BENCHMARKING MEDIUM VOLTAGE FEEDERS USING DATA ENVELOPMENT ANALYSIS: CASE STUDY WPS1 - CEB

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DECLARATION

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ABSTRACT

Benchmarking Medium Voltage Feeders using Data Envelopment Analysis: Case Study WPS1 - CEB

Presently there is no any proper method of finding performance of Medium voltage feeders except the number of feeder failures. Therefore available limited resources are not utilized for the most required feeders and also various issues and contradictions are occurred among Engineers when giving targets to be achieved for feeders. By identifying actual performance of feeders, system improvements can be done to the most needed feeders using limited resources.

Performance benchmarking can be used to identify actual performance of feeders. Results of such benchmarking studies allow the organization to compare feeders with themselves and identify poorly performing feeders. Then the limited resources can be used to develop poorly performing feeders therefore both Utility and Consumers can get maximum benefit from available limited resources.

In order to produce a suitable benchmarking methodology this dissertation focuses on prominent benchmarking techniques used in international regulatory regime and analyses the applicability to Medium Voltage Feeders. Through the analysis Data Envelopment Analysis (DEA) method was selected.

Correlation analysis and DEA analysis with different models were carried out. Then the base model was selected for the analysis and relative performance of 32 Medium voltage feeders of Western Province South-I of CEB were evaluated using the Data Envelopment Analysis (DEA). Relative efficiency scores can be identified for each feeder. This paper also discusses the classification of Feeders according to the sensitivity analysis.

Generally, the study concludes that DEA analysis can be carried out to evaluate the performance of Medium Voltage Feeders.

The evaluation can be carried out once a year or once in two years with the medium voltage Distribution Development Plan in order to identify the performance of feeders and utilized the available limited resources efficiently.

Key words: Relative Performance, Data Envelopment Analysis, Medium voltage feeders, Relative efficiency Score, Western Province South-I

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List of Abbreviations

Abbreviation	Description
CEB	Ceylon Electricity Board
CSC	Consumer Service Centre
CRS	Constant Returns to Scale
DD4	Distribution Division 04
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
MV	Medium Voltage
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
VRS	Variable Returns to Scale
WPSI	Western Province South-I
DD1	Distribution Division 1
DD3	Distribution Division 3
DD4	Distribution Division 4
GSS	Grid Substation
LECO	Lanka Electricity Company
DDLO	Drop down lift over
LBS	Load break switch
ABS	Air Break Switch

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CHAPTER ONE

1 Introduction

1.1 Background

Most of the Provinces of Ceylon Electricity Board (CEB) carried out 100 % electrification programs and successfully achieved the targets [01], [02]. When we talk about Western Province South –I (WPS-I) of CEB almost 100 % of the area has been electrified [03], [04]. After this electrification work the main focus is given to improve the performance of the network.

Many proposals can be identified for improving performance of medium voltage feeders but with limited resources only some of them can be implement in a given time period. The present practice is implementing proposals which are essential to keep the network at stipulated margins [05] (voltage levels at + or – 6 present, feeder and transformer loading at rated values, etc) and select few other network improving proposals [03], [04], [06], [07].

Various issues and contradictions are occurred among Area Engineers, Distribution Maintenance Engineers and Planning Engineers when giving targets to be achieved for feeders due to lack of proper method to evaluate the current performance of feeders.

Performance benchmarking is widely used in whole over the world and it is very important for any type of organization. Results of such benchmarking studies allow the organization or the unit to compare themselves with the best organization or unit and to develop strategic plans for improvements in their performance.

Distribution Networks were benchmarked on Geographical or Area wise in the world [08], [09], [10], [11], [12], [13], [14]. Other than that few Distribution feeders were benchmarked to evaluate the capability of integration of Distributed energy Resources [15], [16]. But we cannot use those methods directly to Sri Lanka because many medium voltage feeders go through many consumer service centers (CSCs) and Areas. Therefore poor performance or failures in one CSC or Area can affect the performance indicator of other CSC or Area. Annex-1 shows feeding areas of each and every MV feeders of WPS-I.

1.2 Motivation

Evaluating the performance and having a clear idea regarding their performance is very much vital for any type of organization.

If we have a proper method to evaluate the performance of feeders limited resources can be fully utilized and system improvements can be done to the most needed feeders.

1.3 Objective of the Study

The main objectives of this study are to Introducing a methodology to benchmark MV feeders in Sri Lanka and to do a case study for WPS-I of CEB using the introduced methodology.

1.4 Methodology

To complete the project, the work flow was arranged in as shown in the figure 1.1.

A literature survey was carried out to identify how the worldwide practice the benchmarking of Medium voltage feeders. Benchmarking techniques were studied and Data Envelopment Analysis was selected and then Data requirement was identified. After that following steps were followed,

- Data collection
- Selecting suitable model
- Selecting inputs and outputs for the model
- Benchmarking
- Sensitivity analysis
- Model recommendation & Real Situation Comparison
- Final Recommendations

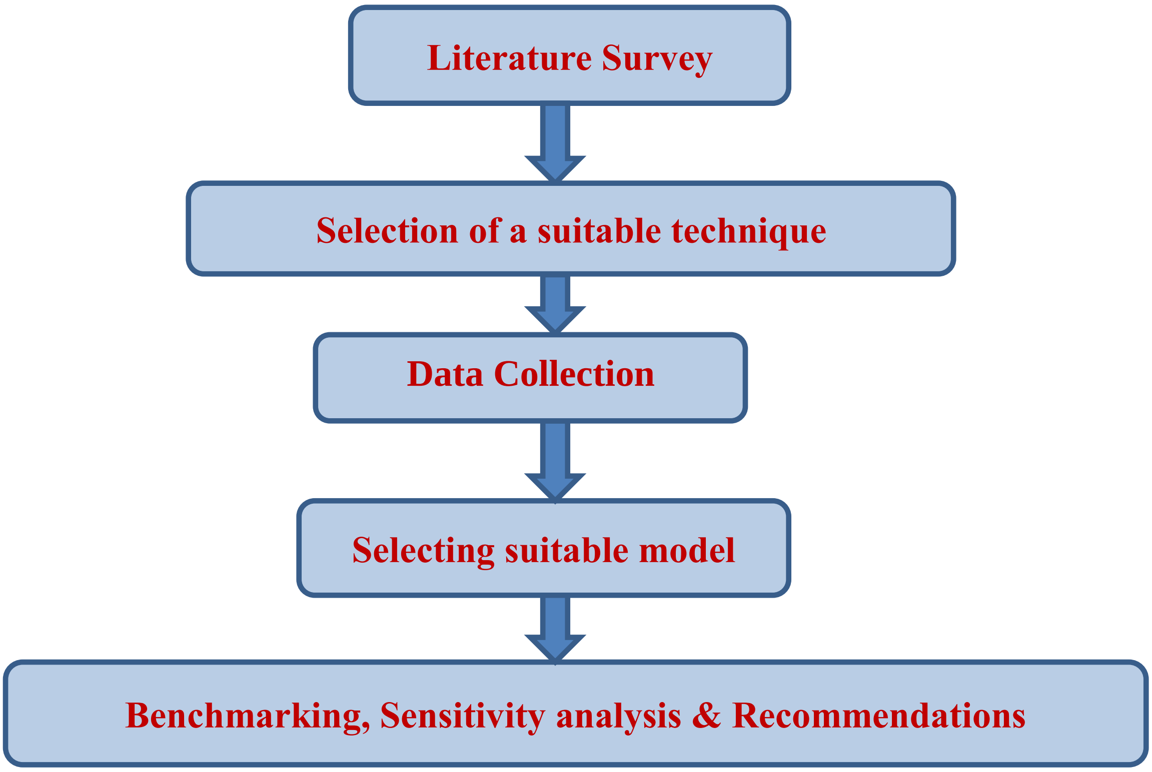

Figure 1.1 Methodology followed

1.5 Thesis organization

Rest of the thesis is organized as follows. Chapter 2 summarizes prominent benchmarking methods and the reasons for selecting Data Envelopment Analysis (DEA) method and Chapter 3 explains DEA. Chapter 4 explains in detail about the study carried out on Medium Voltage feeders of WPS-I using DEA. Chapter 5 compares the obtained results from the study with practical situation for few feeders, and the final Chapter presents conclusions and `Recommendations.

CHAPTER TWO

2 PROMINENT BENCHMARKING TECHNIQUES

In assessing the most appropriate benchmarking methodology, following principles have to be considered [17].

- **Practical application**: It should be straightforward to implement the technique in practice, given the available data. Some of the more sophisticated techniques based on econometric methods may be inappropriate when there is only a relatively small practical application.

- **Robustness**: The model selected must be robust to changes in assumptions and methodologies. In particular, the ranking of firms, especially with respect to the 'best' and 'worst' performers, and the results over time should demonstrate reasonable stability; and the different approaches should have comparable means, standard deviations and distributional properties.

- **Transparency and verifiability**: In order to ensure accountability and confidence in the price control it is important that the benchmarking process is both fully transparent and verifiable.

- **Ability to capture business conditions adequately**: The approach taken should be able to capture the particular characteristics of the industry concerned.

- **Restrictions**: The restrictions placed on the relationship between the chosen performance measure and variables should be minimized.

- **Consistency with economic theory**: The approach taken should ideally conform to Economic theory.

- **Regulatory burden**: The burden placed on the organization in terms of data collection and analysis should not be overly burdensome.

Some prominent benchmarking methods are given in the table 2.1.

Table 2.1 Prominent Benchmarking Methods

Approach	Technique
Linear Programming	Data Envelopment Analysis
Econometric	Corrected Ordinary Least Squares
Econometric	Stochastic Frontier Analysis
Partial Performance Indicators (PPIs)	Compare the ratio of a single output to a single input

Table 2.2 presents the findings of a survey of the use of benchmarking methods in few countries regarding Electricity Transmission and Distribution utilities [18]. DEA is the most widely used benchmarking method.

Table 2.2 Methods used to Electricity Transmission and Distribution utilities benchmarking

Sample	Method of Analysis
32 power supply authorities in Australia, 51 power boards in New Zealand, and 173 distributors in Sweden	DEA, Monte Carlo simulation, lognormal input Distribution
8 Australian infrastructure industries incl. electricity 1991-96	Performance indicators, TFP, DEA
Malaysian, 27 LDCs and the UK utilities	DEA

76 Turkish distribution organizations (72 public, 2 private, 2 integ. private) 1991	DEA
12 RECs in England 1980/81 to 1992/93	SFA using cross-sectional and panel data
74 municipals, 45 co-operatives under Tennessee Valley Authority 1985-89	Profit function mode, Cobb-Douglas model
Electricity systems of 85 LDCs	DEA
US rural electric co-operatives and investor- owned utilities 1988 (Gen., Trans, and Dist.)	Translog cost functions for IOUs and co-operatives
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74 municipals, 45 co-operatives under Tennessee Valley Authority 1985-89	Profit function mode, Cobb-Douglas model
Electricity systems of 85 LDCs	DEA

The evaluation of prominent benchmarking techniques revealed that each technique have pros and cons relative to each other. Summarization of characteristics of these techniques is given in table 2.3. According to the characteristics of Benchmarking methods, DEA is the most suitable method to benchmark Medium Voltage Feeders.

