ANALYTICAL HIERARCHY APPROACH FOR LOAD SHEDDING SCHEME: A CASE STUDY BASED ON THE JOHOR SYSTEM

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Load shedding is defined as an amount of load that must almost instantly be removed from a power system to keep the remaining portion of the system operational [1]. This load removal is in response to the system that was disturbed which causes a generation deficiency condition and if not properly executed can leads to a total system collapse. Common disturbances that can cause this action to occur include major generation outages or important power transmission line outages, faults, switching errors, lightning strikes, etc [1-2].

Thereupon, by removing a substances amount of load can ensure the remaining portion of the system operational. That remaining portion should be only the vital and most critical loads in the system. And the substances amount of load in discussed to be shed or switched off should be from any non-vital loads available in the same disturbed system [3]. By switching off that selected load, the balance between the power generated and load demand could be brought back. Hence, the skill to properly differentiate what load to be shed first and so forth is important in achieving an ideal load shedding module. The process of differentiating can be done by ranking them in hierarchy.

Therefore in this study, the analysis outcome in interest is to remove loads by ranking them according to their priority. By earning the first rank means that the priority is less as the load shedding module aims is to ensure power continuity to only vital and most critical loads in the system. The module begins with non-vital loads shedding and follows by semi-vital loads removal. The vital loads can only be removed if the system is disturbed by large disturbances such as major generation outages.

On the other hand, TOPSIS is known as the Technique for Order Preference by Similarity to Ideal Solution introduced by Hwang and Yoon [18]. It shares the similarity with AHP as it also helps in to identify the ranking of all the alternatives considered. The differences are the decision making matrix and weight vector are determined as crisp values, while the outputs of the decision matrix are a measured distances between the index value vector of each sample and ideal solution along with the negative ideal solution of the comprehensive evaluation known as the positive ideal solution (PIS) and a negative ideal solution (NIS) [18]. PIS is considered as the best value of criteria while NIS is the worst value of criteria.

PIS and NIS are determined through a set of TOPSIS steps. The list of alternatives to a decision maker is classified through the TOPSI‘s two artificial alternative hypotheses which are “Ideal Alternative‟ and “Negative Ideal Alternative‟. Ideal Alternative represents the best level of all attributes while the Negative Ideal Alternative represents the worst attributes value. Next, sets of calculations using eigenvector, square rooting and summations to obtain a relative closeness value of the criteria are tested. Then through the values of relative closeness, TOPSIS will ranked the whole system by selecting the highest value of the relative closeness as the best attributes in the system.

1.2 Problem Statement

Problem statement or motivation can be understood as a presentation of the study’s argument of selecting such research. As mention before, the interest outcome of this study is to rank the load in hierarchy according to their priority. This is as to assist or illustrated the flow of one load shedding. Load shedding can be initiated whenever a stability of a power system is affected by any disturbances. It can be shed through control theory and manual load shedding operation.

Control theory is defined as the methods and principles to control different systems, processes and objects using system analysis. And for the system to analyses effectively, it requires information about the state of the system. The more information about the system is available, the more accurate and efficient operation will be committed [7]. For example, under frequency relay scheme and programmable logic controller-based load shedding (PLC) are two kinds of control theory approach of shedding load. They rely solely on the data from the frequency measuring systems. These kinds of load shedding principles cannot be programmed with the knowledge gained by the power system engineers. They have to perform numerous system studies that include all of the conceivable system operating conditions and configurations as to correctly design the power system load shedding [1]. Because of numerous variables involved, it is usually difficult, if not impossible to obtain precise frequency characteristic. This unavailability of information for future changes and enhancement of the system will significantly reduce the protection system performance.

Meanwhile, manual load shedding operation relies on the system operator. He will select a contingency in which the system is affected. The shedding will be carried out after the operator confirms the execution. The arrangement of shedding which load is made based upon a hierarchy load shedding module [3]. This kind of shedding is suitable for equipment overloading like generators, grid transformer of a reactor and 33kV bus under frequency. And it is known as slow load shedding and the algorithm is framed on a symptom-based approach.

Even though the first example is known as the primary load shedding which is framed on generation deficit and the shedding command is generated through fast actuating relays, but it does not means it is more reliable. For any reliable load shedding, ensuring of data validity is a must. The data is in terms digital and analog inputs come through a field interface which is validated before using in a program [3].

Thus in assisting the shedding to be more effective either to the control theory approach or to the manual load shedding operation, it is best to develop a reliable load shedding module by illustrating the respective loads in hierarchy form. The top load in the hierarchy conveys the meaning of less priority load therefore should be removed first and immediately. In contrast to the bottom of the hierarchy is by far the most important and vital load. The removal of the final load should only be made if the power system is still in jeopardy, as the system main concern is to ensure the continuity of power to that group of load.

In short, the primary purpose of this study is to illustrate a flow or in other words, to form a hierarchy structure of load shedding priority in providing an adequate tool for decision support to the operator calls. And likely, the results of this study may also help in improving load shedding execution so that the areas of weakness or lack of knowledge could be exposed to those who are responsible for shaping and creating a better protection for power system.

1.3 Project Objectives

Structured objectives were developed with an aim of illustrating an ideal scheme of shedding loads upon disturbances effects on any power system. The objectives are:

a) To implement AHP and TOPSIS the multi criteria decision making methods in the load shedding scheme.
b) To evaluate AHP and TOPSIS performances by performing a case study.
c) To compare the effectiveness of multi-criteria decision making methods in load shedding scheme.

1.4 Project Scopes

The system study was carried out using the Microsoft Excel software application. The following salient points are taken into consideration:

a) The system study is carried out to rank load priority for load shedding scheme as one of the defense scheme/protection system for Johor system.
b) Due to the limited availability of the latest substation load data and load priority from Johor system.
c) For this analysis, only power generated and load demand were taken into consideration.
d) The type of disturbance considered in this analysis was large contingency such as major generator outages or important power transmission line outages.

