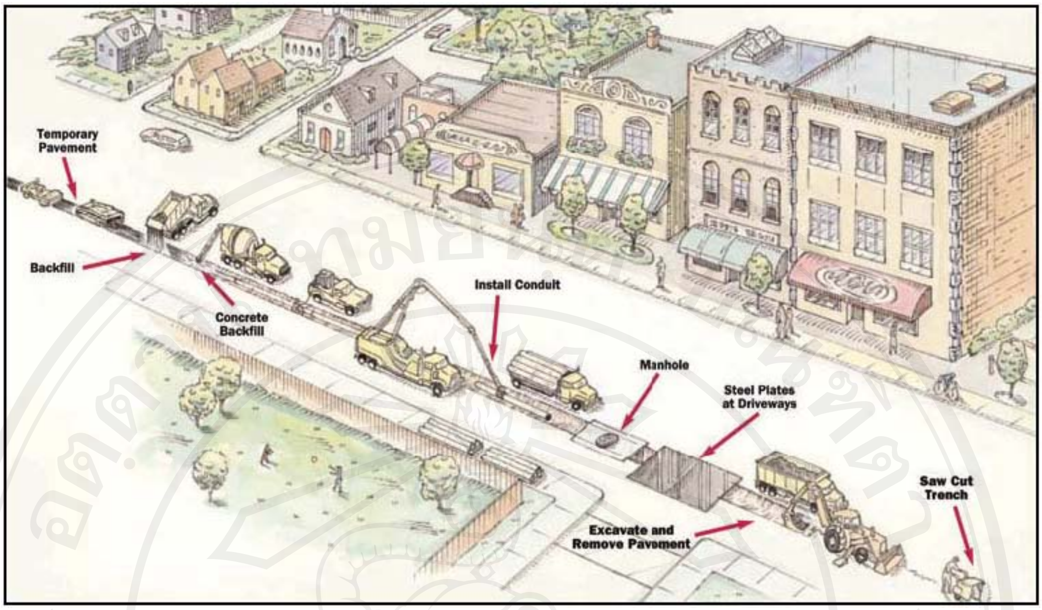
Figure 8.8 Installation of cable in duct

Open-cut Ductbank

With this method, the number of ducts for installing the cables will be formed up inside a long groove and encased with concrete; joined by manhole at certain distance. This method needs the surface excavation similar to the direct burial, but it is more expensive. Another disadvantage is its fragility due to a ground slide or soil movement. Since the cable is installed in the encased ducts so the cable is well-protected from the nearby digging activities. Moreover, not only this method is able to offer a spare duct for the future cable installation; but it also allows utility to use the same duct in case of cable upgrade or replacement. The open-cut ductbank is the most preferable option in case of newly constructed road, since it can be made at the same time of road construction.