Table 2.3 Characteristics of Benchmarking Methods

Characteristic	PPI	DEA	COLS	SFA
Easiness to compute and understand (verifiability and transparency)	Very Easy	**Easy**	Easy	Easy
Accommodate differences in operating environments	No	**Yes**	Yes	Yes
Describe overall performance of Feeder	No	**Yes**	Yes	Yes
Extension to multiple outputs / inputs	**No**	**Easy**	**Difficult**	**Very Difficult**
Inefficient feeders are compared with actual feeders or linear combinations of those rather than to statistical measure	***No***	***Yes***	***No***	***No***
Strong assumption required (for the cost function)	**No**	**No**	**Yes**	**Yes**
Requirement of functional relationship with inputs and outputs	No	No	Yes	Yes
Data volume requirement	**Low**	**Low**	**High**	**High**

From the table 2.3, it can be seen that PPI, DEA, COLS, and SFA fulfill the following desirable characteristics.

- Easiness to compute
- Easiness to understand

However, PPI has to be avoided since it cannot accommodate for differences in operating environments and not describe overall performance of Feeders.

DEA, COLS and SFA Accommodates differences in operating environments and describe overall performance of Feeders.

COLS and SFA need functional relationship with inputs and outputs but it is very difficult to find functional relationships in the properties of medium voltage feeders. Other than that strong assumptions are needed in COLS and SFA. If the method itself is complicated with assumptions and harder to understand then there would be a doubt in the minds about the results.

Other than the above constraints COLS and SFA are difficult to extent for multiple inputs and multiple outputs.

Therefor DEA is the only suitable method to benchmark Medium voltage feeders.

Chapter 3

3 DATA ENVELOPEMNT ANALYSIS

3.1 Introduction to DEA

DEA is a commonly used benchmarking technique which is developed by Charnes, Cooper and Rhodes in 1978. Data Envelopment Analysis (DEA) is a very powerful service management and benchmarking technique originally developed to evaluate nonprofit and public sector organizations. DEA has since been proven to locate ways to improve service not visible with other techniques.

DEA can be considered as a non-parametric programming technique which creates an efficiency frontier by optimizing the weighted output to input ratio of each DMU. This is subject to the condition that this ratio can be equal to 01, but never exceed 01 for any DMU considered. DEA is a linear programming type technique and it is based on an optimization platform [13].

DEA evaluates the relative efficiencies considering the input and output variables used for the analysis. It also identifies most efficient units and inefficient units which need improvements. This can be obtained by analyzing the inputs used and the outputs produced by of all the units or divisions. DEA evaluates the amount of resources or the properties to be reduced in order to become efficient as other units.

The targets are given to relatively inefficient units by DEA analysis to become relatively efficient. By implementing various system developments, units or organization can achieve the best practice or relatively efficient unit’s performance. By that system will be developed gradually in the most economical way.

3.2 Mathematical Formulation of DEA

In order to obtain highest possible value for efficiency rating θ for the DMU being considered the set of values for the coefficients u's and v's are evaluated using linear programming technique [13].

In the model,

j	= number of DMUs considered for DEA
DMU_j	= DMU number j
θ	= relative efficiency rating of the DMU being evaluated by DEA
y_{rj}	= amount of r^{th} output produced by j^{th} DMU
x_{ij}	= amount i^{th} input consumed by j^{th} DMU
i	= number of inputs used by the DMUs
r	= number of outputs generated by the DMUs
u_r	= coefficient or weight assigned by DEA to output r
v_i	= coefficient or weight assigned by DEA to input i

If the value obtained for the efficiency rating θ for a particular DMU is less than 100%, then that DMU is called relatively inefficient. That means it has the capability to produce the same level of output with lesser amount of inputs.

Objective Function [13]

$$\text{Maximize} \quad \theta = \frac{u_1 y_{1o} + u_2 y_{2o} + \ldots\ldots + u_r y_{ro}}{v_1 x_{1o} + v_2 x_{2o} + \ldots\ldots + v_m x_{mo}} = \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}} \tag{3.1}$$

Here the efficiency rating θ is maximized for the DMU O.

The above mentioned objective function is subjected to the constraint that when same set of u and v values are applied to all the DMUs being considered the efficiency rating θ is always less than or equal to unity [13].

DMU=Decision Making Unit

$$DMU1: \frac{u_1 y_{11} + u_2 y_{21} + ... + u_r y_{r1}}{v_1 x_{11} + v_2 x_{21} + ... + v_m x_{m1}} = \frac{\sum_{r=1}^{s} u_r y_{r1}}{\sum_{i=1}^{m} v_i x_{i1}} \leq 1 \quad (3.2)$$

$$DMU2: \frac{u_1 y_{11} + u_2 y_{22} + ... + u_r y_{r2}}{v_1 x_{12} + v_2 x_{22} + ... + v_m x_{m2}} = \frac{\sum_{r=1}^{s} u_r y_{r2}}{\sum_{i=1}^{m} v_i x_{i2}} \leq 1 \quad (3.3)$$

....

$$DMUo: \frac{u_1 y_{1o} + u_2 y_{2o} + ... + u_r y_{ro}}{v_1 x_{1o} + v_2 x_{2o} + ... + v_m x_{mo}} = \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}} \leq 1 \quad (3.4)$$

....

$$DMU_j: \frac{u_1 y_{1j} + u_2 y_{2j} + ... + u_r y_{rj}}{v_1 x_{1j} + v_2 x_{2j} + ... + v_m x_{mj}} = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \quad (3.5)$$

$$u_1, ..., u_s > 0 \quad \text{and} \quad v_1, ..., v_m \geq 0 \quad (3.6)$$

In order to run DEA on a standard linear program package it can be algebraically reformulated as follows.

$$\text{Maximize} \quad \sum_{r=1}^{s} u_r y_{ro} \quad (3.7)$$

Subject to

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \ j = 1, ..., n \quad (3.8)$$

$$\sum_{i=1}^{m} v_i x_{io} = 1 \quad (3.9)$$

$$u_r, v_i \geq 0$$

Assume that there are n DMUs.

Then the dual linear program of above model can be interpreted as follows.

Minimize θ

Subject to

$$\sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta x_{io} \qquad i = 1,2,\ldots,m\ ; \qquad (3.10)$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{ro} \qquad r = 1,2,\ldots,s\ ; \qquad (3.11)$$

$$\lambda_j \geq 0 \qquad j = 1,2,\ldots,n\ . \qquad (3.12)$$

Here the meaning of equation 3.10 is weighted sum of inputs of other DMUs is less than or equal to the input in to efficiency rating of the DMU being considered. The equation 3.11 shows that weighted sum of outputs of other DMUs is greater than or equal to the output of the DMU being considered. Here the weights are the λ values. This model is referred to as "envelopment model" [13].

3.2.1 Orientations in DEA

In performance evaluation DEA basically comprises of 03 orientations. According to the type of organization, their service or main task, the most appropriate orientation can be selected. There are mainly three orientations in DEA called input-oriented, output-oriented or base oriented models.

In **input-oriented models** a given amount of outputs have to be produced consuming smallest possible amount of inputs. That is outputs are uncontrollable and inputs are controllable.

In **output-oriented models** the DMU will produce maximum number of outputs with given amount of inputs. Here the inputs are uncontrollable and outputs are controllable.

In **base oriented models** the DMUs are expected to utilize minimum level of inputs to produce maximum level of outputs. That means both inputs and outputs are controllable. Figure 3.1 depicts the projection of an inefficient unit on the frontier with the three possible orientation of a DEA model [13].

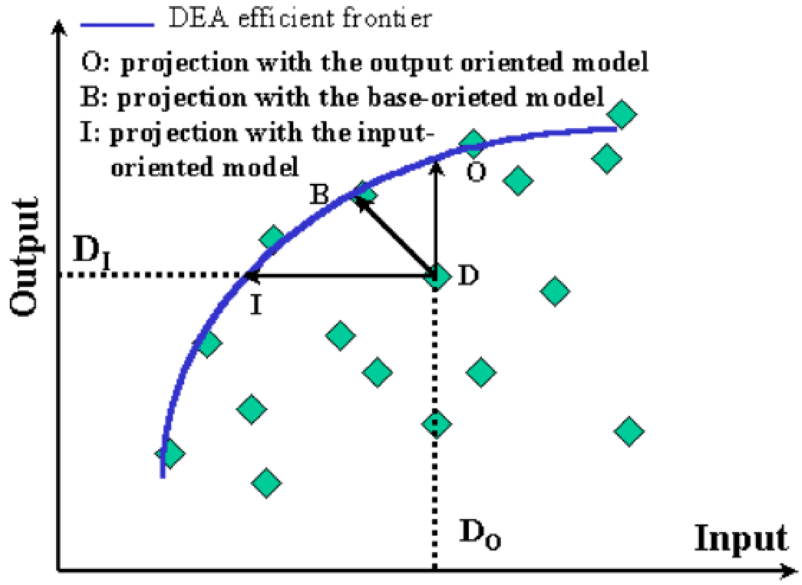


Figure 3.1 Projection of an inefficient unit on the frontier

3.3 Graphical representation of DEA

Let's take four feeders of a system where only three parameters can be measured.

Table 3.1 Parameters of Feeders

	Power Loss (kW)	Number of feeder trippings	Feeder length (km)
Feeder 01	90	95	45
Feeder 02	68	70	27
Feeder 03	85	75	40
Feeder 04	70	64	25

In these parameters Power losses and number of Feeder trippings can be reduced by introducing various improvements to the feeders. But feeder length cannot be controlled easily because a particular feeder needed to be provide the supply to a particular geographical area and changing the length of a feeder is impractical.

Power loss and Feeder trippings are higher in Feeder1 and Feeder 3 than the Feeder 2 and Feeder 4. Therefore by just looking into these two information someone can say that Feeder 2 and Feeder 3 are better than Feeder 1 and Feeder 2.

But when it consider the power loss per unit length and Feeder trippings per unit length the Feeder 1 and feeder 3 are better than Feeder 2 and Feeder 4.

In practical situations this kind of contradictions are occurred in utilities. With the increase of parameters that can be measured complexity of this kind of contradictions are increased.

If the partial performances are calculated values can be shown as below.

Table 3.2 Power Loss per Unit Length of a Feeder

	Power Loss (kW)	**Feeder length (km)**	**Power loss per unit length**		**Relative partial efficiency**
A	**B**	**C**	**D = (B/C)**	**E = (1/D)**	**F= E/(Max of Es)%**
Feeder 01	80	50	1.60	0.63	100
Feeder 02	68	20	3.40	0.29	47
Feeder 03	85	45	1.89	0.53	85
Feeder 04	70	15	4.67	0.21	34

Table 3.3 Feeder trippings per Unit Length of a Feeder

	Number of feeder trippings	Feeder length (km)	Feeder tripings per unit length		Relative partial efficiency
A	**B**	**C**	**D = (B/C)**	**E = (1/D)**	**F= E/(Max of Es)%**
Feeder 01	95	50	1.90	0.53	88
Feeder 02	70	20	3.50	0.29	48
Feeder 03	75	45	1.67	0.60	100
Feeder 04	64	25	2.56	0.39	78

These data can be mentioned on a graph as follows.