CHAPTER 2

LITERATURE REVIEW

2.1 AHP and TOPSIS

In the task of making management decisions and prognoses of possible results, analyst usually has to deal with complex system of interdependent criteria (resources, required results or goals) that has to be analyzed. There are a variety of multiple criteria techniques to aid selection in conditions of multiple criteria. Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) are two best known and most widely applied techniques multi-attribute or multi-criteria decision making (MADM/MCDM) problems in the real world [4],[5].

For example, Les Frair et al used the AHP in assisting a development of a new curriculum design [8]. This new curriculum should satisfy the ABET 2000 criteria, University core curriculum requirement and also the appropriate subjects to be offered. The new curriculums involved were Industrial Engineering (IE) Manufacturing Alternative, IE Engineering Management Alternative and IE General Alternative. The decision they were seeking was a curriculum alternative recognized as excellent by all affected parties (students, faculty, alumni, ABET, university, employers and IE Community).

In addition, AHP also helped in analyzing a future energy supply infrastructure for a suburb with approximately 2000 households and possible additional industrial demand as studied by Espen Loken et al [9]. The planning involved with five criteria – minimizing investment, minimizing operating cost, minimizing CO2 emission, minimizing NOx emission and minimizing heat dump from CHP plants to the environment. It also has to be analysed from an investment point of view which were – do they have to reinforce the electricity grid with a new supply line or do they have to build a new CHP plant, and the new location for the newly build plant should be either near an industrial site or nearby residential area.

Moreover, AHP analysis not only managed to assist in general field such as management and industry but also succeeded in quantifying power quality level at many loading points with different operating conditions which is in engineering field [10]. This factor was researched by S. A. Farghal et al aiming in identifying whether total harmonic distortion, frequency of under voltage events and load stiffness affected the performance of electric power quality during a steady operation, occasional events and load-related power quality determinant factor (PQDF) modules.

TOPSIS (technique for order performance by similarity to ideal solution) is a useful technique in dealing with multi-attribute or multi-criteria decision making (MADM/MCDM) problems in the real world. It helps decision maker(s) (DMs) organize the problems to be solved, and carry out analysis, comparisons and rankings of the alternatives. Accordingly, the selection of a suitable alternative(s) will be made. However, many decision making problems within organizations will be a collaborative effort. Hence, this study will extend TOPSIS to a group decision environment to fit real work. A complete and efficient procedure for decision making will then be provided.

The basic idea of TOPSIS is rather straightforward. It originates from the concept of a displaced ideal point from which the compromise solution has the shortest distance. Hwang and Yoon [1] further propose that the ranking of alternatives will be based on the shortest distance from the (positive) ideal solution (PIS) and the farthest from the negative ideal solution (NIS) or nadir. TOPSIS simultaneously considers the distances to both PIS and NIS, and a preference order is ranked according to their relative closeness, and a combination of these two distance measures. According to Kim et al. and our observations, four TOPSIS advantages are addressed: (i) a sound logic that represents the rationale of human choice; (ii) a scalar value that accounts for both the best and worst alternatives simultaneously; (iii) a simple computation process that can be easily programmed into a spreadsheet; and (iv) the performance measures of all alternatives on attributes can be visualized on a polyhedron, at least for any two dimensions. These advantages make TOPSIS a major MADM technique as compared with other related techniques such as analytical hierarchical process (AHP) and ELECTRE. In fact, TOPSIS is a utility-based method that compares each alternative directly depending on data in the evaluation matrices and weights. Besides, according to the simulation comparison from Zanakis et al., TOPSIS has the fewest rank reversals among the eight methods in the category. Thus, TOPSIS is chosen as the main body of development.

2.2 Load shedding events in Malaysia

In 2010, the total installed capacity of TNB and IPP in Peninsular Malaysia remains at 7,040 MW and 14,777 MW respectively. However, the maximum demand of the grid system in Peninsular Malaysia has increased from 14,245 MW in 2009 to 15,072 MW, recorded on 24 May 2010. Due to increasing electricity demand, reserve margin has dropped from 53 percent in 2009 to 45 percent in 2010.

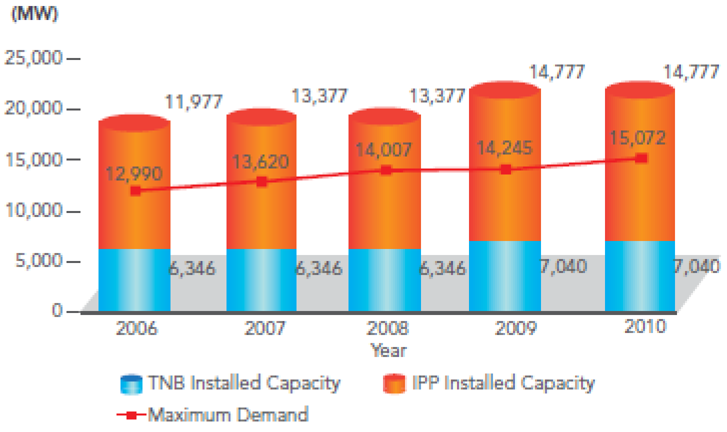


Figure 2.1: Installed Capacity and Maximum Demand in Peninsular Malaysia from 2006 to 2010

Maximum demand in KHTP has increased from 76 MW in 2006 to 149 MW in 2010. The higher maximum demand in 2010 compared with the 2009 level was attributed by the entry of several large industrial users.

