

CHAPTER 2

RESEARCH METHODOLOGY

2.1 Introduction

The reliability performances of generation system are normally not affected by the regional characteristics to be presented in this Chapter. The scheduled outages of transmission system in terms of the outage duration and frequency of customers' power supply, or the SAIDI and SAIFI, are much less than the forced outages of the same transmission system, because the utility can properly coordinate the construction or maintenance work of transmission system with the customers. Both the generating unit outages and the scheduled outages of transmission system shall not be accounted in this dissertation. Namely, the theme of this dissertation is the SAIDI and SAIFI performance of transmission and distribution systems but excluding the scheduled outage of transmission system. The objective is to propose a rational procedure for comparison of the relative SAIDI performance as well as the relative SAIFI among the regional power systems of same utility.

Taking Taipower as an example, the statistics of SAIDI and SAIFI records include both the forced outage and the scheduled outages. Referring to Table 2.1, for the SAIDI, 20% is due to forced outage and 80% due to scheduled outage. As to SAIFI, referring to Table 2.2, forced outage accounts for 70% and scheduled outage accounts for 30%. As to the causes of forced outage, in the year of 2002 of Taipower, the cause percentages for the transmission line outage are shown in Fig. 2.1, for the substation outage are shown in Fig. 2.2 and for the distribution system outage are shown in Fig. 2.3 [45-47].

Table 2.1 SAIDI Records caused by Forced and Scheduled Outages of Taipower

(Minutes/Year-Customer)

Year	1997	1998	1999	2000	2001	2002	2003
Forced	17.67	15.79	12.44	13.25	13.93	11.342	7.039
Scheduled	100.90	95.93	83.64	73.19	71.22	58.052	34.909
Total	118.57	111.72	96.08	86.44	85.15	69.394	41.948

Table 2.2 SAIFI Records caused by Forced and Scheduled Outages of Taipower

(Times/Year-Customer)

Year	1997	1998	1999	2000	2001	2002	2003
Forced	0.83	0.79	0.61	0.67	0.68	0.550	0.404
Scheduled	0.37	0.34	0.31	0.30	0.28	0.226	0.141
Total	1.20	1.13	0.92	0.97	0.96	0.776	0.545

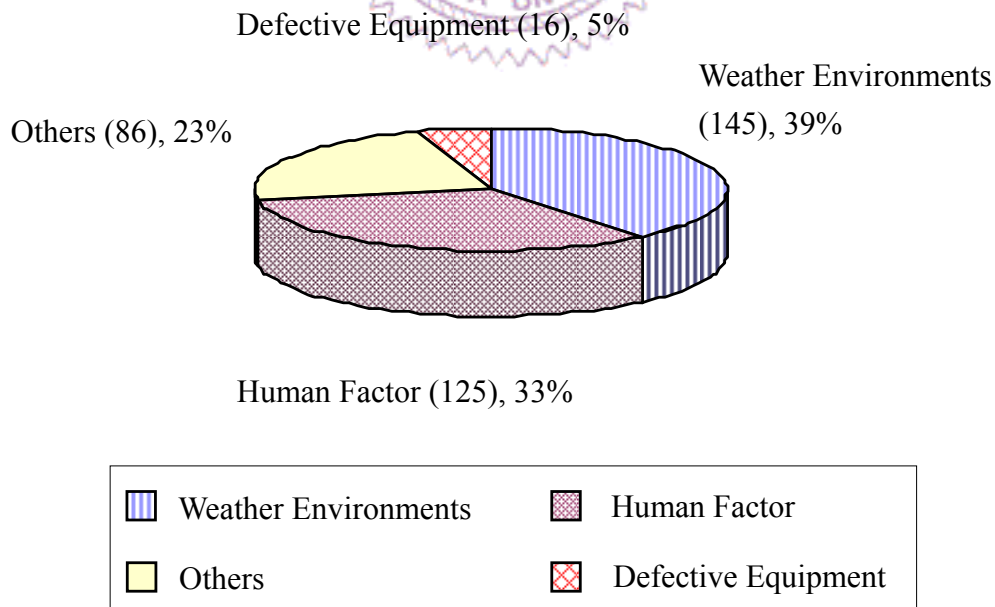


Fig. 2.1 The causes of forced outage on transmission line, in the year of 2002 of Taipower.

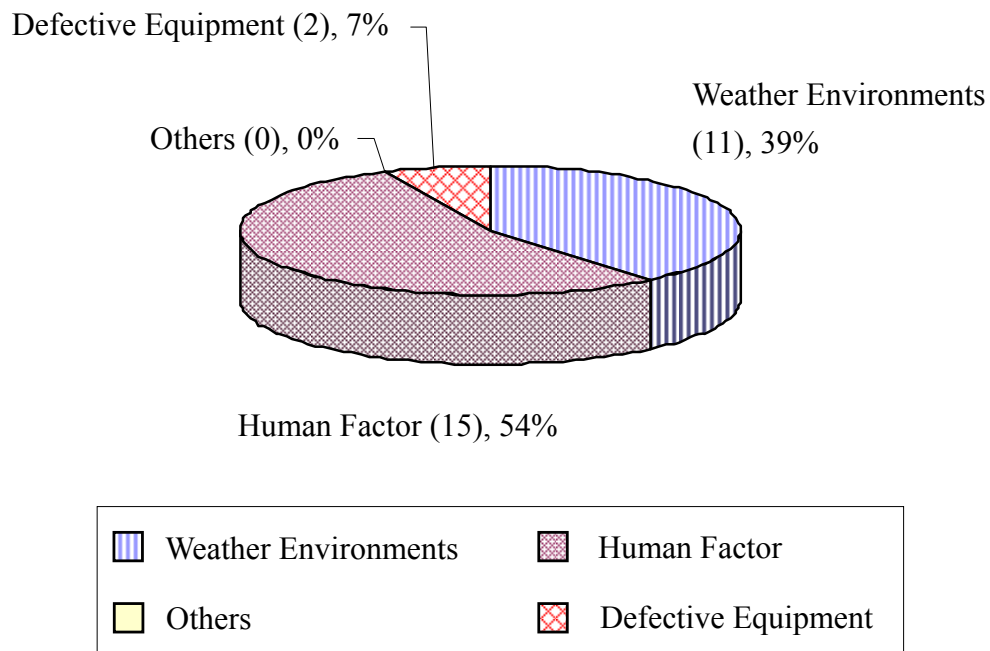


Fig. 2.2 The causes of forced outage on substation of transmission system, in the year of 2002 of Taipower.