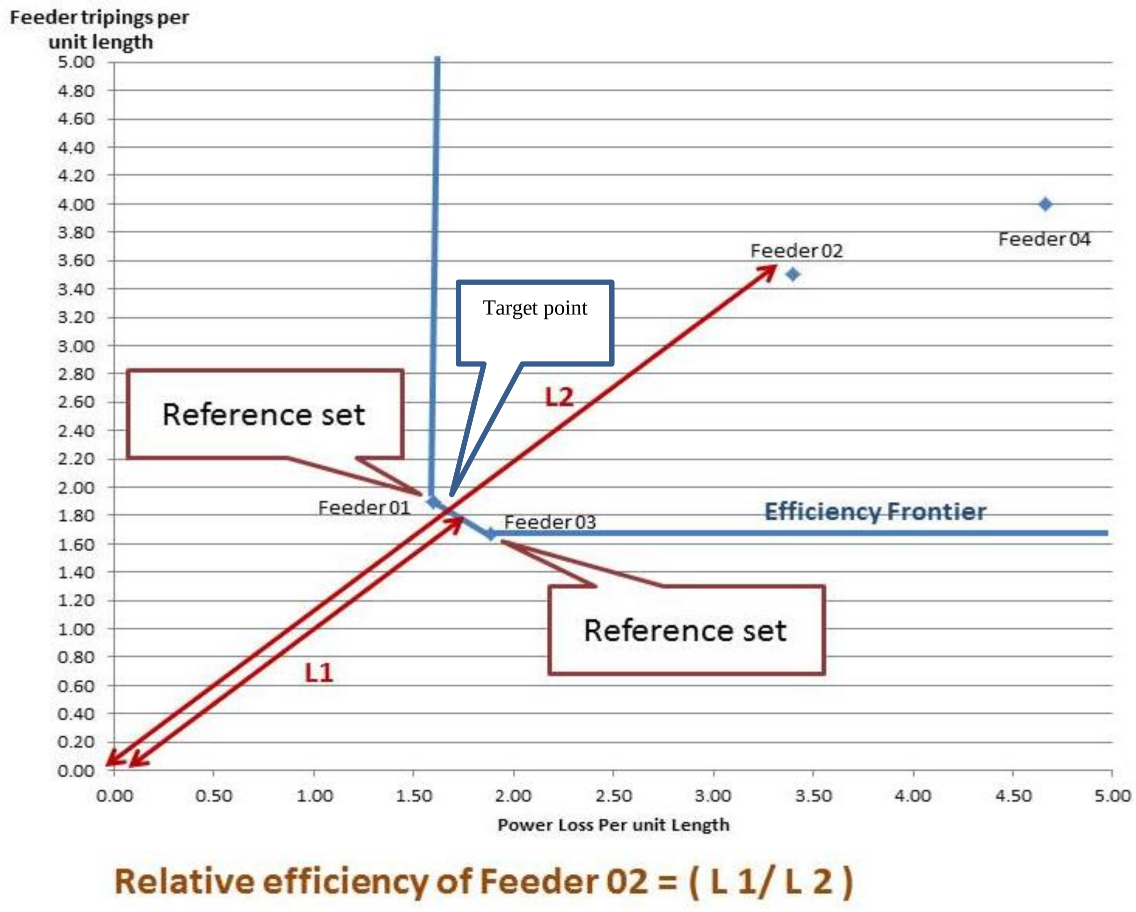


Figure 3.2 Graphical representation of DEA

If it draw the curve connecting points situated close to the axis of the graph, that curve is known as the efficiecy frountier. After that relative effciencies of all the feeders can be given as a propotion of distence from the zero point to efficient frountier and zero point to perticular feeder (refer figure 3.2).

In this method curves which are situated on the efficient frountier have relative efficincy score of 100 % . While all the other feeder's relative efficiency score is below 100 %.

In DEA targets are assigned for each and every relatively inefficient feeders. Targets are the values related to target point. Target point is the point where the line drown from perticular feeder to zero point intercept the efficient frountier. If a feeder achive to the target point that perticular feeder becomes relatively efficient.

Efficiency reference sets are the feeders which are beside the efficiency frontier, where the line drowns from particular feeder intercepts the efficiency frontier.

When the complexity increases it is very difficult to represent them on a graphical format.

3.4 DEA analysis Software

Simple problems can be solved using equations and graphical methods as shown in above example.

Slightly advance problems can be solved using solver parameter in excel [19]. This method is difficult to use for detailed studies in DEA.

Licensed software (Warwick DEA software, DEA Frontier Analyst Software, Performance Improvement Management Software (PIM-DEA), etc.) have been developed to solve advance and detailed DEA analysis.

Other than that free and open source software (DEA Frontier Analyst Free software) are available for DEA analysis.

Characteristics of above methods are summarized in the following table. Considering those factors, DEA Frontier Analyst Free software is used in this research. By this software only 20 Feeders can be evaluated once.

Table 3.4 Characteristics of DEA evaluation methods

Characteristic	**Graphical method**	**Solver parameter in excel**	**Licensed software**	**Frontier Analyst Free**
Easiness to compute	Hard	Slightly Hard	Easy	Easy
Detailed studies can be done easily	No	Very hard	Yes	Yes
Time requirement for a study	Very long	Very long	Short	Short
Number of feeders can be evaluated at once	Any amount of feeders	Any amount of feeders	Any amount of feeders	Up to 20 feeders
License fee required	No	No	Yes	No

CHAPTER FOUR

4 EVALUATING DEA EFFICIENCY SCORES

4.1 Selection of Input & Output Variables

4.1.1 Introduction

Selection of suitable input and output variables are very significant in DEA analysis. The criteria of selection of these inputs and outputs are quite subjective. A DEA study should start with an exhaustive, initial list of inputs and outputs that are considered relevant for the study. At this stage, all the inputs and outputs that have a bearing on the performance of the DMUs to be analyzed should be listed. Screening procedures, which may be quantitative or qualitative may be used to pick up the most important inputs and outputs [13]. A rule of thumb (from international practices) is that for m number of inputs and n number of outputs, there has to be n x m number of Feeders. Otherwise all the Feeders would get closer to 100% efficiency and discrimination could be difficult [19].

Factors to be considered when selecting input and output variables

- Availability of data
- Easiness to collect data
- Relevant to electricity distribution
- Accuracy
- Common usage in available literature
- Transparency

4.1.2 World practice of selecting Inputs and outputs

Following tables shows the summery of various inputs and outputs were selected in 20 Data Envelopment Analysis methods used in the world related to Power Distribution [18].

Table 4.1 Frequency of the use of variables in 20 DEA studies of distribution utilities

Input		Output	
Item	**Frequency**	**Item**	**Frequency**
• Units sold	2	• Units sold	12
• No. of customers		• residential sale	6
• Network size	11	• residential sale	6
• LV lines	2	• No. of customers	11
• MV line		• no. resid. cust.	5
• HV lines	2	• no. non-resid. cust.	5
• Transformer capacity	11	• Network size	4
• MV transf. cap.		• Transformer capacity	
• HV transf. cap.		• no. of transformers	
• Service area	2	• Service area	6
• Maximum demand		• Maximum demand	4
• Purchased power	2	• Power sold to other utilities	
• Losses	4		
• Labour inputs	15	• **<u>Miscellaneous:</u>**	
• admin. labour			
• technical labour		➢ service reliability	
		➢ load factor	
• **<u>Cost measures:</u>**		➢ net margin	
➢ OPEX	7	➢ revenues	
➢ OPEX+tangible depreciation		➢ distance index	
➢ admin./account costs	2	➢ network density	
➢ maintenance costs		➢ categorical variable for urban areas	
➢ capital	5		
➢ CAPEX user cost+labour costs			
➢ materials			
• **<u>Miscellaneous:</u>**			
➢ Ind. demand			
➢ customer dispersion			
➢ share of industrial energy	2		
➢ network size/customers			
➢ % system unload			
➢ residential/total sales			
➢ outage			
➢ no. residential customers/network size			
➢ inventories			
➢ line length*voltage			

Following table shows various inputs and outputs selected for DEA studies of distribution utilities in the world [18].

Table 4.2 Inputs and Outputs selected for DEA studies of distribution utilities in the world

	Inputs	**Outputs**
76 Turkish retail distribution organization 1991	• Labor • Transformer capacity • Network size • General expenses • Network losses	• No. of customers • Units supplied • Max demand • Service area
45 dist. Districts of the Greek Public Power Corporation (PPC)	• Network size • Transf. cap • General expenses • Administrative labor (hrs) • Technical labor (hrs)	• No. of custom. • energy supplied • network size • transf. cap • dummies for urban centers • service area
289 Swedish distribution utilities 1970– 1986	• Labor (hrs) • LV lines • HV lines • transf. cap.	• LV units delivered • HV units delivered • no. of LV customers • no. of HV customers
18 Dutch regional network utilities	• OPEX • OPEX+ tangible depreciation	• no. of customers • no. of small customers • no. of large customers • network size • no. of transformers • network density • no. of customers • no. of small customers • no. of large customers • network size • no. of transformers • network density
9 Spanish distribution utilities 1995	• LV lines (km) • MV lines (km • HV lines (km) • transf. cap. HV to MV/LV • transf. cap. MV to LV	• No. of LV custom • no. of MV/HV custom. • service area • units sold • service reliability
9 Japanese and 14 US utilities 1983–1993	• Generation cap. • fuel (kCal) • fuel (kCal) • power purchases	• Residential sales (GWh • non-residential sales (GWh)
85 electricity systems in developing countries	• Labour • thermal power • hydropower • nuclear power • other generation	• Electricity output (GWh)
82 Danish distr. utilities 1991	• No. of employees • wages • OPEX • losses • capital value	• Network size • electricity supplied • no. of custom.

4.1.3 Data Collection

Information of Medium voltage feeders were obtained under following categories.

- Number of substations connected to the feeder
- Feeder lengths
- Voltage Drop (%)
- Consumer Data (Number Primary substations , bulk consumers and Retail consumers)
- Feeder Tripping Data
  - Auto trippings
    - Total number of Auto Trippins
    - Number of Auto trippings >5 min
    - Number of Auto trippings <5 min
    - Total feeder off duration due to auto trippings
    - Feeder off duration due to auto trippings > 5 min
    - Feeder off duration due to auto trippings < 5 min
  - Manual trippings
    - Total number of manual trippings
    - Number of manual trippings > 5 min
    - Number of manual trippings < 5 min
    - Feeder off duration due to manual trippings
    - Feeder off duration due to manual trippings > 5 min
    - Feeder off duration due to manual trippings < 5 min
  - total number of trippings
- Maximum voltage drop
- Maximum demand of the feeder
- Energy supplied by the feeder(MWh)
- Peak Power loss (kW)

These data are shown in Annex 2.

4.1.3.1 Facts regarding Data Collection

A feeder rearrangement was done in July 2014 in Panadura GSS due to addition of a new Power Transformer to the GSS therefore Data was obtained from 2013 July to 2014 July.

Peak Power loss and maximum voltage drop were obtained from SynerGee software for the normal feeding arrangement of feeders. That software is used by CEB for Power Distribution panning purposes.

LECO Primary substation is considered as a one unit (even though it has more transformers).

Reliability indices were not calculated separately. Because Summation feeder off duration due to auto tripping and is feeder off duration due to manual tripping equals to SAIDI value of a particular feeder. Summation of Number of auto trippings and Number of manual trippings is equals to SAIFI value of a feeder.

4.1.4 Correlation analysis

All the available data cannot be used for DEA analysis as the multiplication of number of input and number of output should be a minimum value. Therefore most appropriate inputs and outputs are needed to be selected. Correlation analysis was done to identify relationships between available data categories.

The relationship between two numerical variables is measured by correlation. Here the target is not to use one variable to predict another variable. But it shows the strength of the linear relationship between two variables.