(a) arrangement of ducts

(b) concrete encased ductbank



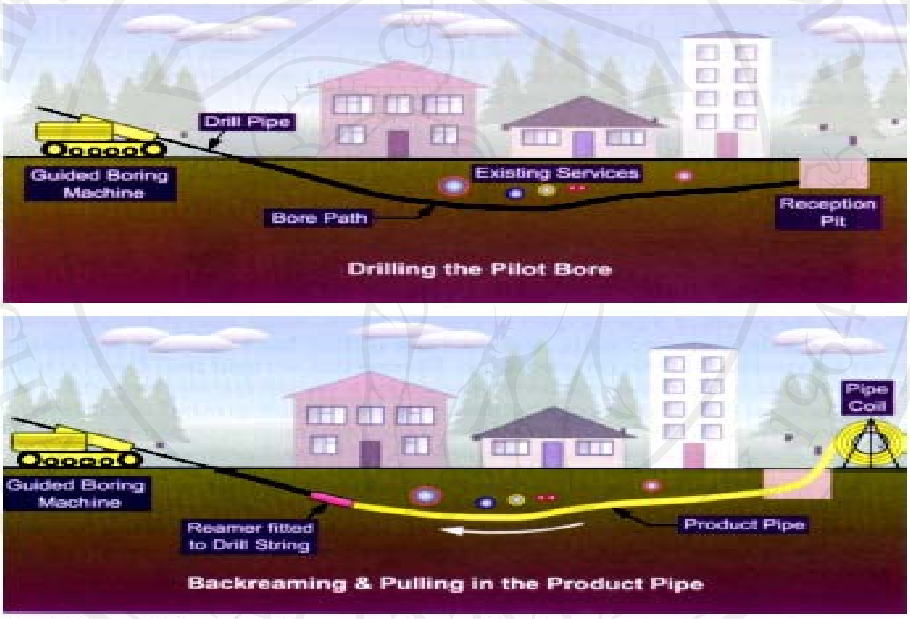
(c) construction of open-cut ductbank

Figure 8.9 Open-cut ductbank

Horizontal Directional Drill (HDD) Duct

The directional drilling process begins with boring a small, horizontal hole under the crossing obstacle, such as canals or roadways, with a continuous string of steel drill rod. When the bore head and rod emerge on the opposite side of the crossing, a special cutter, called a back reamer, is attached and pulled back through the pilot hole. The reamer bores out the pilot hole so that the pipe can be pulled through. The pipe is usually pulled through from the side of the crossing opposite the drill rig. A special mud, called bentonite, is used to reduce drilling torque, impart lubrication to the pipe, provide annular flushing of the freshly cut borehole soil debris, and give stability and support to the bored hole. With this method, utility can avoid the surface digging, stay away from underground obstacle, while the price is comparable to the open-cut ductbank. The only constraint of employment of this kind is the soil should be soft clay otherwise the bore head and back reamer may not be able to cut the soil. In addition, it also has the disadvantage of less protection for the cable as compare to concrete encased ductbank because the ducts in use are of polymer type and no additional protection is applied around the ducts, being clogged by accumulated seeping mud due to its sagging.

(a) drilling machine (b) pull back of polymer ducts



Drilling of the pilot bore (top) and backreaming (bottom) to enlarge the hole and install the pipe.

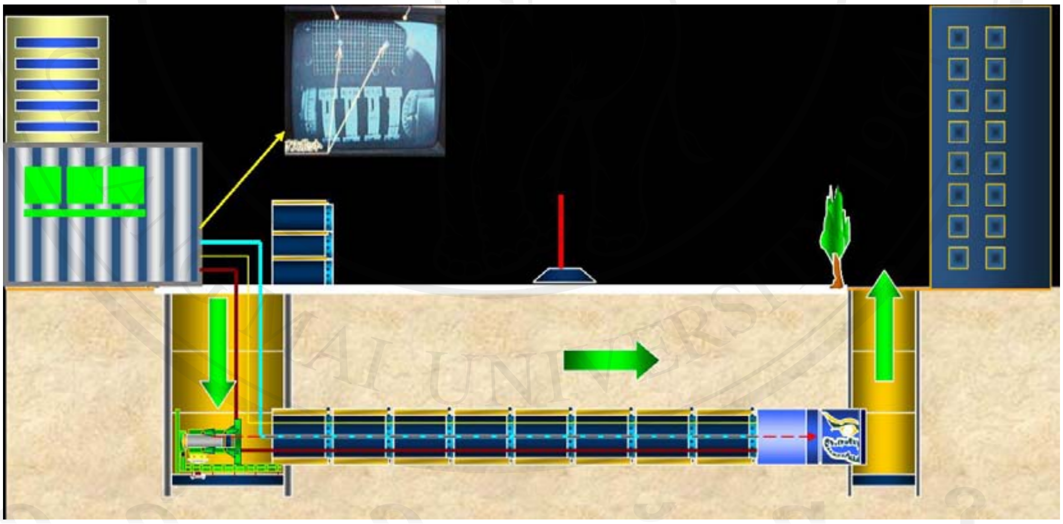
(c) construction of horizontal directional drilling ducts

Figure 8.10 Horizontal directional drilling ducts

Pipe- jacking Ductbank

Pipe jacking is a technique for installing underground pipelines, ducts and culverts. In order to install a pipeline using this technique, thrust and reception pits are constructed, usually at manhole positions. Powerful hydraulic jacks are used to push specially designed pipes connected to tunneling machine through the ground, at the same time as excavation is taking place within the shield by machine. The method provides a flexible, structural, watertight, finished pipeline as the tunnel is excavated. Jacking and excavation are remotely controlled using techniques that require sophisticated electronic guidance systems using a combination of lasers and screen based computer techniques. After the pipe is already in place, the ductbank is placed inside and then filled the pipe with concrete. The cost of implementation is much more expensive than the abovementioned methods; using more complicated machineries. However, it offers less digging; able to avoid the underground obstacle, has less affect from ground movement, and offers supreme protection for cables. It is usually employed for crossing underneath the obstacle.