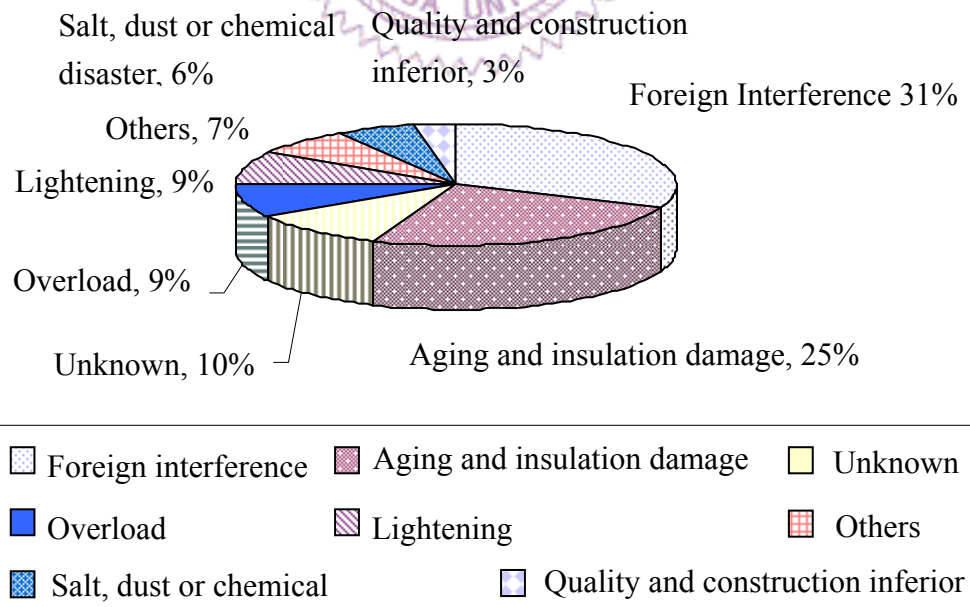


Fig. 2.3 The causes of forced outage on distribution system, in the year of 2002 of Taipower.

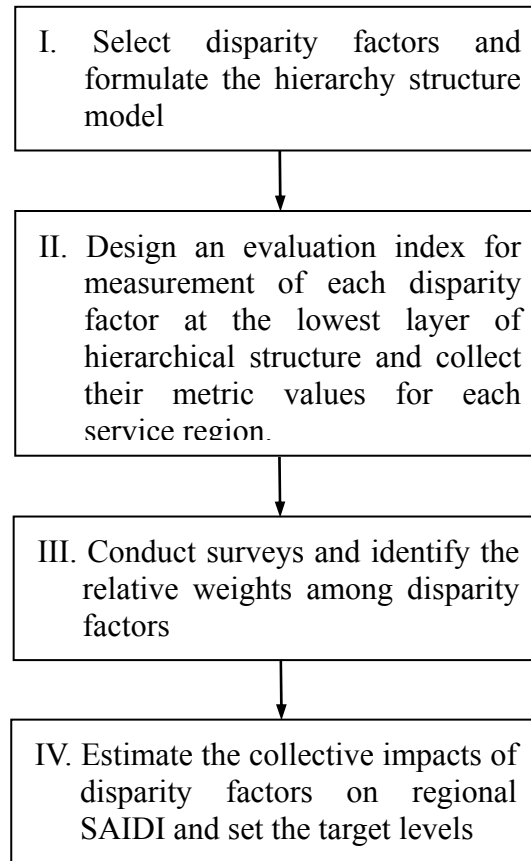


Fig. 2.4 Flowchart of overall procedure in setting the regional SAIDI target levels for the service regions of a utility.

As the AHP is adopted in this thesis as the key methodology for evaluation of the SAIDI and SAIFI target values across the regional transmission and distribution systems, the AHP including its working procedure shall be discussed in this chapter.

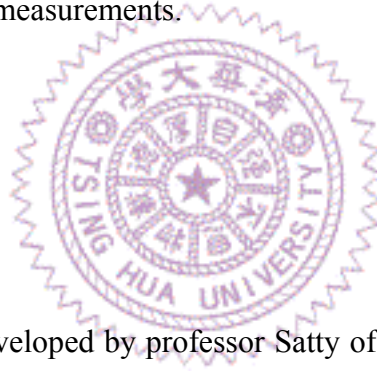
2.2 Research Flow

To set the SAIDI or SAIFI target values across the regional power systems, the disparity among these regions have to be identified. How are these disparities measured and how importantly do these disparities affect the regional SAIDI (or SAIFI) should next be clarified. The AHP is selected in this research to assist in the

weighting of these disparity factors. The enumeration and the measurement of these disparity factors are mainly based on the experience of utility engineers. Surveys are conducted for acquisition of the experiences. Figure 2.4 depicts the overall procedure in setting the regional SAIDI target levels for the service regions of a utility. The same procedure has been applied to setting SAIFI.

Referring to Fig. 2.4, the overall procedure can be divided into four stages:

- (1) Exhaustive enumeration of disparity factors,
- (2) Design of an index for measurement of regional disparities on each factor,
- (3) Evaluating the relative weights among factors, and
- (4) Derivation of the regional target levels by evaluating the weights and the regional disparity measurements.



2.3 The Essence of AHP

The AHP has been developed by professor Satty of University of Pittsburgh and other researchers since 1971 [48-61]. This theory can solve a complex problem which comprises a multitude of influential elements, controllable or not, through performing decomposition by hierarchies and synthesis by finding relations through informed judgment. The main purpose of the process is to find out how strongly do the individual factors at the lowest layer of the hierarchy structure influence its top target. That is led to identification of their intensity or weights. This determination of the weights of the lowest factors relative to the goal can be reduced to a sequence of priority problem, one for each layer, and each such priority problem to a sequence of pariwise comparisons.