Table 4.3 shows a guide line to correlation analysis. When correlation coefficient $r = \pm 1$ it indicates that there is a perfect positive or negative correlation between those two variables. If the value of $r=0$ that means there is no any relationship between the two variables. All other values of r fall between -1 & 1 and the value indicates the strength of the relationship between two variables

Table 4.3 below may be used as a guideline as to what adjective should be used for values of r obtained after calculation to describe the relationship [13].

Table 4.3 Guideline to correlation analysis

Exactly -1	A perfect negative linear relationship
-0.7	A strong negative linear relationship
-0.5	A moderate negative relationship
-0.3	A weak negative linear relationship
0	No linear relationship
0.3	A weak positive linear relationship
0.5	A moderate positive relationship
0.7	A strong positive linear relationship
Exactly +1	A perfect positive linear relationship

Annex 3 shows the results of the correlation analysis carried out for available variables.

Maximum voltage drop percentage and Peak power loss have strong positive linear relationship. This might be because that data are obtained from SynerGee software. In SynerGEE software voltage difference between two nodes (small section of a feeder modeled in the software) is used to calculate power losses.

Feeder length, Number of manual trippings, Number of manual trippings < 5 minutes and Feeder off duration due to manual trippings < 5 minutes have strong positive linear relationships. When we talk about a normal feeder comparatively higher portion of them are less than five minutes because most of manual trippings are done for load transferring and switching operations (for switches like DDLO and Air circuit Breakers where on-load operations are not possible). Most of the switching operations take less than five minutes time periods. With the increase of feeder length, amount of switches of the feeder increases and switching operations increases. That is the reason for having strong positive linear relationship among above categories.

Number of substations, Number of bulk consumers and Number of consumers of a feeder have strong positive linear relationships. In areas like Dehiwala and Rathmalana consumer density is higher and also power demand is higher therefore substations are situated closer, also bulk consumers are situated closer when comparing to places like Agalawatta and Kalutara areas (where consumer density is lower and bulk consumer density is also lower) .

Feeder off duration due to auto trippings and Feeder off duration due to auto trippings > 5 min have strong positive linear relationships. This is because for transient faults and momentary faults feeder outage durations are very less compared to other faults.

Numbers of Primary substations of a feeder and Energy supplied by a feeder has strong positive linear relationship. This is because the demand for power of a feeder increases with the number of Primary substations of the feeder.

It is important to consider results of Correlation analysis when selecting Inputs and outputs for DEA analysis.

4.1.5 Selection of DMUs

In WPS-I Thirty two Medium voltage feeders provides power, but only 20 feeders can be evaluated once, because the DEA Frontier Analyst Free software only let 20 DMUs to be evaluated at once. Therefore feeders were divided into two categories named as urban and rural by considering the Homogeneity of feeders.

Feeders of Dehiwala GSS, Rathmalana GSS and Pannipitiya GSS were added to urban category. Feeders of Mathugama GSS and Panadura GSS were added to rural category.

Accuracy of DEA analysis results are increased due to this categorization because similar types of feeders are compared at once. Therefore differences occurs due to consumer density, Per capita power consumption, Consumer mix and Geographical issues were minimized.

4.1.6 Input and output variables used in literature

When it consider feeders, it needs to supply demanded power and should maintained the network by minimizing the feeder trippings and power losses, etc. Input-oriented model is needed for this kind of study because in Input-oriented models given amount of outputs have to be produced consuming smallest possible amount of inputs, that is outputs are uncontrollable and inputs are controllable.

As we are going to find relative efficiency scores of feeders items needed to be controlled should to be added as the inputs.

Normally manual trippings are taken for load transferring situations and line maintenance work. In that kind of situations power for the consumers in the feeder is supplied by extending other feeders (by switching operations part of the feeder can be energized, only the required section of the feeder for maintenance is interrupted) most of the time. If the consumers are going to be interrupted that consumers will be informed earlier about the interruption. Information of partly interrupted section are difficult to calculate, and some information are not available. Manual trippings are taken to improve the condition of a feeder therefore feeder off duration due to manual trippings is not considered as an input to the model.

When a feeder is switched off all the consumers of a feeder are affected. Therefore number of trippings needed to be controlled. Number of feeder trippings is a mojor parameter when deciding the condition of a feeder. Therefore it is better if it can divide feeder trippings into few categories. But amount of variables cannot be increase as our wish, because if the amount of inputs of the model increases more number of feeders obtain relative efficiency score of 1. Therefore number of feeder tripping only divided into number of auto trippings and number of manual trippings (causes for manual trippings are difference from causes for auto trippings). Therefore number of feeder trippings are divided into two categories as number auto trippings and number of manual trippings.

Table 4.4 shows the input and output variables that can be used for the study.

Table 4.4 Input output variables can be used

Inputs	**Outputs**
Number of Auto trippings	Feeder Length
Feeder off duration due to auto trippings	Number of Sub stations
Number of manual trippings	Number of consumers in the feeder
Peak Power loss (kW)	Maximum demand
Maximum Voltage Drop (%)	Energy supplied
SAIDI	
SAIFI	

4.2 Selection of Inputs and Outputs for the Base Model

DEA analysis relies heavily on the initial choice of inputs and outputs. The efficiency scores tend to be sensitive to the choice of input and output variables and, in some circumstances, inappropriate choices may lead to inaccurate relative efficiency scores.

To select base model DEA analysis was carried out for several models in order to analyze the variation of the results for different input and output combinations. Table 4.5 shows the evaluated models. Relative Efficiency scores obtained from this study are shown in Annex 4.

Table 4.5 Evaluated Models

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
INPUT																			
Number of Auto trippings	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Feeder off duration due to auto trippings	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Number of manual trippings	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Peak Power loss (kW)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
Maximum Voltage Drop (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0
SAIDI																			0
SAIFI																			0
OUTPUT																			
Number of S/S	0		0				0	0	0						0	0			
maximum demand (A)	0			0				0		0				0	0				
Energy supplied (MWh)	0				0				0		0		0	0		0			
Number of consumers	0					0						0	0	0					
Feeder length (km)		0					0			0	0	0	0	0	0	0	0	0	0

4.2.1 Evaluation with Peak Power Loss and Maximum Voltage Drop

Even though maximum voltage drop percentage of a feeder and peak power loss are major parameter when deciding a condition of a feeder, according to the correlation analysis maximum voltage drop percentage and Peak power loss have strong positive linear relationship (correlation index of 0.913). Therefore only one parameter can be selected for the model. Model number 2 is evaluated with both Peak Power Loss and Maximum Voltage drop Percentage in the model. Model number 17 is evaluated with Peak Power loss & without Maximum Voltage drop Percentage. Model number 18 is evaluated without Peak Power loss & with Maximum Voltage drop Percentage.

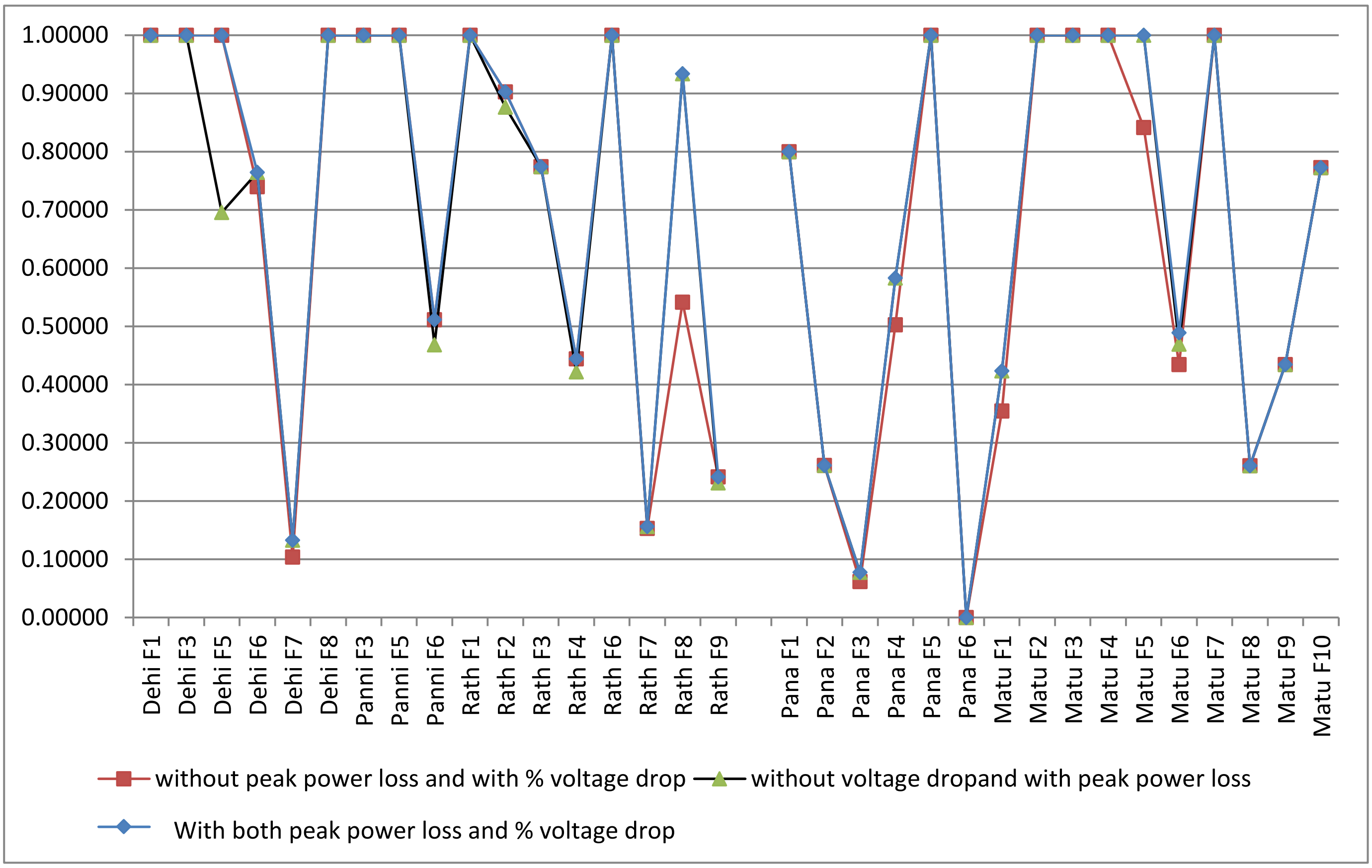


Figure 4.1 Relative efficiency score variation with regard to Peak Power loss and Maximum Voltage drop Percentage

According to the results some Feeders shows significant variations in the relative efficiency scores in the evaluated above models. Therefore both variables are significant variables and both the Peak Power loss and Maximum Voltage drop Percentage are taken to the base model.

4.2.2 Evaluation with Reliability Indices

In international benchmarking practices, the use of reliability indexes as a variable is rare, but at present reliability indexes (SAIDI & SAIFI) are the most widely used variable to measure performance of Power distribution sector. But when a feeder is considered SAIDI value is equals to summation of Feeder off duration due to Auto trippings and manual trippings (Available information about feeder off duration due to manual trippings are incomplete and impossible to calculate, therefore only feeder off duration due to auto trippings is used for the benchmarking process). Number of Auto trippings and Number of manual trippings is equals to SAIFI value of a feeder. (Note: information about partial interruption of feeders are not available).

A separate study (Model number 19) was done by using reliability indices. In this study summation of number of Auto trippings and number of manual trippings are taken as SAIFI value. Feeder off duration due to Auto trippings is taken as SAIDI value. Therefore only difference occurs in model number 19 compared to model 2 is in the model number 2, number of feeder trippings are taken as two variables (manual trippings and auto trippings) while in the model number 19 number of feeder trippings are taken as only one variable.