(a) arrangement of ducts in concrete pipe (b) concrete pipe filled with concrete



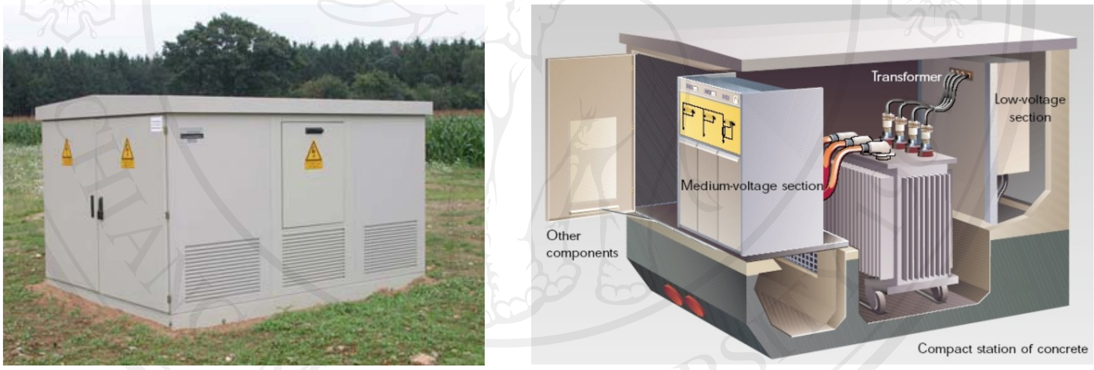
(c) illustration of pipe jacking process

Figure 8.11 Pipe jacking ductbank

The second group of the underground distribution network components is the distribution substation. The distribution substation which is usually employed by the utility are of two types: conventional and compact unit. The conventional substation is obtained by simply installing the switchgear and transformer inside the building which was constructed beforehand at site whereas the compact unit substation, every thing is completely installed and fabricated at the factory before mounting at site. Figure 8.12 and 8.13 show the graphical illustration of both types.

(a) substation house (b) switchgear and transformer

Figure 8.12 Conventional distribution substation



(a) unit substation (b) internal view

Figure 8.13 Compact unit distribution substation

When the combination of the cable system and distribution substation as described above are formed, the alternative choices to be employed for undergrounding the overhead network in the city of temples are then be formulated. However, by preliminary expert judgment, the HDD and pipe jacking methods are discarded for this undergrounding case. This is because the HDD does not suit the soil condition of the city mountainous area; and the pipe jacking costs too high to obtain while the simple excavation methods can be done with less difficulty. Hence, the options for realizing the underground distribution network in the city of temples can be formulated as follows.

- Direct buried cables and conventional substation (DR-CS)
- Direct buried cables and compact unit substation (DR-US)
- Cable in ductbank and conventional substation (DB-CS)
- Cable in ductbank and compact unit substation (DB-US)

Using the asset categorization framework proposed in chapter 4 and work breakdown structure discussed in chapter 6, the cost to obtain each undergrounding alternative can be summarized and tabulated in table 8.9.

Table 8.9 Cost of various undergrounding projects

Feeder Asset	**Project Costs (Baht)**			
	DR-CS	**DR-US**	**DB-CS**	**DB-US**
Cable container	13,403,600	11,802,000	32,407,200	30,805,600
Cable components	11,327,400	10,760,400	14,244,300	13,677,300
Underground switches	25,443,250	49,171,500	25,443,250	49,171,500

8.3.4 Development of Decision Model Hierarchy

It shall be noted for the safety criterion that the experts view the hazardous degree of all four implementation options to the employees and public community similar. Although there are some minor difficulty affected people's lives during the construction stage, the underground power system is regarded as the safest system of electric network. The safety criterion is hence discarded from the decision model. The decision model hierarchy can then be developed as shown in figure 8.14.