2.3.1 Hierarchy Structure

The basic hierarchy structure of AHP is shown in Fig. 2.5. The evaluation target is positioned at the first layer. The factors which directly affect or structure the evaluation target are positioned at the second layer. As shown in Fig. 2.5, there are totally N_2 factors at the second layer. Among them, we assume the second factor can be detailed to N_3 factors which are shown at the third layer. The purpose of AHP is to analyze the contribution to the evaluation target of each factor on the lowest layer of the hierarchy structure.

There are two kinds of parameters need to be collected or calculated for each disparity factor shown in Fig. 2.5 through the process.

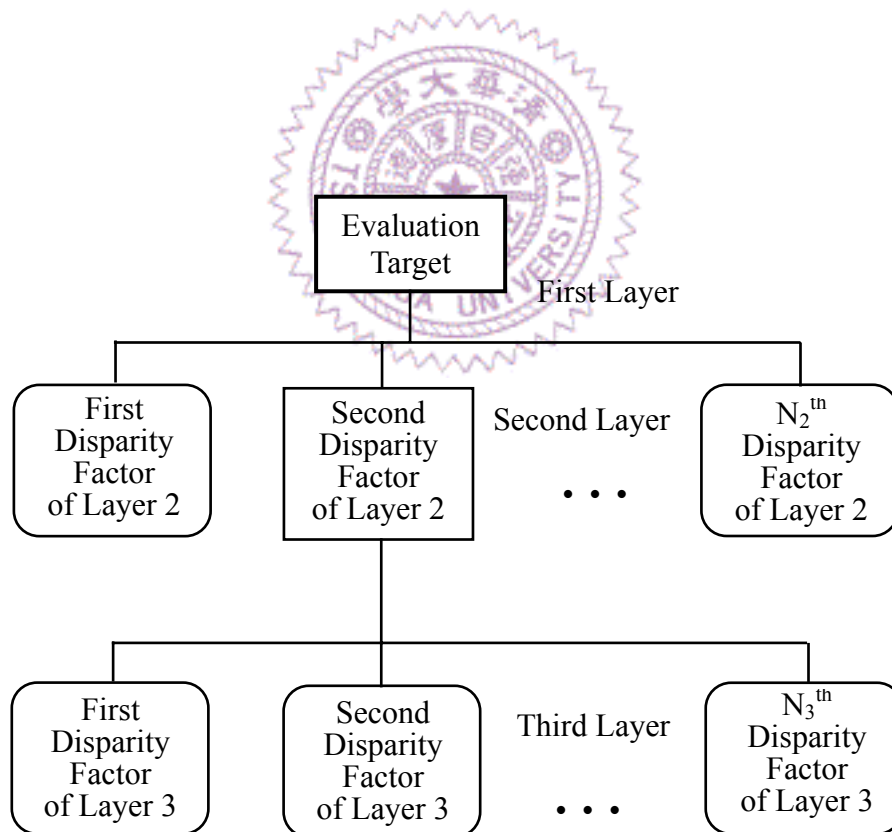


Fig. 2.5 The hierarchy structure model formulated according to AHP (three layers as an example).

- Evaluation Indices

The indices refer to the numerical values which are designed to measure the disparity factors at the bottom layer of the structure such as those at the third layer of Fig. 2.5. These data could be collected subjectively from decision makers or could be taken directly from the objective data source.

- Relative Weights

The weights refer to the subjective data which measure the relative importance among factors at the same layer. These weights are commonly collected through questionnaire interview with decision makers.

Only the metric values of factors at the lowest layer of the structure need to be collected. Each of the metric values of factors at the upper layers is derived from the factors located at the corresponding lower layers, i.e.,

$$V_{m,i} = \sum_{i=1}^{N_{m+1}} (V_{m+1,i}) (W_{m+1,i}) \quad (2-1)$$

where

$V_{m,i}$: metric value for the i^{th} factor at the m^{th} layer;

N_{m+1} : total number of factors at layer $m+1$;

$V_{m+1,i}$: metric value for the i^{th} factor at layer $m+1$;

$W_{m+1,i}$: weight of the i^{th} factor at layer $m+1$.

2.3.2 Calculation of Weight

The disparity factors listed at the same layer are pairwise compared by decision makers through a self-administered questionnaire survey. In the linguistic comparison (ref. Table 2.3), the degree of relative importance can be presented into ratio scale. The ratio scale suggested by professor Satty is shown in Table 2.3. These ratio values

ticked or filled into blanks of questionnaire by decision makers can then be complied into a comparison matrix. The weight acquisition process of AHP, which is a mathematically well proven process, though partially subjective, having been tested successfully in our field study and is described in the following of this section.

Table 2.3 Suggested Ratio Scale

Intensity of importance	Definition
1	Equal importance
3	Weak importance of one over another
5	Essential or strong importance
7	Very strong or demonstrated importance
9	Absolute importance
2, 4, 6, 8	Intermediate values between adjacent scale values when compromise is needed

Let C_1, C_2, \dots, C_n be the set of disparity factor at the same layer. The quantified judgments on pairs of disparity factor C_i, C_j are represented by an n-by-n matrix

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ a_{n1} & a_{n2} & a_{n3} & \cdots & a_{nn} \end{bmatrix}, \quad (i, j = 1, 2, \dots, n) \quad (2-2)$$

The entries a_{ij} are defined by the following entry rules:

- Rule 1: If $a_{ij} = \alpha$, then $a_{ji} = 1/\alpha$, $\alpha \neq 0$
- Rule 2: If C_i is judged to be of equal relative importance as C_j , then $a_{ij} = 1$,

$a_{ji} = 1$; in particular, $a_{ii} = 1$, for all i .

Thus the matrix A has the form

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} & \cdots & a_{1n} \\ 1/a_{12} & 1 & a_{23} & \cdots & a_{2n} \\ 1/a_{13} & 1/a_{23} & 1 & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ 1/a_{1n} & 1/a_{2n} & 1/a_{3n} & \cdots & 1 \end{bmatrix} \quad (2-3)$$

Matrix A is reciprocal.