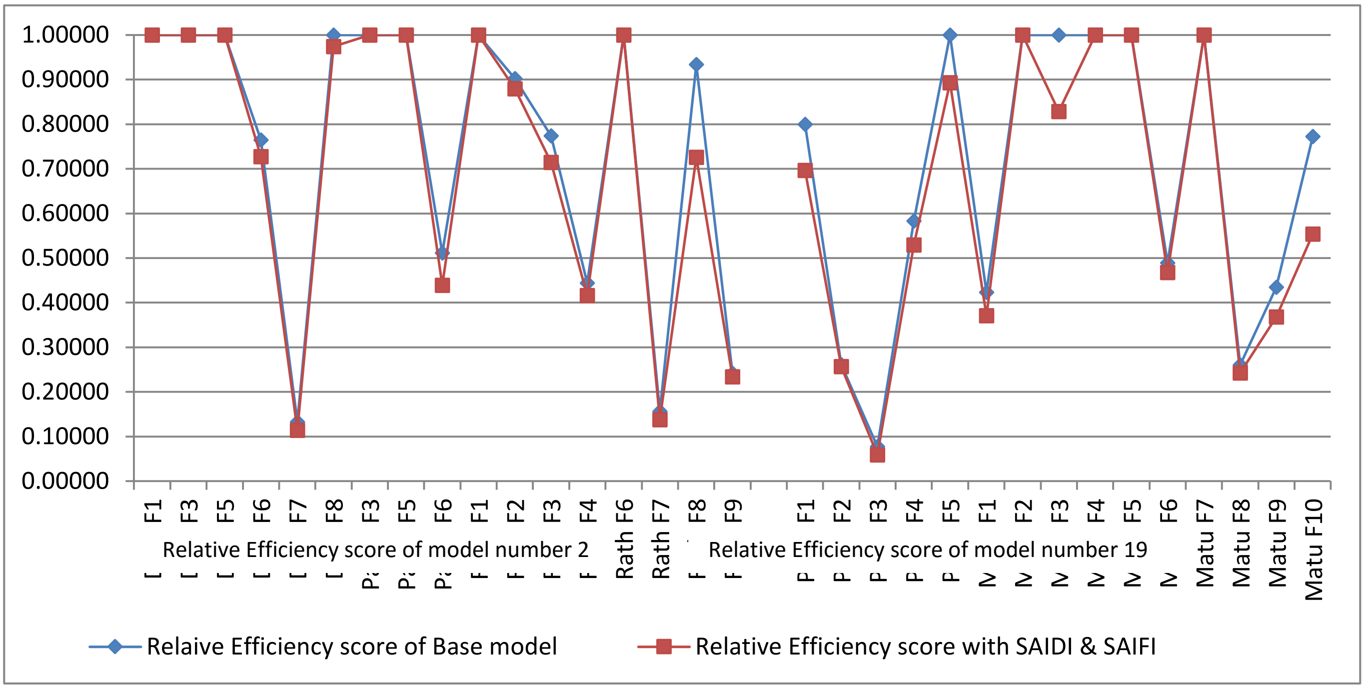


Figure 4.2 Relative efficiency score variation with Reliability indices

Some feeders show significant differences in model 2 and the model 19 with reliability indices. In model number 2 data is observed in detail. Specially when obtaining targets to be achieved to become relatively efficient and when doing sensitivity analysis it is more advisable to have more information. Therefore the model number 2 is more suitable than the model number 19 with reliability indices.

4.2.3 Study done to select suitable output

Even though we have used items beyond our control as outputs, selection of output needed to be done carefully. Relative efficiency scores obtained from the evaluation needed to be justified. Therefore to select most accurate outputs, various combinations of feasible outputs (model number 1 to 16) were studied.

It is observed that relative efficiency score changes considerably with the selected outputs. Those evaluated outputs are uncontrollable variable. Changing the relative efficiency score regard to Number of Substations of the feeder, Number of consumers of the feeder, Maximum demand of the feeder and Energy supplied by the feeder are cannot be justified (when number of these outputs increase more number of feeder trippings, voltage drops, power losses etc can be happened without reducing the relative efficiency score).

Other than that deciding the relative efficiency score based on Number of Sub stations of the feeder, Number of consumers of the feeder, Maximum demand of the feeder and Energy supplied by the feeder are cannot be verified. Therefore from feasible outputs only feeder length is taken as output for the evaluation.

4.2.4 Analysis with base model and with exclusion of one variable at a time

To check the suitability of selected inputs relative efficiency scores were checked with different models upon exclusion of one variable at a time. Figure 4.3 shows the relative efficiency score changes in different models (obtained relative efficiency scores are shown in Table 4.9 under section 4.3.2). In all the models relative efficiency scores changes significantly with regard to selected base model. Therefore all the selected input variables for the base model are significant.

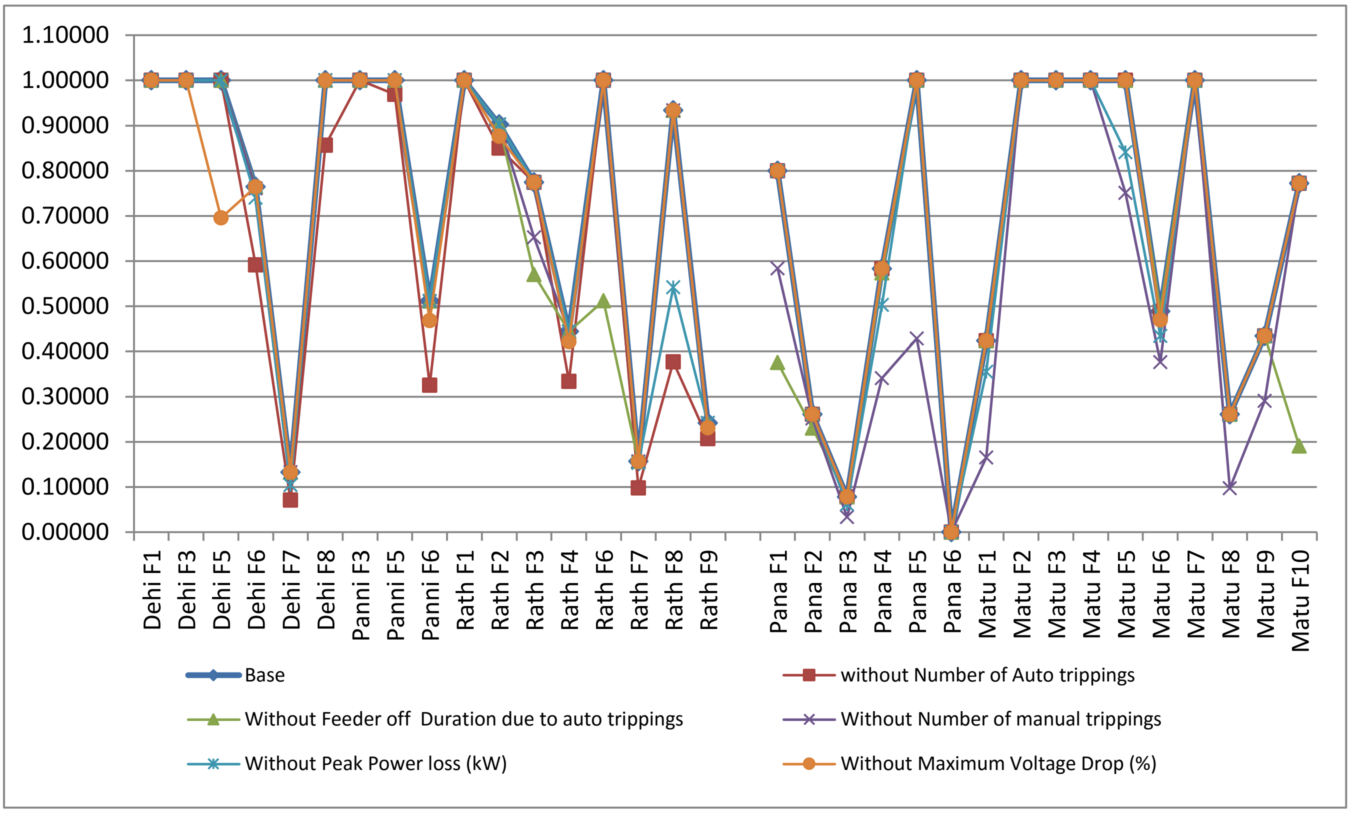


Figure 4.3 Efficiency scores of base model and with exclusion of one variable at a time

4.2.5 Justification of the selected base model

When considering the above facts model number 2 is the only suitable model for the base model, therefore model number 2 is taken as the base model for the evaluation.

The selected base model for the analysis can be justified from the results of the analysis done after running different DEA models. Table 4.6 depicts the justification of the selected base model.

Table 4.6 Justification of the selected base model

Input Variables	Results obtained from analysis	Output Variables	Results obtained from analysis
Number of Auto trippings	Significant variable	Feeder length	Significant and suitable variable
Feeder off duration due to auto trippings	Significant variable	Number of Sub stations	Not suitable variable
Number of manual trippings	Significant variable	Number of consumers in the feeder	Not suitable variable
Peak Power loss	Significant variable	Maximum demand	Not suitable variable
maximum Voltage Drop percentage	Significant variable	Energy supplied	Not suitable variable
SAIDI	Equals to Feeder off duration due to trippings (therefore not required)		
SAIFI	Equals to summation of Number of manual trippings & Auto trippings (therefore not required)		

Input Variables	Output Variables
Number of Auto trippings	Feeder length
Feeder off duration due to auto trippings	
Number of manual trippings	
Peak Power loss	
maximum Voltage Drop percentage	

4.3 DEA Analysis

4.3.1 Relative efficiency score

DEA model was solved using DEA Frontier Free Software. Relative efficiency scores for the Input Oriented model were obtained and are listed in table 4.7.

Table 4.7 Relative efficiency scores

DMU No.	DMU Name	Relative Efficiency Score	Catergory
1	Dehi F1	1.00000	Urbon
2	Dehi F3	1.00000	
3	Dehi F5	1.00000	
4	Dehi F6	0.76435	
5	Dehi F7	0.13271	
6	Dehi F8	1.00000	
7	Panni F3	1.00000	
8	Panni F5	1.00000	
9	Panni F6	0.51118	
10	Rath F1	1.00000	
11	Rath F2	0.90261	
12	Rath F3	0.77412	
13	Rath F4	0.44431	
14	Rath F6	1.00000	
15	Rath F7	0.15664	
16	Rath F8	0.93353	
17	Rath F9	0.24160	

18	Pana F1	0.80003	Rural
19	Pana F2	0.26111	
20	Pana F3	0.07792	
21	Pana F4	0.58322	
22	Pana F5	1.00000	
23	Matu F1	0.42336	
24	Matu F2	1.00000	
25	Matu F3	1.00000	
26	Matu F4	1.00000	
27	Matu F5	1.00000	
28	Matu F6	0.48892	
29	Matu F7	1.00000	
30	Matu F8	0.26083	
31	Matu F9	0.43445	
32	Matu F10	0.77239	

It can be noted that out of 32 feeders (seventeen feeders in urban category and fifteen feeders in rural category), 14 feeders (eight feeders in urban category and six feeders in rural category) have got the efficiency score 1.0. Mathugama Feeder 8 has the lowest efficiency score in rural category and Dehiwala Feeder 7 has the lowest efficiency score in urban category. Figure 4.1 depicts the Relative Efficiency Score obtained by each DMU.