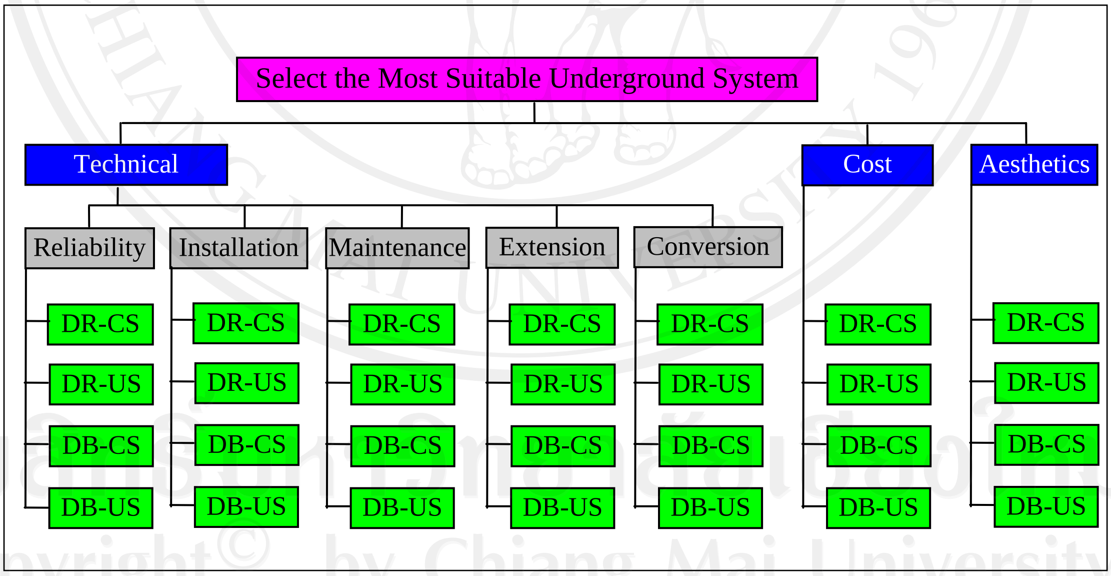


Figure 8.14 Undergrounding methodology decision hierarchy

8.3.5 Priority Ranking Using AHP

Utility engineers and managers as well as the other concerned authorities were invited to the meeting and asked to express their opinions in terms of preference towards four implementation options proposed. The comparison matrixes were then formulated and the final priority ranking of all four options was laid out. Table 8.10 shows the overall ranking of implementation options obtained from analysis.

Table 8.10 Overall ranking of implementation options

Criteria	**Significant Weight**	**DR-CS**	**DR-US**	**DB-CS**	**DB-US**
Reliability	.1183	.0477	.1080	.2588	.5854
Construction & installation	.0453	.0732	.1969	.1969	.5330
Maintenance	.0534	.0569	.1219	.5579	.2633
Extension	.0159	.3750	.1250	.3750	.1250
Conversion procedure	.0275	.1250	.1250	.3750	.3750
Aesthetics	.6333	.3750	.1250	.3750	.1250
Cost	.1062	.5579	.2633	.1219	.0569
Overall marks (%)		31.81	14.08	33.61	20.50

8.3.6 Discussion and Analysis

From above case study, the findings and discussion on the results are illustrated as the followings:

- It is also apparent that most of the criteria (except cost figure) cannot easily transform into quantifiable terms. But the decision support framework offers the possibility to make them comparable.
- Different feeder undergrounding alternatives can be assembled using the asset model provided in the asset categorization. In addition, the cost figure of each alternative can be easily quantified.
- It is evident from the results shown in table 8.10 that if taking all the preset criteria stated in table 8.8 into consideration, the option of cable in ductbank and convention substation (DB-CS) is the most preferable option. This is due to the consideration that:
    - It is obvious that aesthetic is the prime important for city distribution network undergrounding. So the construction type that can blend into local environment would be preferred.
    - Apart from the reliability, construction and conversion process is need to be examined to make an undergrounding processes run effectively and smoothly.
    - Cost and reliability are approximately equally important and have less significance than aesthetic issue.
    - Although DB-CS option is not the most financially preferable, but due to its higher reliability, simplicity of construction and installation, ease of maintenance, ease of extension and simple to conductor an overhead to underground conversion process.
    - The safety criterion is not brought into the AHP evaluation process; this is because the experts gave a view that all four options offer the same level of safety (since all of them are already underground).
- If there exist more criteria/requirements to examine, they can be added into the decision hierarchy without any difficulty.