Assume that weight of criteria C_i is w_i and the weight of criteria C_j is w_j then,

$$\frac{w_i}{w_j} = a_{ij}, \quad (i, j = 1, 2, \dots, n)$$

Therefore, Eq. (2-3) can be written as

$$A = \begin{bmatrix} w_1/w_1 & w_1/w_2 & w_1/w_3 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & w_2/w_3 & \cdots & w_2/w_n \\ w_3/w_1 & w_3/w_2 & w_3/w_3 & \cdots & w_3/w_n \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ w_n/w_1 & w_n/w_2 & w_n/w_3 & \cdots & w_n/w_n \end{bmatrix} \quad (2-4)$$

Then, matrix A is called “consistent”.

For $w = [w_1 \ w_2 \ \dots \ w_n]^T$ and $w_1 + w_2 + \dots + w_n = 1$

$$Aw = nw$$

For any matrix A, if $\lambda_1, \lambda_2, \dots, \lambda_n$ are the numbers satisfying the equation

$$Ax = \lambda x \quad (2-5)$$

i.e., $\lambda_1, \lambda_2, \dots, \lambda_n$ are the eigenvalues of A, and if $a_{ii} = 1$ for all i , then

$$\sum_{i=1}^n \lambda_i = n \quad (2-6)$$

Therefore, if A is consistent, then $\lambda_{\max} = n$, the other $n-1$ eigenvalues are all 0,

and

$$w_i = \frac{\sum_{j=1}^n a_{ij}}{\sum_{i=1}^n \sum_{j=1}^n a_{ij}} , \quad (i = 1, 2, \dots, n) \quad (2-7)$$

If A is consistent, then a small variation of the a_{ij} can keep the largest eigenvalue, denoted by λ_{\max} , close to n, and the remaining eigenvalues close to zero.

There are 4 methods for estimation of the eigenvector $w = [w_1 \ w_2 \ \dots \ w_n]^T$ corresponding to the maximum eigenvalue λ_{\max} as following:

$$w_i = \frac{\sum_{j=1}^n a_{ij}}{\sum_{i=1}^n \sum_{j=1}^n a_{ij}} , \quad (i = 1, 2, \dots, n) \quad (2-8)$$

$$w_i = \frac{\frac{1}{\sum_{k=1}^n a_{ki}}}{\sum_{j=1}^n \left(\frac{1}{\sum_{i=1}^n a_{ij}} \right)} , \quad (i = 1, 2, \dots, n) \quad (2-9)$$

$$w_i = \frac{1}{n} \sum_{j=1}^n \left(\frac{a_{ij}}{\sum_{k=1}^n a_{kj}} \right) , \quad (i = 1, 2, \dots, n) \quad (2-10)$$

$$w_i = \frac{\sqrt[n]{\prod_{k=1}^n a_{ik}}}{\sum_{j=1}^n \sqrt[n]{\prod_{k=1}^n a_{jk}}} , \quad (i = 1, 2, \dots, n) \quad (2-11)$$

If the comparison matrix is completely consistent, the above 4 methods all get the same results. For a matrix with less inconsistent characteristics, the 4 methods can get similar results. The comparison of accuracy of correctness is:

method 1, in Eq. 2-9 < method 2, in Eq. 2-10 < method 3, in Eq. 2-11 <

method 4, in Eq. (2-12),

but method 4 takes the longest computational time.

After eigenvector $w = [w_1 \ w_2 \ \dots \ w_n]^T$ is estimated, the maximum eigenvalue λ_{\max} is then calculated by using the following two formulas in Eqs. 2-14 and 2-15.

$$\sum_{j=1}^n a_{ij} w_j = \lambda_{\max} w_i \quad (2-12)$$

which yields

$$\sum_{j=1}^n \sum_{i=1}^n a_{ij} w_j = \sum_{i=1}^n \lambda_{\max} w_i = \lambda_{\max} \quad (2-13)$$

or

$$\frac{1}{n} \sum_{i=1}^n \left(\frac{\sum_{j=1}^n a_{ij} w_j}{w_i} \right) = \frac{1}{n} \sum_{i=1}^n \left(\frac{\lambda_{\max} w_i}{w_i} \right) = \lambda_{\max} \quad (2-14)$$

If the matrix is less inconsistent, the above 2 methods can obtain similar results. If the matrix is poorly consistent, the accuracy of the latter method is generally better than the former method [48].

Since the small changes in a_{ij} imply a small change in λ_{\max} , the Consistency Index (CI) is designed as an indicator of “the closeness to consistency”, i.e.

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (2-15)$$

The consistency index of a randomly generated reciprocal matrix from the scale 1 to 9, with reciprocals forced, tested by the Oak Ridge National Laboratory and the Wharton Business School is called the random index (RI) [49]. Table 2.4 gives the order of the matrix and the average RI determined.

The ratio of CI to RI for the same order matrix is called the Consistency Ratio

(CR):

$$CR = \frac{CI}{RI} \quad (2-16)$$

A consistency ratio of 0.1 or less is considered acceptable [48]. If the consistency index is sufficiently large to warrant the judgmental revision, a matrix of weight ratios w_i / w_j is formed to consider the matrix of absolute differences $[|a_{ij} - (w_i / w_j)|]$ and attempt to revise the judgment on the element or row sums (as shown in Eq. 2-17) with the largest such differences. This element or row shall be replaced by the corresponding w_i / w_j [48].

$$\text{Absolute differences of row sums} = \max_i \sum_{j=1}^n |a_{ij} - w_i / w_j| \quad (2-17)$$

The above procedure is repeated until the iteration is converged so that the consistency ratio of our requirements (e.g. 0.1) is met. Figure 2.6 depicts the whole procedure of revising judgments. A numerical example shall be given in Section 2.8 to help understanding the AHP.