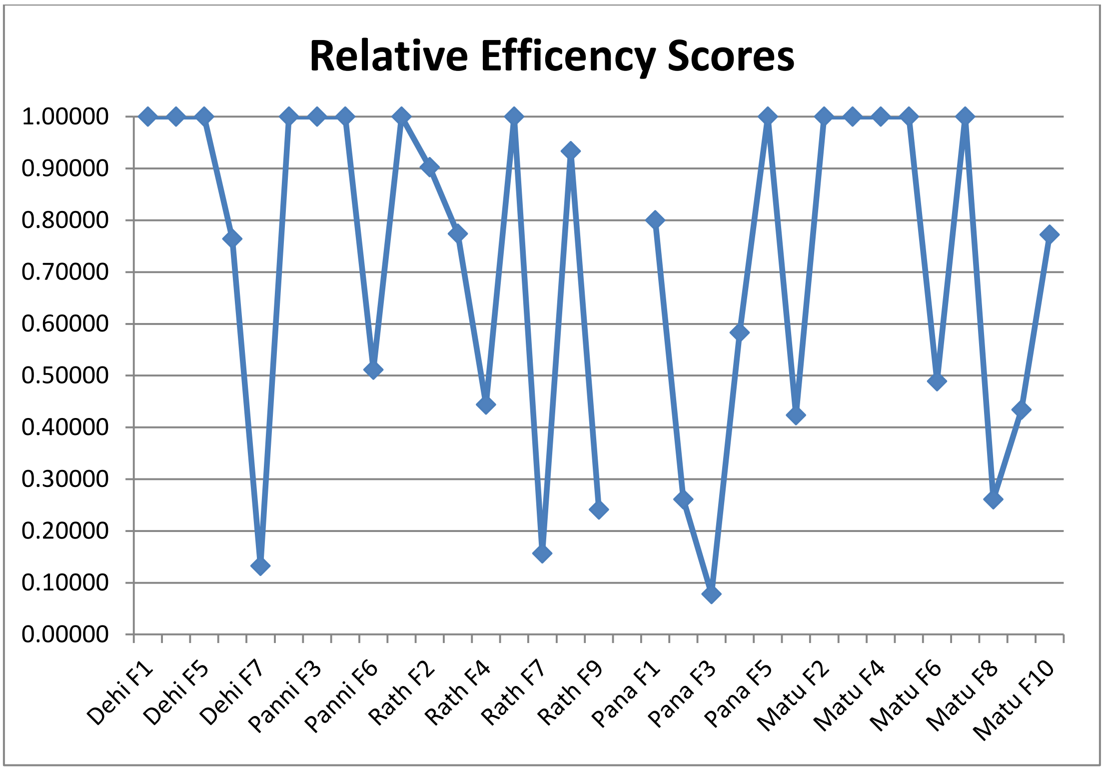


Figure 4.4 Relative efficiency score plot

All the inefficient feeders are given some targets to be achieved to become relatively efficient. Efficient Input Target assigned by DEA analysis for feeders are shown in table 4.8. These values can be used to get an idea regarding how the relatively inefficient feeders needed to be improved. In-depth analysis needed to be done observing the practical constraints, field issues and the efficiency targets assigned by the study.

Table 4.8 Efficient Input Target assigned by DEA analysis

	Efficient Input Target				
DMU Name	Number of Auto trippings	Feeder off duration due to auto trippings	Number of manual trippings	Peak Power loss (kW)	m Voltage Drop (%)
Dehi F1	32	156	11	0	0
Dehi F3	43	275	11	149	4
Dehi F5	57	362	12	0	0
Dehi F6	39	124	15	40	1
Dehi F7	5	17	2	7	0
Dehi F8	23	194	13	152	5
Panni F3	39	79	10	3	0
Panni F5	20	38	11	2	0
Panni F6	40	92	10	11	0
Rath F1	44	54	26	5	0
Rath F2	115	265	29	35	1
Rath F3	39	94	10	15	1
Rath F4	34	90	9	19	1
Rath F6	50	22	24	3	0
Rath F7	5	30	1	16	0
Rath F8	7	22	3	7	0
Rath F9	14	60	4	25	1
Pana F1	9	26	17	14	0
Pana F2	4	60	14	57	1
Pana F3	6	14	5	2	0
Pana F4	94	323	92	45	1
Pana F5	131	390	37	62	1
Matu F1	27	157	30	77	1
Matu F2	11	609	230	215	5
Matu F3	19	219	123	4	1
Matu F4	16	24	27	0	0
Matu F5	36	681	127	42	3
Matu F6	19	177	63	14	1
Matu F7	13	299	60	296	5
Matu F8	4	63	12	59	1
Matu F9	24	176	30	129	2
Matu F10	6	26	13	18	0

Further study has been carried out for few inefficient feeders (Mathugama Feeder 9, Rathmalana Feeder 2, Mathugama Feeder 5 and Mathugama Feeder 7) and the discussion is given in the section 5.1 and section 5.2.

4.3.2 Sensitivity Analysis

In order to check the stability of efficiency scores obtained from DEA analysis according to the variations in inputs and outputs, it is required to carry out a sensitivity analysis. Here one input variable or output variable is removed from the base model at a time and DEA analysis is carried out to find the efficiency score. Then obtained efficiency score is compared with the base model efficiency scores. When carrying out sensitivity analysis it can be noted that efficiency scores of Feeders will never increase upon removal of input and output variables from the model.

Results from sensitivity analysis can be used as a base for classification of Feeders. Considering the pattern obtained from the graph of efficiency variation with different models upon removal of variables at a time the Feeders can be classified in to five categories [13].

- Robustly efficient – DEA efficiency score stays at one or decrease very slightly when the variables are removed from the model one at a time.
- Marginally efficient – Efficiency score is 01 for the base model and remains at 01 in some situations, but drops significantly in other situations.
- Marginally inefficient – DEA efficiency score is below 1 but above 0.9 for the base model and stays in that range during the sensitivity analysis
- Significantly inefficient – DEA efficiency score is below 1 but above 0.9 and drops to much lower values during the sensitivity analysis.
- Distinctly inefficient – DEA efficiency is significantly low (below 0.9) in all the situations

Following table shows the efficiency scores of feeders found in the sensitivity analysis.

Table 4.9 Results of Sensitivity Analysis

Feeder number	Base	without Number of Auto trippings	Without Feeder off Duration due to auto trippings	Without Number of manual trippings	Without Peak Power loss (kW)	Without Maximum Voltage Drop (%)
Dehi F1	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
Dehi F3	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
Dehi F5	1.00000	1.00000	1.00000	1.00000	1.00000	0.69534
Dehi F6	0.76435	0.59180	0.76435	0.76076	0.73995	0.76435
Dehi F7	0.13271	0.07089	0.13271	0.13271	0.10419	0.13271
Dehi F8	1.00000	0.85621	1.00000	1.00000	1.00000	1.00000
Panni F3	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
Panni F5	1.00000	0.96924	1.00000	1.00000	1.00000	1.00000
Panni F6	0.51118	0.32554	0.51118	0.51118	0.51118	0.46816
Rath F1	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
Rath F2	0.90261	0.84981	0.90261	0.90261	0.90261	0.87609
Rath F3	0.77412	0.77412	0.57007	0.65254	0.77412	0.77412
Rath F4	0.44431	0.33347	0.44431	0.44431	0.44431	0.42186
Rath F6	1.00000	1.00000	0.51211	1.00000	1.00000	1.00000
Rath F7	0.15664	0.09778	0.15664	0.15664	0.15325	0.15664
Rath F8	0.93353	0.37713	0.93353	0.93353	0.54161	0.93353
Rath F9	0.24160	0.20710	0.24160	0.24160	0.24160	0.23128
Pana F1	0.80003	0.80003	0.37576	0.58391	0.80003	0.80003
Pana F2	0.26111	0.26111	0.22997	0.25168	0.26111	0.26111
Pana F3	0.07792	0.07792	0.07792	0.03310	0.06201	0.07792
Pana F4	0.58322	0.58322	0.57401	0.34115	0.50296	0.58322

Pana F5	1.00000	1.00000	1.00000	0.42830	1.00000	1.00000
Matu F1	0.42336	0.42336	0.42336	0.16534	0.35490	0.42336
Matu F2	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
Matu F3	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
Matu F4	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
Matu F5	1.00000	1.00000	1.00000	0.75065	0.84122	1.00000
Matu F6	0.48892	0.48892	0.48892	0.37610	0.43434	0.46952
Matu F7	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
Matu F8	0.26083	0.26083	0.26083	0.09713	0.26083	0.26083
Matu F9	0.43445	0.43445	0.43445	0.29083	0.43445	0.43445
Matu F10	0.77239	0.77239	0.19085	0.77239	0.77239	0.77239

According to the study nine feeders are Robustly efficient, five feeders are Marginally efficient, two feeders are Significantly inefficient and sixteen feeders are Distinctly inefficient. Following table shows the summery of feeders categorized in the sensitivity analysis.

Table 4.10 Summery of the sensitivity analysis

Item	Nos. Of Feeders	Feeders of Urban category	Feeders of Rural category
Robustly efficient	9	Dehi F1, Dehi F3,Panni F3, Panni F5, Rath F1,	Matu F2, Matu F3,Matu F4,Matu F7
Marginally efficient	5	Dehi F5, Dehi F8, Rath F6,	Pana F5, Matu F5,
Marginally inefficient	0		
Significantly inefficient	2	Rath F2, Rath F8	
Distinctly inefficient	16	Dehi F6, Dehi F7, Panni F6, Rath F3, Rath F4, Rath F7, Rath F9,	Pana F1, Pana F2, Pana F3, Pana F4, Matu F1,Matu F6 , Matu F8, Matu F9, Matu F10

Following graph shows the number of feeders categorized in the sensitivity analysis.

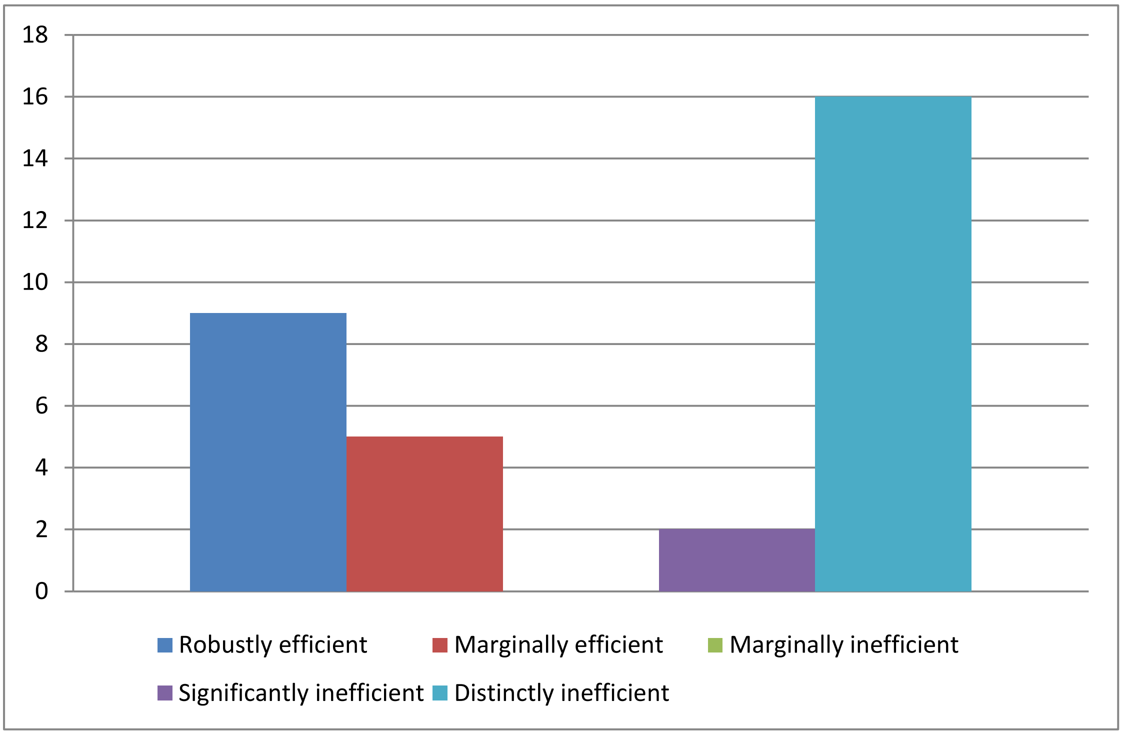


Figure 4.5 Summery of Sensitivity analysis

Sensitivity based classification is important when improving the performance or increasing the efficiency scores of Feeders. That is for a particular unit or to an organization it is essential to know its strength and weaknesses in order to achieve their targets.