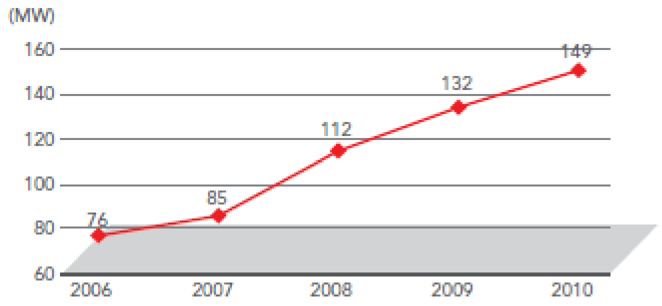


Figure 2.2: Maximum Demand in Kulim Hi-Tech Park (KHTP) reported by NUR Distribution Sdn. Bhd. from 2006 to 2010

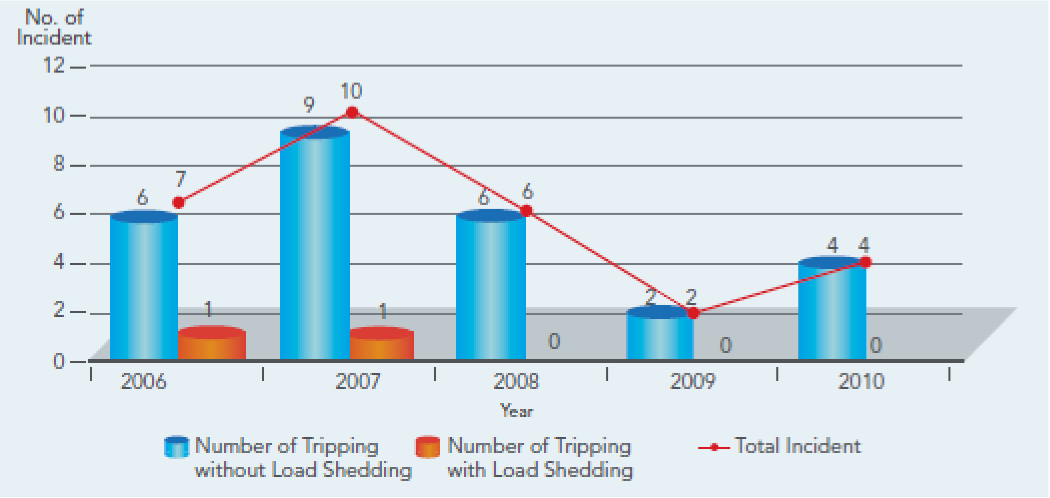
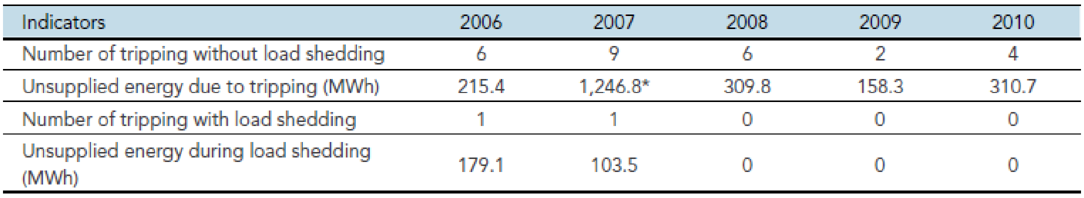


Figure 2.3: Number of Transmission System Tripping with Load Loss above 50 MW from 2006 to 2010

In 2010, TNB’s transmission system has lower performance compared to the previous year. This is due to the increment in the number of tripping to 4 in 2010 compared to only 2 in 2009. Meanwhile, the amount of unsupplied energy has also increased to 310 MWh, an increase of 96.2 percent from the previous year.

Table 2.1: Transmission System Tripping with Load Loss above 50 MW from 2006 to 2010



Indicators	2006	2007	2008	2009	2010
Number of tripping without load shedding	6	9	6	2	4
Unsupplied energy due to tripping (MWh)	215.4	1,246.8*	309.8	158.3	310.7
Number of tripping with load shedding	1	1	0	0	0
Unsupplied energy during load shedding (MWh)	179.1	103.5	0	0	0

2.3 Previous Method of Load Shedding

Load shedding has been practiced by many and through various techniques and approach. The simplest method is the breaker interlock scheme [1]. Signals are automatically sent to load breakers to open when a generator breaker or a grid connection is lost for any reason. It acts very fast since there is no processing required and decisions about the amount of load to be shed were made long before the fault occurred.

In addition, the more common method is through under frequency relay scheme [1]. This scheme does not detect disturbances as the former method, but it reacts to the disturbances. It detects either a rapid change in frequency or gradual frequency deterioration and initiate staged operation of interlocked breakers. For example, a sudden loss of generation capacity on a frequency will be accompanied by a decrease in system frequency. The characteristic of that decrement will be selected as the settings frequency limit for the relays and is sets in few stages. If certain limit is reached as the system frequency goes down, the relay trips a sizeable load. And when the first stage is reached, the relay waits a predetermined amount of time as to avoid nuisance tripping before trips one or more load breakers. The shedding is staged accordingly to the rate-of-change-of frequency.

Through recent year, the evolution of load shedding method and approach has become better and more sophisticated. For example, the use of Programmable Logic Controllers (PLCs) for automatic sequencing of load has become an important part of substation automation [1]. They were used in industrial load management and curtailment scheme in early 1980s but it was not until power management systems were combined with microprocessor based PLCs that can distributed a fast load shedding systems became reality. In spite of that, the PLCs and under frequency relays share a common ground. Their load shedding scheme is initiated based on the system frequency deviation [1]. The scheme requires a pre-programmed circuit breaker in shedding a pre-set sequence of loads. Similar to under frequency relays, the sequence is executed in staged manner. The sequence is continued until the frequency returns to a normal condition.