Table 2.4 Random Index with the Order of Matrix

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

2.3.3 The Mean of Weight

If the survey result of the weight of disparity factors is more than one sample (e.g., the surveyed in our study are more than one engineers), the weights of each disparity factor has to be averaged. The calculation of average can be done in the following two approaches:

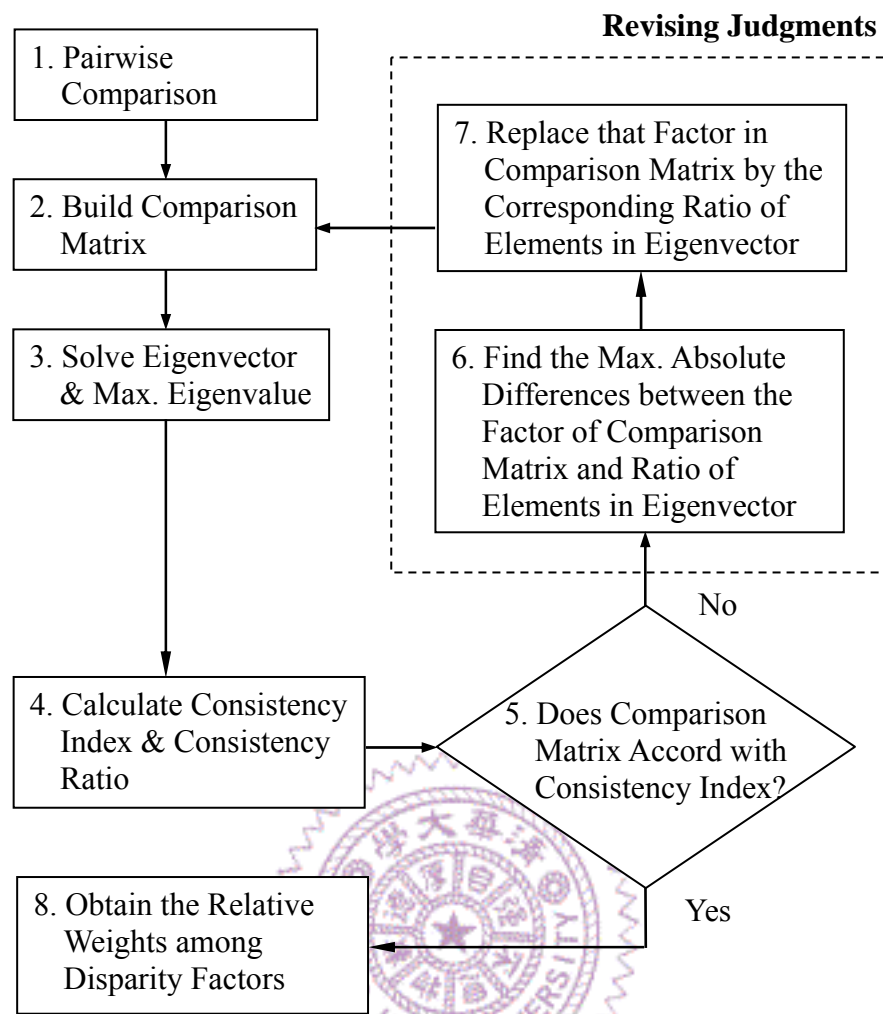


Fig. 2.6 Flow chart of weights calculation for each single layer of Fig.2.5 by AHP.

Arithmetic mean calculation

- (1) For the disparity factors at the same layer, build comparison matrices according to the answers from questionnaires (90 transmission engineers and 44 distribution engineers surveyed in this study, which results in 90 and 44 comparison matrices for the transmission and distribution reliability evaluation respectively);
- (2) Perform revising judgment for each comparison matrix (90 or 44 comparison matrices in this study);
- (3) Find the weight of each disparity factor for each questionnaire (90 or 44 weight vectors);

- (4) Calculate the arithmetic mean of weight of each disparity factor from all questionnaires (1 weight vector per disparity factor).

Geometric mean calculation

Repeat steps (1) and (2) as above, but steps (3) and (4) here are revised as below:

- (3) Build a new comparison matrix by calculating the geometric mean of corresponding elements from all comparison matrices (1 comparison matrix in this study);
- (4) Find the weight of each disparity factor from the above comparison matrix (1 weight vector in this study).

2.4 Disparity Factor Selection

A variety of factors can affect the SAIDI metric value. For example, the repair time required after the forced outage of a transmission line depends on the nature of the fault, the time of the day, the day of the week, the prevailing weather condition, the distance the crew has to travel to reach the fault and the accessibility of the fault location etc. Some of the literatures state that numerous factors can impact the accuracy, the uniformity, and the consistency of reliability indices [62-74]. According to the surveyed results of Electric Power Research Institute (EPRI), the factors which impact the metric value of distribution reliability indices can be classified in 4 categories and each category includes several factors listed as follows [10]:

(1) Definition and data classification

- Major event (included or not included)
- Interruption (definition of minimum duration for a sustained interruption)
- Planned/Unplanned (planned outage included or not included)

- Distribution/Transmission (transmission outage included or not included)

(2) Data collection process

- Outage notification
- Outage reporting
- Step restoration process
- Customer to network connectivity

(3) Service territory

- Geography
- Weather pattern
- Vegetation pattern
- Vehicle access pattern
- Animal activity

(4) System design

- Urban/rural/downtown
- Load characteristics
- Underground/overhead
- Voltage level
- Protection scheme



Written by D. O. Koval and A. A. Chowdhury, both the IEEE fellows, the factors that should be standardized in establishing distribution reliability standards for cross comparison purposes among utilities are [17]:

(1) Data pool

- Definition of outage causes (included or excluded)
- Definition of major event (included or excluded)
- Data sufficiency (need a uniform data sufficiency period)

(2) Definition of terms

- Definition of sustained interruption
- Definition of customer
- Major event (included or excluded)
- Scheduled outage (included or excluded)
- Bulk power system outage (included or excluded)

(3) System characteristics

- Rural, urban, suburban or mixed
- Load or customer density
- Circuit ratios (overhead/underground)
- System topologies
- Weather environment

(4) Outage data collection system

- Fully automated
- System coverage extended to the individual customer level

C. A. Warren, the chairman of the IEEE/PES working group on system design that wrote the IEEE guide for electric power distribution reliability indices Std. 1366-2003, pointed out the following key factors that need to be taken into account when conducting a reliability benchmark exercise [75].

(1) Step restoration methodology

- The definition of start and end time of an interruption

(2) Geographic area

- The location of the network (rural, urban), network distance from field service centers and the terrain (forests, mountains)

(3) Lightning ground flash density

- The number of lightening strikes experienced/km² of ground-year
- (4) Network exposure and design
 - Overhead/underground
- (5) Degree of outage management system automation
 - Complete and detailed data connectivity with fully integrated GIS and automatic tracing of events.
- (6) Completeness and accuracy of data connectivity
 - Complete and accurate number of customers connected to a transformer
- (7) Degree of system automation (SCADA and distribution automation)
 - Improve the duration-related reliability indices.
- (8) Reliability measurement methodology
 - Planned outage/public-caused interruption/events over a duration (included or excluded)

Although the feature of these influential factors is identified, none of the literature had provided any systematic approach to incorporating the regional disparity factors into the setting of regional reliability targets.