In distinctly inefficient Feeders, the efficiency score is below 0.9 for all the cases including base model. That kind of Feeders needs special attention to improve their performance. In-depth studies needed to be carried out about these feeders and needed to find methods to improve performance of these feeders. Existing limited resources needed to be focused mainly to these distinctly inefficient feeders and give priority for these feeders in implementing system development work.

Significantly inefficient feeders also needed to be given close attention and needed to be done detailed studies to find methods to improve the performance. These feeders also needed to be given good attention in implementing system development work (if the resources are available after implementing solutions to distinctly inefficient Feeders).

At the same time marginally efficient Feeders are very sensitive to changes in some variables only. Therefore it is required to identify important variables for these kinds of Feeders and prevent them from becoming inefficient. Studies are needed to be done to identify to improve these sensitive variables (if the resources are available after implementing solutions to distinctly inefficient Feeders and significantly inefficient feeders).

Robustly efficient feeders perform well, when they are compared with all the considered feeders. These feeders are not needed to be given close attention in short term. It is more beneficial to do system development work to other categories of feeders than this category.

Figure 4.3 to Figure 4.6 depicts four different categories of Feeders that has been observed during the sensitivity analysis.

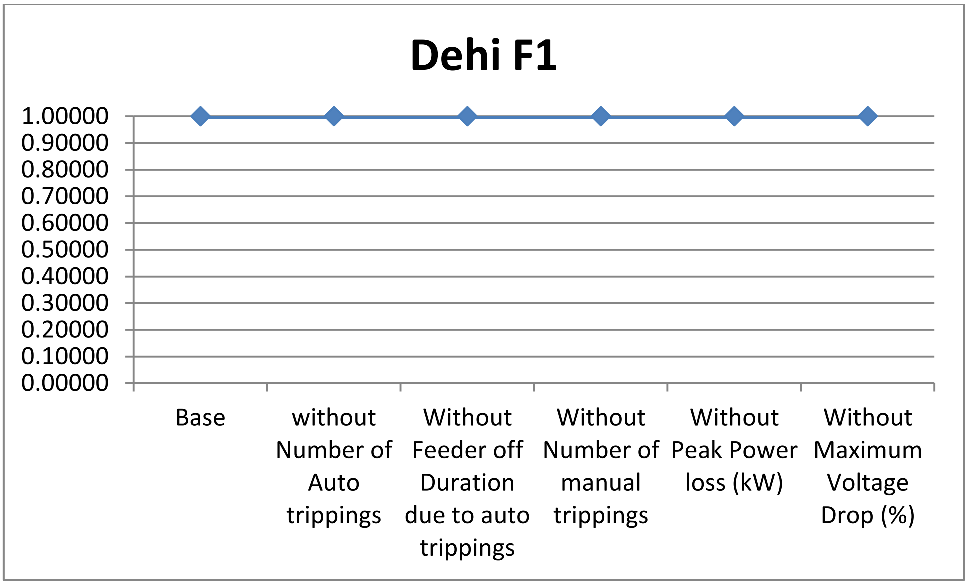


Figure 4.6 Sensitivity profile of a Robustly Efficient Feeder

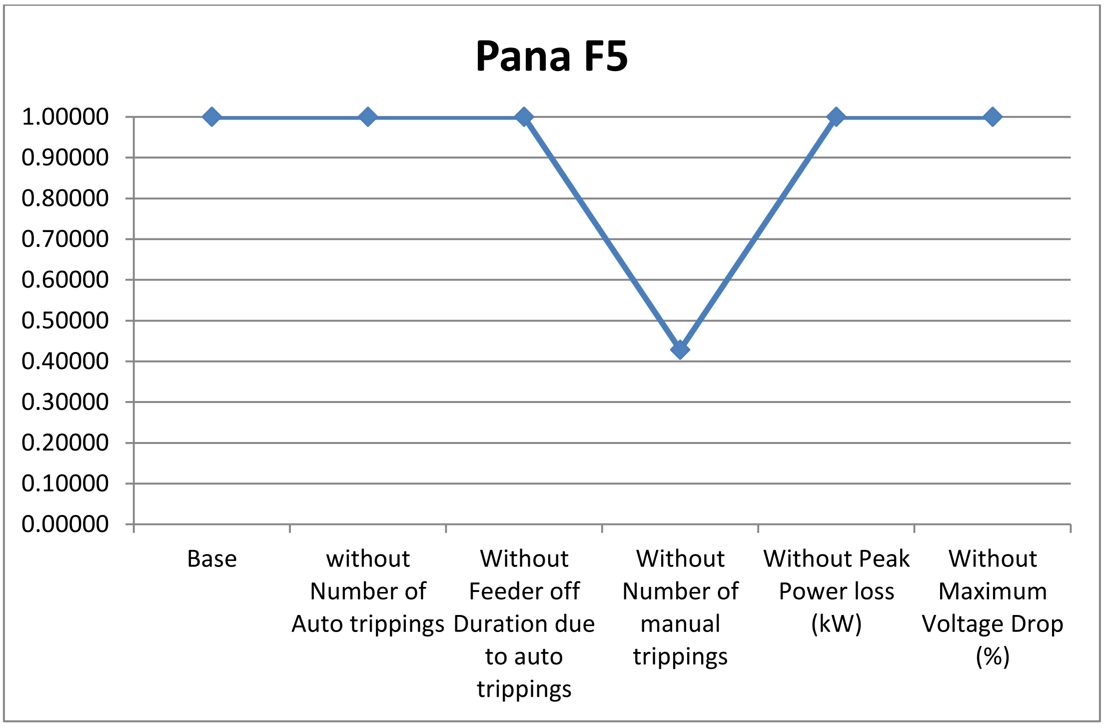


Figure 4.7 Sensitivity profile of a Marginally Efficient Feeder

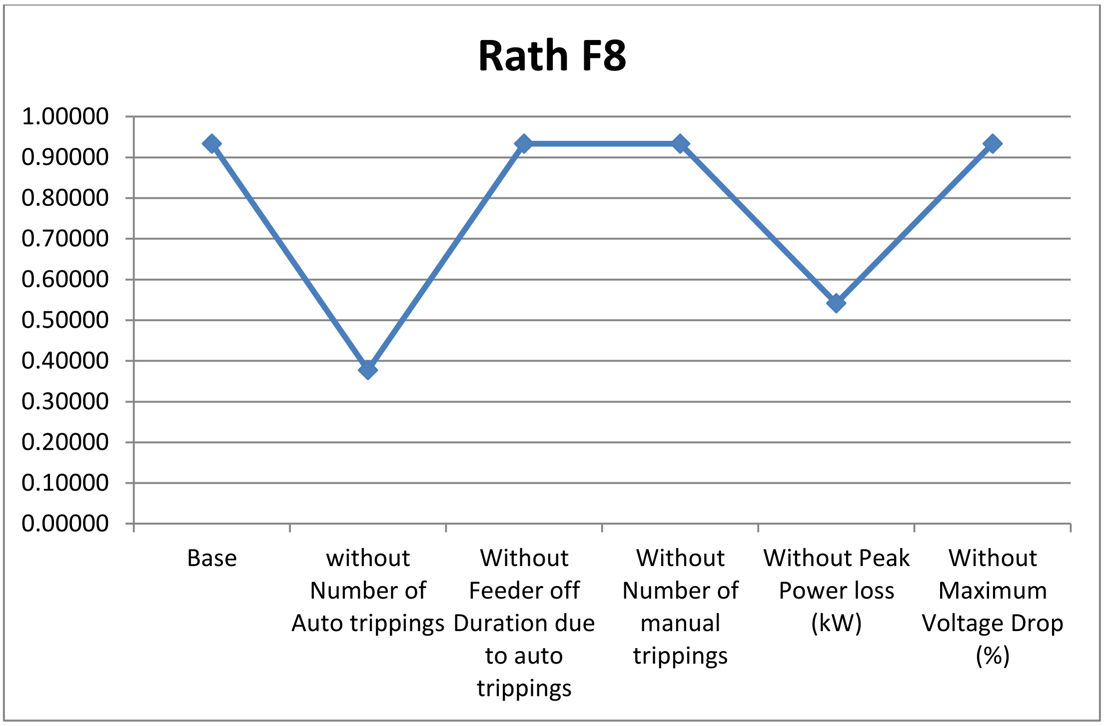


Figure 4.8 Sensitivity profile of a significantly Inefficient Feeder

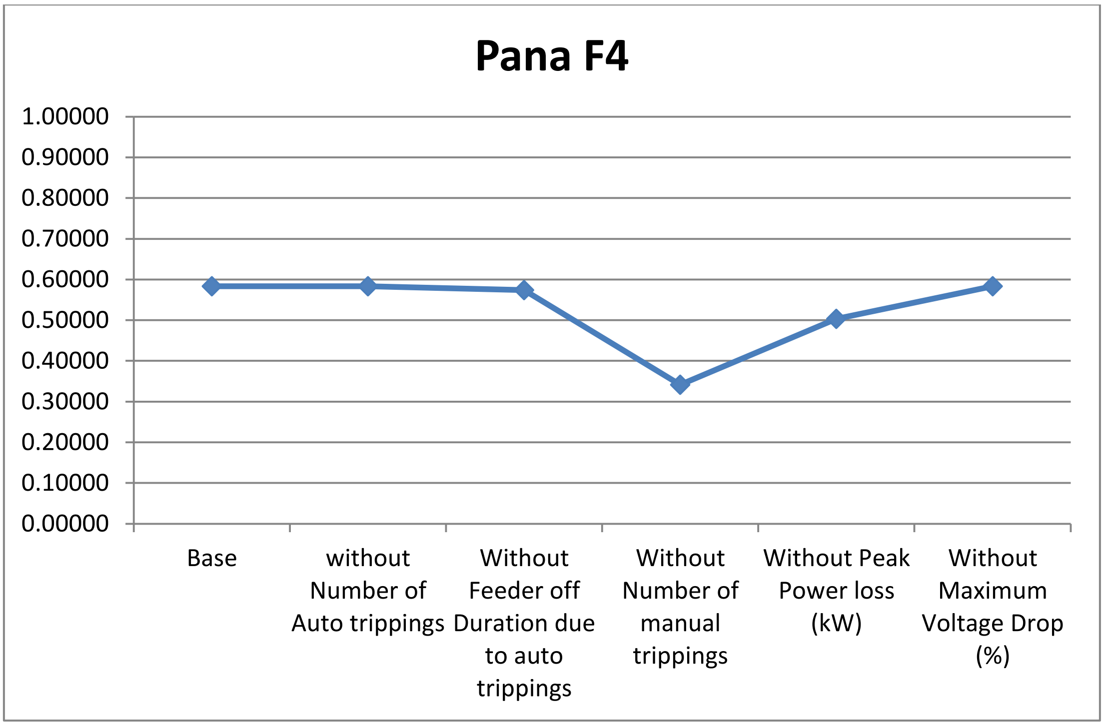


Figure 4.9 Sensitivity profile of a significantly Inefficient Feeder

CHAPTER FIVE

5 Practical situation comparison of the feeders

In this chapter one feeder from each category of feeders were compared with practical situation of feeders.