The evolution of this scheme does not stop here. Recently, the electric power networks have become more and more automated, interconnected and computerized [14]. While interconnection and advanced technologies lead to greater efficiency and reliability, they also bring new sources of vulnerability through the increasing complexity. For example, executing the PLCs load shedding scheme is limited to the sections of the system that are connected to the data acquisition system [1]. Furthermore in Japan, Chubu Electric Power Co. (CEPCO) also depends on telecommunication network and performs stability calculations using on-line network model based on the collected data. The effectiveness of the on-line network depends heavily on the information gathered to determine precisely the amount of generator shedding. Also in PT Newmont Batu Hijau, a mining plant in Indonesia a so-called Intelligent Load Shedding (ILS) server is installed in the power plant control room [1]. This server which served as a processor and calculator for the network data acquisition, circuit breaker status and other pertinent information in determine the optimum load shedding.

Other approaches such as Smart Load Shedding System and Comprehensive Load Shedding System [3] also utilize the information technology in improving the operation and functionality of the existing system. For example, in Smart Load Shedding System each district is equipped with interactive measuring device, a device which receives information about active power consumption and generation as well as load shedding and restoration control. And while in the Comprehensive Load Shedding System, the network selected to be tested has a supervisory control and data acquisition system (SCADA) and network management system. These communication systems monitor the system network status on an online basis [3]. Henceforth, the evolutionarily of load shedding will continues to evolved around the ever-increasing complexity and sophisticated interconnected and advanced technologies power network.

But still, even with the high-tech and edge technologies an electric utility power company should always have a backup system just in case if the technologies failed on them. Thus, the designed backup systems cannot follow the technological evolution of the load shedding scheme. This system should adopt a conventional control to be unique in switching off the selected loads. This can be executed by the help of an operator. The operator will shed the load by defining its priority up. The priority to be shed is calculated based on the accumulated load table of the selected contingency [3].

There are a few examples researchers have done concerning this matter. ARGOS, a computer program has been developed and uses a bottom-up approach in simulating both single family and large-area daily load profiles, starting from the electric energy end uses. In addition, a 0-1 Knapsack Problem method also uses the priority up approach by developing a systematic procedure that can be followed by setting priority coefficients for utility maximization in feeding loads during times when the available power is limited. The latter method has been widely used in wide application field for such as logistics, finance for investment mix, medicine for the control of the skin, for the elaboration of the DNA self-assembly model, neural networks and electrical power systems. This methodology was chosen foremost because it does not use statistical considerations and is to arrive at a mathematical formulation that could be effectively be implemented in a control-system software.

By far, 0-1 Knapsack Problem is not the only mathematical technique that can be employed in producing a priority up output. The ever famed method is the AHP and TOPSIS. These two also have been known to be used in areas such as engineering, government, industry, management, manufacturing, personal, political, social and sports. And until recently, AHP usages have been extended into load shedding. If 0-1 Knapsack Problem sees the load shedding as an optimization problem, AHP and TOPSIS see the load shedding as a multi criteria decision making problem.

Load shedding is not a one criterion problem. In executing an ideal load shedding, more than one criterion has to be considered. For example, total generation, total load to shed for each triggering event, generation capacity, total spin reserve, minimum load to be shed for each triggering event and optimal combination of circuit breakers [1]. Not only that, load shedding module also has to takes into consideration the types of faults or contingencies that have impacted or causes disturbances to the system [2]. Thus, in offering a guide for an operator in executing a load shedding module outside from the primary execution, the AHP and TOPSIS are the most suitable techniques as they can take in multiple criteria in assisting the operator to make a prompt and right decision.

For example, in a shipboard power system load shedding, AHP is used as load priority selection. It was used as to calculate the weight factor of each system criterion and its effectiveness. On the other hand, in an electrical power system load shedding scheme; AHP was used to value the importance between frequency, voltage and stability. And yet, the usage of AHP in load shedding scheme has not been fully utilized by many. The lack of such information represents a gap in this study. Therefore, it became the interest of this study, to research more on these two techniques in performing a load shedding module. And likely, the results of this study may also help in improving load shedding steps so that the areas of weakness or lack of knowledge could be exposed to those who are responsible for shaping and creating a better protection for power system.

CHAPTER 3

METHODOLOGY

3.1 Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) was developed by Professor Thomas L. Saaty in the 1970s and has been extensively studied and refined since then [19]. It is a method for solving complex decision making based on the alternatives and multiple criteria, as it names stated. It is also a process for developing a numerical score to rank each decision alternative based on how well each alternative meets the decision maker’s criteria.

Nowadays, there are many versions of AHP existed. Originally, AHP was designed to calculate the nth root of the product of the pair-wise comparison values in each row of the matrices and then normalizes the aforementioned nth root of products to get the corresponding weights [19]. Meanwhile the modified AHP version normalizes the pair-wise comparison values within each of the matrices and then averages the values in each row to get the corresponding weights and ratings [19].

However both versions give almost the same results. For this research, the original method has been chosen to be implemented as the Multi Criteria Decision Making. Generally process of AHP analysis can be shown in three main steps.

Step 1: Develop the weights for the criteria: [17],[19],[20]

a) First, develop a single pair-wise comparison matrix for the criteria as shown in the equation below:

$$A_C = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \end{array}$$

where, C1, C2, …,Cn representing the criteria,

aij represents the rating of Ci with respect to Cj

b) Then, multiply the values in each row together and calculates the nth root of the said product as shown in the equation below:

$$n^{th} root\ of\ product = \sqrt[n]{product\ of\ each\ row} \qquad (3.2)$$

where n= positive integer number.

c) After that, normalizing the aforementioned nth root of products to get the appropriate weights by using the formula given in equation 3.3:

$$weight = \frac{n^{th}\ root\ of\ product}{\Sigma(n^{th}\ root\ of\ product)} \qquad (3.3)$$

d) Lastly, perform the Consistency Ratio (CR) by using the formula as shown below:

$$CR = \frac{CI}{RI} \qquad (3.4)$$

The value of Random index (RI) can be found using Table 3.1 where Random Index (RI) is a constant and it is a standard for AHP analysis.