Among all the factors that impacted the SAIDI metric value, some factors have to be segmented from the evaluation or the benchmark data. The factors suggested here for segmentation are: (1) the disparity of managerial effort and/or efficiency among the regional offices, and (2) the common factors across regions that can have the same impacts on the regional performances.

As the field tests conducted in this study are the service regions within the same utility, these common factors can thus refer to: the SAIDI/SAIFI definitions, the outage data collection process, the SAIDI/SAIFI metric value calculation process, the corporative administration (e.g., the shortage of skilled maintenance manpower) etc.,

which are common to all service regions in the evaluation. If the tested are across the utilities, these common factors have to be also taken into account.

Among the factors collected, some of the factors can be detailed or need to be further decomposed to more specific factors. For example, the system capability for load transfer depends on the system spare capacity, the automation of feeders for remote switching etc. It is thus necessary sometimes to decompose the individual disparity factors of the same (n^{th}) layer into their corresponding more specific explanation factors which form the $n+1^{\text{th}}$ layer. This is one of the reasons why the hierarchy structure of AHP is adopted here for this study.

2.5 Regional Disparity Measurement

The disparity factors after segmentation are arranged into the lowest layer of the hierarchy structure. Then for each disparity factor, an index is designed for measurement of the disparities among regions.

Each disparity factor is measured by a evaluation index after several meetings with the regional transmission (and distribution) maintenance and operation engineers, so to capture the essential characteristics of regional transmission (and distribution) system. The measurement indices are so specified that one can easily obtain the metric values from the regional database, and further, the index values must be able to portray the regional characteristics of transmission (or distribution) system and express the disparity among the regional subsystems.

With these measurement indices, then the survey is conducted at each regional transmission (or distribution) office to collect data for the indices so to describe the present status for each regional transmission (and distribution) system.

2.6 Questionnaire Design and Weight Acquisition

The identification for the relative weight of factors that affect system interruption duration relies heavily on decision makers' experiences. There are two kinds of measurement for acquiring the weight of disparity factors, namely the relative measurement and the direct measurement. In this study, we adopted the relative measurement to extract decision makers' experiences and to gain the weight of disparity factors through questionnaires designed by following the AHP.

To ensure the effectiveness of the questionnaire, testing questionnaires are designed to examine the response. We notice that it is difficult for respondent to identify the direct relations between the disparity factors and the SAIDI (or SAIFI) metric value or even the relative importance between two disparity factors by pairwise comparison, e.g. the relation between the SAIDI and the total circuit length or the relation between the SAIDI and the radial circuit ratio or the relative importance between the total circuit length and the radial circuit ratio in view of their influence on the SAIDI metric value. One more example is that, underground feeders can cause less times of customer power interruption than overhead feeders. However, customer outage duration due to underground equipment failures can be longer than the overhead as the underground requires a more complete process to locate fault and to get the repair done. Therefore, it is generally difficult for respondents to evaluate their impact on the SAIDI metric value. One of the reasons is that SAIDI not only accounts for the times of service interruption but also the duration and the number of customers affected of each service interruption.

The SAIDI and SAIFI definitions presented in Chapter 1 are repeated below:

$$SAIDI = \frac{\sum r_i N_i}{N_T} \quad (2-18)$$

$$SAIFI = \frac{\sum N_i}{N_T} \quad (2-19)$$

Where r_i , N_i and N_T have been specified along with the definition in Table 1.2.

For the convenience of respondent to answer the questionnaire, the numerator at the right-hand side of Eq. 2-18 is decomposed in this study into three terms, each being evaluated individually. Then Eq. 2-18 can be rewritten as following:

$$SAIDI = \frac{\left[\begin{array}{c} \text{Average} \\ \text{times of} \\ \text{service} \\ \text{interruption} \\ \text{per year} \end{array} \right] \times \left[\begin{array}{c} \text{Average} \\ \text{duration per} \\ \text{service} \\ \text{interruption} \end{array} \right] \times \left[\begin{array}{c} \text{Average} \\ \text{number of} \\ \text{customers} \\ \text{affected per} \\ \text{service} \\ \text{interruption} \end{array} \right]}{(\text{Total number of customers served})} \quad (2-20)$$

Similarly, Eq. 2-19 can also be rewritten as following:

$$SAIFI = \frac{\left[\begin{array}{c} \text{Average} \\ \text{times of} \\ \text{service} \\ \text{interruption} \\ \text{per year} \end{array} \right] \times \left[\begin{array}{c} \text{Average} \\ \text{number of} \\ \text{customers} \\ \text{affected per} \\ \text{service} \\ \text{interruption} \end{array} \right]}{(\text{Total number of customers served})} \quad (2-21)$$

Since the two terms in the numerator at the right-hand side of Eq. 2-21 are same as in Eq. 2-20, this thesis shall thus present the SAIDI performance evaluation in more detail and SAIFI in much less detail for the simplicity of presentation.

Six survey meetings have been conducted each at one of Taipower's 6 transmission regional offices, and 8 regional survey meetings conducted for Taipower's 22 distribution districts. Fifteen experienced engineers who are either the

section chief or the department head of the operation or maintenance department in the same transmission regional office and four experienced engineers in the same distribution district are surveyed; thus total 90 engineers have been surveyed for the transmission forced service interruption and 44 engineers for the distribution forced and scheduled service interruption respectively.

To avoid misunderstanding the disparity factors enlisted in the questionnaire, the same question, for evaluating the factors of the same layer, were asked three times in different forms, i.e.,

Column A	Importance of A over B				Importance of B over A				Column B
	Essential		Weak		Equal		Weak		Essential
Geographical Conditions				√					Radial Circuit Ratio
Geographical Conditions					√				Transformers' Peak Load Rate
Geographical Conditions					√				Lack of Backup Capacity
Radial Circuit Ratio				√					Transformers' Peak Load Rate
Radial Circuit Ratio			√						Lack of Backup Capacity
Transformers' Peak Load Rate						√			Lack of Backup Capacity

Fig. 2.7 One of survey results among the 90 transmission engineers of Taipower surveyed for acquisition of weights for the 4 disparity factors of load transfer inability of average number of customer affected per system interruption.

- (1) the level of importance for each factor (e.g., extremely important, very important etc.),
- (2) the priority order according to their importance, and
- (3) the pairwise comparison as depicted in Fig. 2.7

To assist answering the questionnaire, the above format (3) is taken here as example to demonstrate that in all the above 3 formats, the respondent express their personal opinion by ticking their selected answers only without writing down any phrases. Take the disparity factors for the load transfer inability for evaluating the average number of customers affected per forced service interruption as an example. Figure 2.7 shows one of the survey results among the 90 transmission engineers surveyed. As shown, the respondent accounts for the geographical conditions as of equal importance over transformer's peak load rate, and accounted for the network configuration (referring to the radial circuit proportion out of the total circuits) as of weak importance over the lack of circuit backup capacity. The respondent has been requested answering the same questions but in formats (1) and (2) shown as in Fig. 2.8. The calculations of the weights of disparity factors according to this survey result shall be presented in Section 2.8.

Following the procedure of AHP, each disparity factor and their impacts on the SAIDI metric value are evaluated individually. Each respondent answers 3 sets of questions, base on the 3 AHP sub-models (ref. Eq. 2-20). For each set of questions, the results from all questionnaires can be arranged by the two kinds of procedure described in Section 2.3.3 to calculate the average value of weight of each disparity factor.

This study chooses the results of geometric mean calculation, because the ratio scale adopted by the AHP is based on multiplication rather than summation and

	Insignificant correlation	Small correlation	Mediocre	Largely correlated	Very largely correlated
Geographical Conditions	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Radial Circuit Ratio	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Transformers' Peak Load Rate	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Lack of Backup Capacity	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Please rank the relevancy of the foresaid factors in a sequential order, rated by feeder load transfer inabilities, which are represented by 1 to 4, where 1 being the highest correlation and 2 being the smallest of the four.

☐ Geographical conditions

☐ Radial Circuit Ratio

☐ Transformers' Peak Load Rate

☐ Lack of Backup Capacity

Fig. 2.8 The same question of Fig. 2.7, but in different format for asking the level of importance for each factor, and the priority order according to their importance.

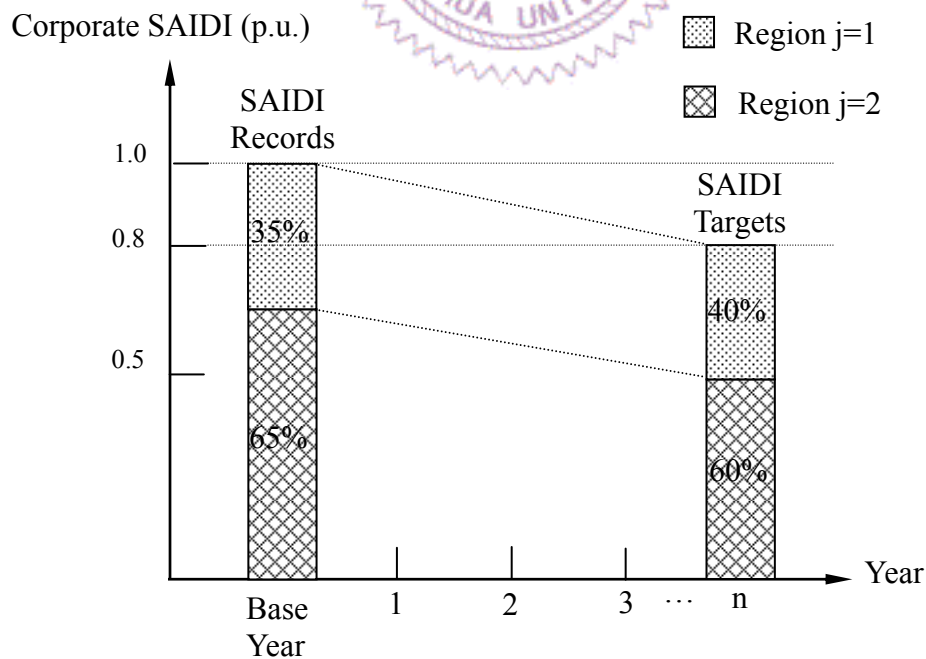


Fig. 2.9 Regional SAIDI targets derived from Eq. (2-23) for a planned (the n^{th}) year versus the present-year or base year SAIDI records where 2 regions and 20% reduction on the corporate SAIDI are assumed.

actually the results of the geometric mean are fairly close to the arithmetic mean after conducting the judgments revision of the comparison matrices to be detailed in Section 2.3.2.

2.7 Derivation of Regional Target Level

At the right-hand side of Eq. 2-20, each multiplication term of the numerator can be evaluated individually by a hierarchy structure model similar to that depicted in Fig. 2.5. At the top of each model is the target level corresponding to a multiplication term of Eq. 2-20. Let V_{frq} , V_{drt} and V_{ctm} denote the target levels corresponding to the three multiplication terms respectively. Each of them is derived by executing Eq. 2-1 recursively, which derives the metric values of factors at the upper layers from the factors located at the corresponding lower layers.

Let j denote the j^{th} service region of the tested utility. Then for region j , each of the three models then yields $V_{j, \text{frq}}$, $V_{j, \text{drt}}$ or $V_{j, \text{ctm}}$. Having obtained $V_{j, \text{frq}}$, $V_{j, \text{drt}}$ and $V_{j, \text{ctm}}$ for all service regions, $j=1, 2, 3, \dots, J$, the normalized regional SAIDI's can be calculated as:

$$\text{SAIDI}_j \% = \frac{\text{SAIDI}_j}{\sum_{j=1}^J \text{SAIDI}_j} = \frac{(V_{j, \text{frq}}) (V_{j, \text{drt}}) (V_{j, \text{ctm}})}{\sum_{j=1}^J (V_{j, \text{frq}}) (V_{j, \text{drt}}) (V_{j, \text{ctm}})} \quad (2-22)$$

where $\text{SAIDI}_j \%$ can be depicted as in Fig. 2-9 for a planned target year which could be the completion year of one or more multi-year network expansion projects.