Table 3.1: Table of Random Index (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

*Note: Value of C.R must be less than the allowable value of 0.10. Therefore, the consistency of the judgment matrix should be within an acceptable tolerance. But if the consistency ratio is greater than 0.10 then the subjective judgment needs to be revised.

While the value for Consistency Index (CI) can be found by using this equation:

$$CI = \frac{Lambda\_Max - n}{n-1} \tag{3.5}$$

And for Lambda_Max,

$$Lambda\_Max = \sum \left(\sum column_{each\ alternative}\ x\ weight_{per\ row} \right) \tag{3.6}$$

where: Σ*column* is the summation of pair-wise values of each alternative vertically and *n* is a positive integer number.

Step 2: Develop the ratings for each decision alternative for each criterion [17], [19]

a) First, develop a pair-wise comparison matrix for each criterion, with each matrix containing the pair-wise comparisons of the performance of decision alternatives on each criterion as shown in equation 3.7 below:

   where A1, A2, …,An represent the alternatives, aij represents the rating of Ai with respect to Aj.

b) Secondly, multiply the values in each row together and calculates the nth root of the said product by using equation 3.8 below:

$$n^{th} root\ of\ product = \sqrt[n]{product\ of\ each\ row} \tag{3.8}$$

   where n= positive integer number.

c) Then, normalizing the aforementioned nth root of product values to get the corresponding ratings by using equation 3.9 below:

$$weight = \frac{n^{th}\, root\ of\ product}{\sum(n^{th}\, root\ of\ product)} \tag{3.9}$$

d) Lastly, perform the Consistency Ratio (CR) using equation 3.10 below:

$$CR = \frac{CI}{RI} \tag{3.10}$$

The value of Random index (RI) can be found using Table 3.2 below where Random Index (*RI*) is a constant and it is a standard for AHP analysis.

Table 3.2: Table of Random Index (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

*Note: Value of C.R must be less than the allowable value of 0.10. Therefore, the consistency of the judgment matrix should be within an acceptable tolerance. But if the consistency ratio is greater than 0.10 then the subjective judgment needs to be revised.

While the value for Consistency Index (CI) can be found by using this equation:

$$CI = \frac{Lambda\_Max - n}{n - 1} \tag{3.11}$$

And for Lambda_Max,

$$Lambda\_Max = \sum \left(\sum column_{each\ alternative}\ x\ weight_{per\ row} \right) \tag{3.12}$$

where: Σ*column* is the summation of pair-wise values of each alternative vertically and *n* is a positive integer number.

Step 3: Calculate the weighted average rating for each decision alternative. Choose the one with the highest score [17],[19].

a) First, find the final score for each of the alternative. The final score for each alternative is the summation of the product of criteria to alternative.

b) Generally, there will be *n* number of overall weight and *n* must be an integer that does not exceed 9. Therefore by using the formula given by equation 3.13 below the value for each decision alternative can be found:

$$\text{Final\_scorealternativeX} = (\text{Criterion A} \times \text{Alternative X}) + (\text{Criterion B} \times \text{Alternative X}) + (\text{Criterion C} \times \text{Alternative X}) + \ldots\ldots + (\text{Criterion I} \times \text{Alternative X}) \quad (3.13)$$

where *Criterion A* = 1st criterion, *Criterion B* = 2nd criterion, …, *Criterion I* = 9th criterion and $1 \leq X \leq 9$

The methodology can be simplified by using flowchart as shown in Figure 3.1. It is much easier to understand since generally it explains step by step process to implement AHP method. While in Figure 3.2, 3.3 and 3.4 show in details every step that must be implementing to reach the final objective.