2.8 A Numerical Example

A numerical example to demonstrate the weight acquisition process in Fig. 2.7 is as following. The process presented below follows [48]. Referring to [48], the survey results of Fig. 2.7 can be transformed into the following comparison matrix:

$$\mathbf{A} = \begin{matrix} & \begin{matrix} \text{Geo. Rad.} & \text{Tr.} & \text{Cap.} \end{matrix} \\ \begin{bmatrix} 1 & 2 & 1 & 1 \\ 1/2 & 1 & 2 & 3 \\ 1 & 1/2 & 1 & 1/2 \\ 1 & 1/3 & 2 & 1 \end{bmatrix} & \begin{matrix} \text{Geographical Conditions} \\ \text{(Geo.)} \\ \text{Radial Circuit Ratio} \\ \text{(Rad.)} \\ \text{Transformers' Peak Load} \\ \text{Rate (Tr.)} \\ \text{Lack of Backup Capacity} \\ \text{(Cap.)} \end{matrix} \end{matrix} \quad (2-23)$$

Of the matrix, the largest eigenvalue (λ_{\max}) is 4.443, the normalized eigenvector ($\mathbf{W}_{\text{major}}$) is: [0.29 0.32 0.17 0.22], and the consistency ratio (CR) is 0.164. With the acceptable CR pre-specified at 0.1, the revision of judgment is required.

To proceed the revision, an ideal matrix denoted by \mathbf{X} , is formulated from the normalized eigenvector ($\mathbf{W}_{\text{major}}$), which, due to its absolute consistency (i.e., CR=0), can be taken as the reference to revise matrix \mathbf{A} . The ideal matrix \mathbf{X} so evaluated is:

$$\begin{aligned} \mathbf{X} &= \begin{bmatrix} 1 & 0.29/0.32 & 0.29/0.17 & 0.29/0.22 \\ 0.32/0.29 & 1 & 0.32/0.17 & 0.32/0.22 \\ 0.17/0.29 & 0.17/0.32 & 1 & 0.17/0.22 \\ 0.22/0.29 & 0.22/0.32 & 0.22/0.17 & 1 \end{bmatrix} \\ &= \begin{bmatrix} 1 & 0.90 & 1.68 & 1.32 \\ 1.11 & 1 & 1.86 & 1.46 \\ 0.59 & 0.54 & 1 & 0.78 \\ 0.76 & 0.69 & 1.28 & 1 \end{bmatrix} \end{aligned} \quad (2-24)$$

The absolute differences between matrix \mathbf{X} and matrix \mathbf{A} are:

$$| \mathbf{X} - \mathbf{A} | = \begin{bmatrix} 0 & 1.10 & 0.68 & 0.32 \\ 0.61 & 0 & 0.14 & 1.54 \\ 0.41 & 0.04 & 0 & 0.28 \\ 0.24 & 0.35 & 0.72 & 0 \end{bmatrix} \quad (2-25)$$

The maximum among matrix elements is 1.54 which is at the second row and the 4th column, so its corresponding element of matrix \mathbf{A} (i.e., 3) should be replaced with the element of matrix \mathbf{X} at the same position (0.32/0.22). Accordingly, in matrix \mathbf{A} , 1/3 should also be replaced with 0.22/0.32, which results in Matrix \mathbf{A}_1 :

$$\begin{aligned} \mathbf{A}_1 &= \begin{bmatrix} 1 & 2 & 1 & 1 \\ 1/2 & 1 & 2 & 0.32/0.22 \\ 1 & 1/2 & 1 & 1/2 \\ 1 & 0.22/0.32 & 2 & 1 \end{bmatrix} \\ &= \begin{bmatrix} 1 & 2 & 1 & 1 \\ 0.5 & 1 & 2 & 1.46 \\ 1 & 0.5 & 1 & 0.5 \\ 1 & 0.69 & 2 & 1 \end{bmatrix} \end{aligned} \quad (2-26)$$

Of matrix \mathbf{A}_1 , $\lambda_{\max} = 4.2355$, $\mathbf{W}_{\text{major}} = [0.29 \quad 0.27 \quad 0.17 \quad 0.27]$, and $\text{CR} = 0.0872$ which is less than the pre-specified acceptable level, 0.1, which indicates that matrix \mathbf{A}_1 fulfills the consistency check.

The weight vector resulted from Fig. 2.7 is then derived as $\mathbf{W}_{\text{major}} = [W_{\text{geo}} \quad W_{\text{rad}} \quad W_{\text{tr}} \quad W_{\text{cir}}] = [0.29 \quad 0.27 \quad 0.17 \quad 0.27]$.

2.9 Summary

The procedure presented in the preceding sections for evaluation of the regional SAIDI (or SAIFI) target level is mainly comprised of total 4 stages: exhaustive enumeration of disparity factors, design of evaluation indices, evaluation of the relative weights among factors, and derivation of the regional target levels, which have been explained respectively in Sections 2.4~2.7.

Referring to Section 2.4 disparity factors that impacted the SAIDI metric values are selected after several meetings with the regional transmission (and distribution) maintenance and operation engineers. The factors selected to set the regional targets have actually excluded the disparity of managerial effort and/or efficiency, and the common factors across regions that can have the same impacts on the regional performances.

If the former had not been excluded, the target setting results would have been unfair to the regional offices which had a high-performance record. Segmentation of the past performance record from the benchmark data for reliability target setting, however, have not been done in the previous works.

The AHP has been adopted to solve this intricate problem and to form the structure for evaluating the weight of disparity factors. Following the AHP, two kinds of parameters have been derived for each disparity factor, i.e., the evaluation indices designed to measure the disparity factors at the bottom layer of the hierarchy structure, and the relative weights for measuring the relative importance among factors at the same layer.

Questionnaires are designed which intend to acquire the experience of decision makers. Six survey meetings have been conducted each at one of Taipower's 6 transmission regional offices, and 8 regional survey meetings conducted for

Taipower's 22 distribution districts. Total 90 engineers have been surveyed for the transmission forced service interruption and 44 engineers for the distribution forced and scheduled service interruption respectively.

Finally in this chapter, a numerical example is given to explain the process for the acquisition of relative weights among disparity factors to be further demonstrated in next chapter.