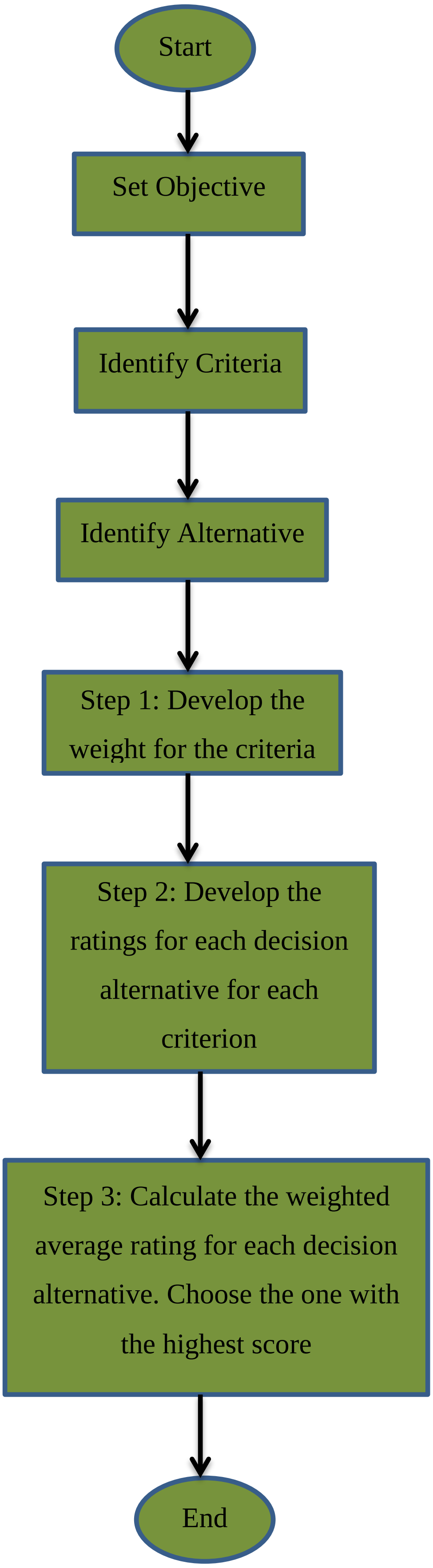


Figure 3.1: Flowchart for AHP Method

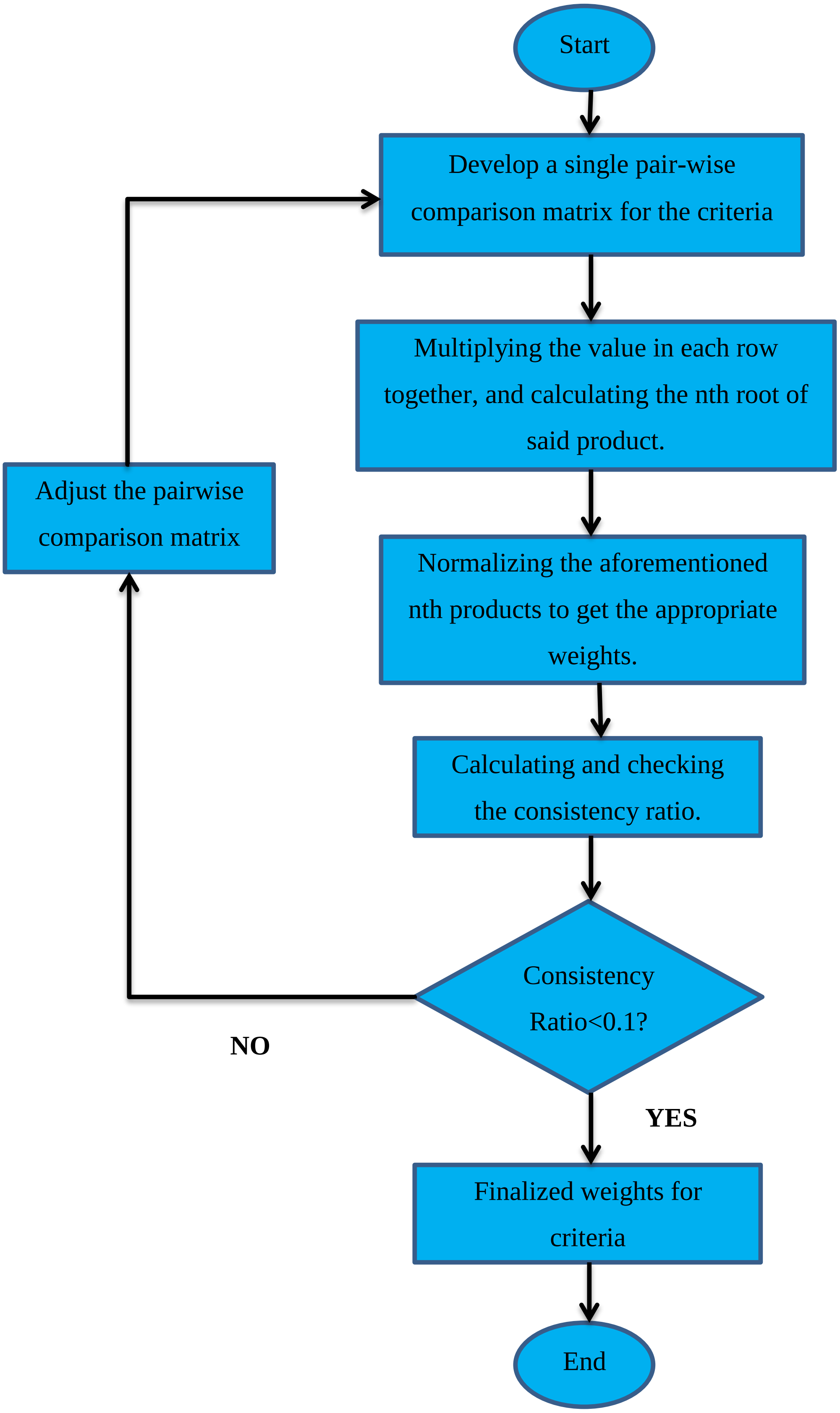


Figure 3.2: Step 1 in AHP Method

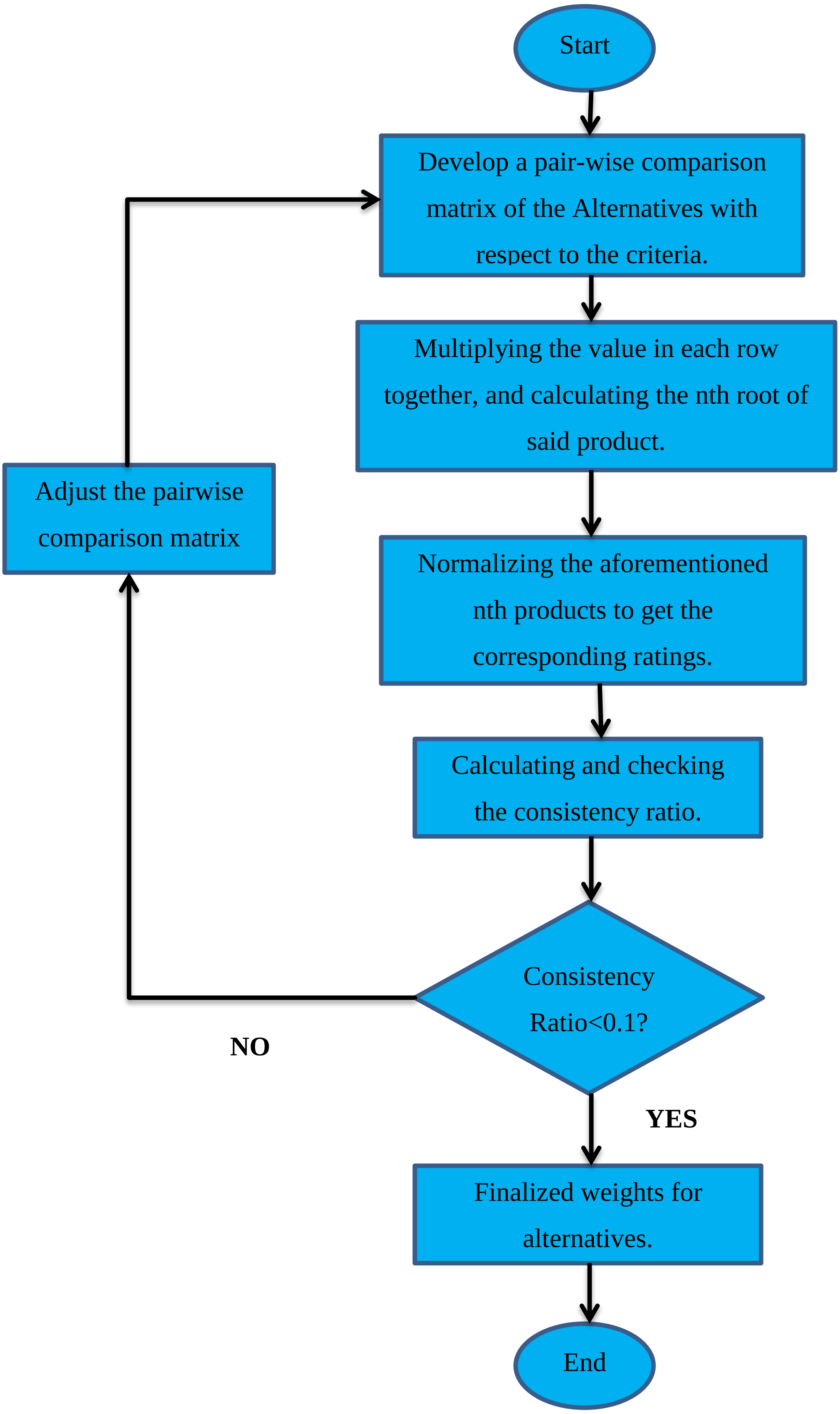


Figure 3.3: Step 2 in AHP Method

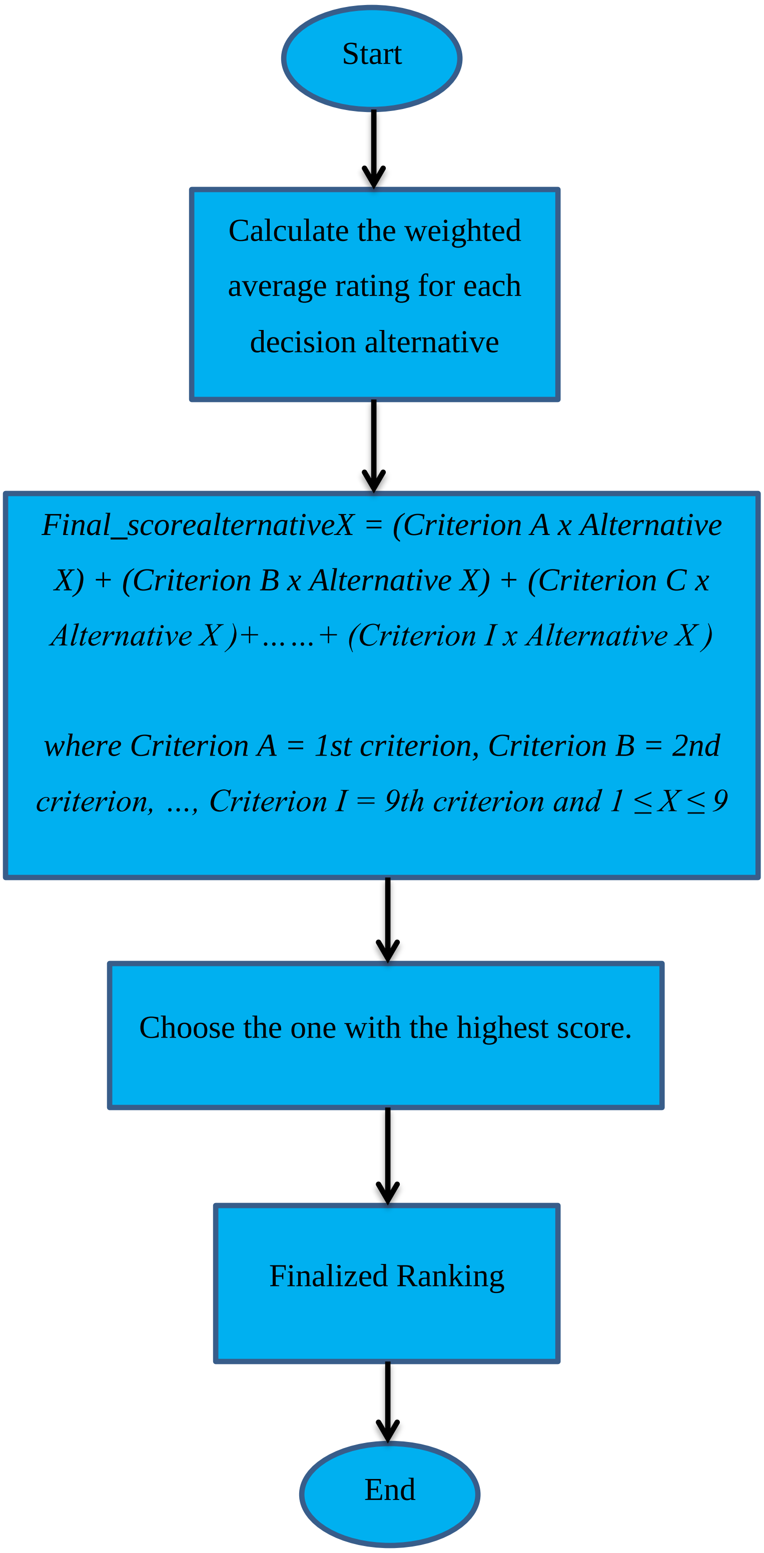


Figure 3.4: Step 3 in AHP Method

3.2 Procedure of Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is known as the ‘‘Technique for Order Preference by Similarity to Ideal Solution’’. This method is a unique technique to identify the ranking of all alternatives considered. In the TOPSIS method, the decision making matrix and weight vector are determined as crisp values and a positive ideal solution (PIS) and a negative ideal solution (NIS) are obtained from the decision matrix. In another word, PIS is a set of best value of criteria while NIS is a set of worst values achievable of criteria. This method is applied to make wide-ranging evaluation of samples where it measured the distances between index value vector of each sample and ideal solution along with the negative ideal solution of the comprehensive evaluation.

The TOPSIS method can be expressed in series of steps as listed below.

(1) Identifying the alternatives over criteria involved to form a decision matrix.

(2) Constructing a weighted of normalized decision matrix using the following equation:

$$rij = \frac{Xij}{\sqrt{(\sum Xij^2)}}$$

$$for\ i = 1, \dots, m;$$

$$j = 1, \dots, n \tag{3.14}$$

(3) Constructing a set of weight normalized decision matrix with criteria weight, w_j provided.

$$V_{ij} = w_j . rij \tag{3.15}$$

where :

rij represents the decision matrix

Wj represents the weighted matrix

i = 1, 2,3 …, m; j = 1, 2, 3, …, n.

(4) Identifying the ideal alternatives and negative ideal alternatives.

Ideal solution

$$PIS = \{v_1^* , \dots , v_n^*\}, where$$

$$V_j^* = \{max(v_{ij})\ if\ j \in J; \min(v_{ij}) if\ j \in J'\}$$

(3.16)

Negative ideal solution

$$NIS = \{v_1', \dots, v_n'\}, where$$

$$V' = \{\min(vij)\ if\ j \in J; \max(vij)\ if\ j \in J'\}$$

(3.17)

(5) Calculate the separation measurement of each alternative in di for ideal solution and dni for negative ideal solution.

Positive Ideal Solution:

$$di = \sqrt{\left[\sum_j \left(v^* - v_{ij}\right)^2, i = 1, \dots, m\right]}$$

(3.18)

Negative Ideal Solution:

$$dni = \sqrt{\left[\sum_j \left(vj' - v_{ij}\right)^2, i = 1, \dots, m\right]}$$

(3.19)

(6) Calculate the relative closeness to ideal solution using the following equation:

$$RC = \frac{sn_i}{sn_i + s_{i,}}$$

i=1,…, m

(3.20)

(7) Ranked the alternatives starting from the value that closest to 1.

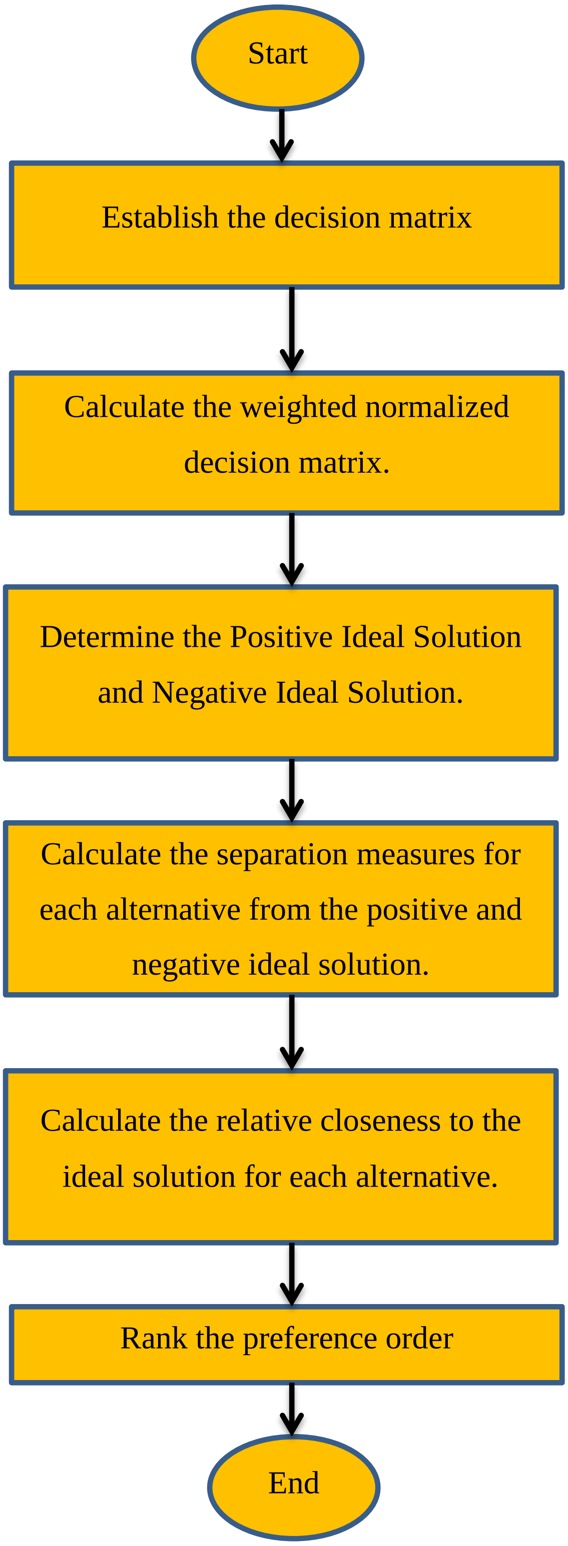


Figure 3.5: Flowchart for TOPSIS method

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