5.1 Distinctly inefficient –Mathugama Feeder 09

This feeder provides supply to Beruwala and Pallegoda areas. The feeder is highly loaded feeder therefore power losses and voltage drop is very high compared to other feeders of the province.

This feeder is not connected to any advance protective equipment other than DDLOs and ABSs. Table 6.1 shows the present values and values assigned by the DEA evaluation to become relatively efficient.

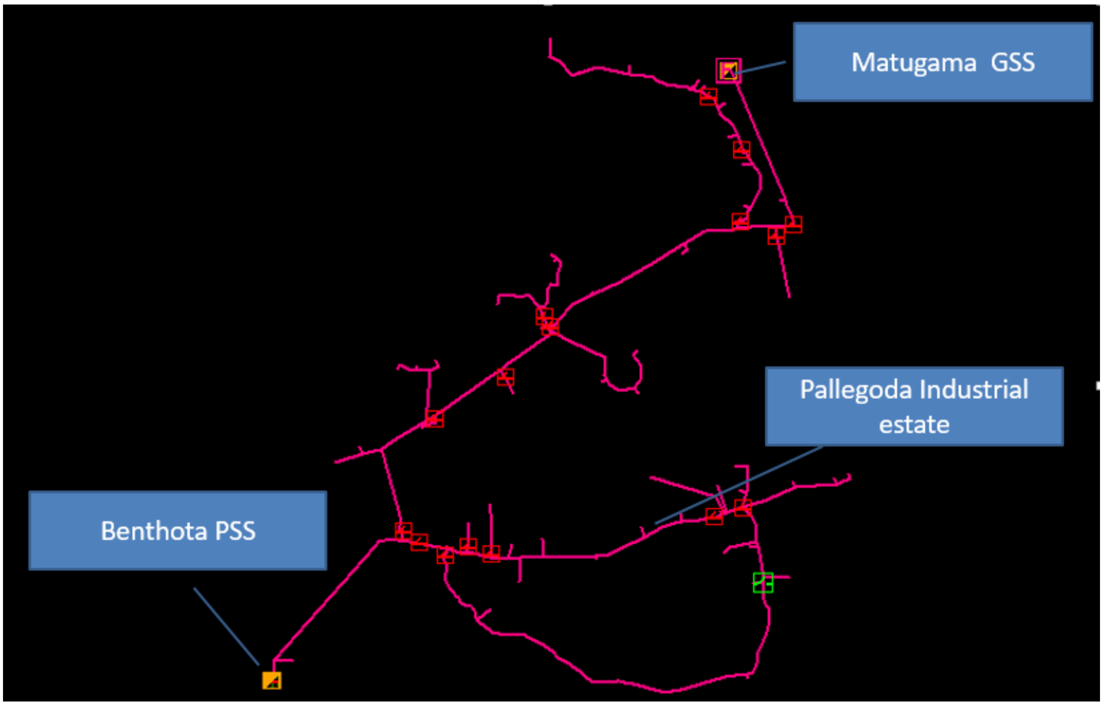


Figure 6.1 Mathugama Feeder 09

	Number of Auto trippings	Feeder off duration due to auto trippings	Number of manual trippings	Peak Power loss %	Maximum Voltage Drop percentage
Present values	55	465	68	549	6.44
Values needed to be obtained to become relatively efficient	24	176	30	129	2

Table 6.1 Parameters of Mathugama Feeder 9

Recommendations:

As this feeder is distinctly inefficient feeder (Relative efficiency score 0.43445), the feeder is needed to be given good attention and needed to find improvements to make this feeder a relatively efficient feeder. In–depth analysis needed to be carryout to identify proposals to develop this feeder.

Following proposals shall be implemented for this feeder.

- This feeder provide power to Pallegoda industrial state (Average demand around 6 MVA). To reduce the voltage drop and peak power loss loads can be transferred to other feeders. At present Mathugama Feeder 1 is loaded lightly (maximum demand 55 A) and goes close to the Pallegoda industrial state. Therefore by constructing a new line section (around 2 km) the load of the Pallegoda industrial state can be transferred to Mathugama Feeder 1. By that Peak Power loss and voltage drop can be reduced.

- This feeder provide power to Benthota PSS while feeding to so many distribution transformers. By constructing a dedicated line to Benthota PSS, reliability of the 33 kV supply of Benthota PSS will be improved while reducing the voltage drop and maximum voltage drop.

- This feeder is divided to few line sections. Autorelosures and sectionalisers can be installed in these sections. By that both number of auto trippings & number of manual trippings will be reduced, other than that feeder off duration will be reduced.

- Fault locaters shall be connected in this feeder. Fault clearing time will be reduced by that.

5.2 Significantly inefficient- Rathmalana Feeder 02

This feeder is going to Mill road gantry from Rathmalana GSS. After that feeder is divided in to several sections and feeds the consumers in Piliyandala and Kasbawa areas. There is no any special protective equipment connected to this feeder other than DDLOs and ABSs. Table 6.2 shows the present values and values assigned by the DEA evaluation to become relatively efficient.

Figure 6.2 Rathmalana Feeder 02

Table 6.2 Parameters of Rathmalana Feeder2

	Number of Auto trippings	Feeder off duration due to auto trippings	Number of manual trippings	Peak Power loss %	maximum Voltage Drop percentage
Present values	127	300	39	54	1.63
Values needed to be obtained to become relatively efficient	115	265	29	35	1

Recommendations:

As this feeder is significantly inefficient feeder (Relative efficiency score 0.90261), the feeder is needed to be given good attention and needed to find improvements to make this feeder a relatively efficient feeder. In –depth analysis shall be carryout to identify proposals to develop this feeder (only if the resources are available after implementing solutions for distinctly inefficient feeders).

Following proposals shall be implemented for this feeder (after implementing proposals identified for distinctly inefficient feeders).

- The feeder is divided into three main line sections after the Milroad gantry. Out of them two feeder sections are having higher vegetation and one feeder section goes to a less vegetation area (Pilyandala Town) Two auto reclosures shall be connected to high vegetation feeder section.

- This feeder is going through a difficult terrain from Suwarapola to Gama gantry. Frequent faults are observed due to vegetation. And also identifying the fault location and clearing the fault is also difficult.

    - It can install fault locaters and sectionalisers in this section to isolate and easy identification of faults.
    - Vegetation clearing program shall be improve in this section.

- Voltage drop of the feeder is 1.63%. This value is very much below the stipulated limit of 6% and the peak power loss is 54 kW. But DEA model recommends to reduce voltage drop value to 1% and peak power loss to 35 kW. Feeder reconductoring can be done to achieve this target. A new Grid substation will be installed at Kasbawa. Voltage drop and peak power loss will be reduced after energisation of this grid substation because some major loads of Rathmalana feeder 2 will be transferred to new Kasbawa Grid substation. Therefore it will not be required for recondoctoting.

5.3 Marginally efficient –Mathugama Feeder 05

Mathugama feeder 05 goes from Mathugama GSS to Kithulgoda gantry through a tower circuit. Tower lines are less vulnerable for faults when comparing with pole lines. After that the feeder is divided into several sections of pole lines.

Figure 6.2 Mathugama Feeder 05

One Autoreclosure is connected to this feeder at Kithulgoda gantry. Therefore, for faults occurs beyond the Kithulgoda gantry, feeder is switched off from the Kithulgoda gantry.

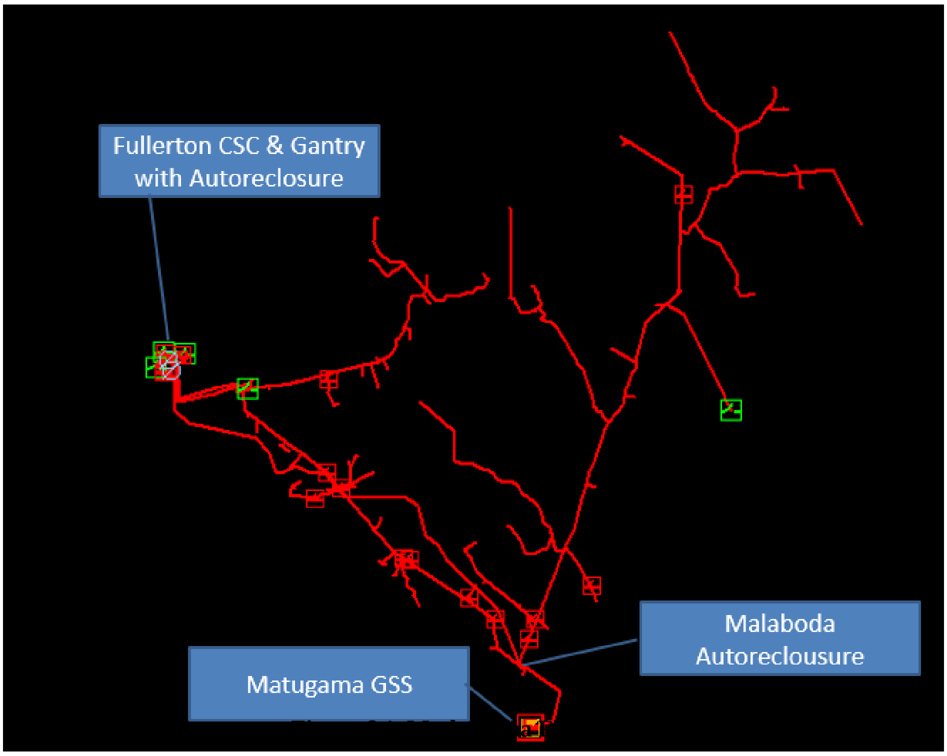
Even though Aotoreclosure at Kithulgoda gantry is switched off for faults, access for the Kithulgoda gantry is difficult as the gantry is situated in a difficult terrain. Other than that this feeder goes through comparatively difficult and highly vegetation area.

As this feeder is in marginally efficient feeder, the feeder needed to be given some attention if not the feeder will become inefficient in the future.

Fault locaters, remote operating switches shall be installed to this feeder if the resources remains even after implementing proposals to improve the relative efficiency for Distinctly inefficient, Significantly inefficient and Marginally inefficient feeders.

5.4 Robustly efficient Feeder –Mathugama Feeder 07

Mathugama Feeder 07 goes from Mathugama GSS to Fullerton Gantry through a tower line. Tower lines are less vulnerable for faults when comparing with pole lines. Poles lines are connected to this feeder at Malaboda and Fullerton through Autoreclosures. Therefore when fault occurs only faulty section is isolated without switching off the total feeder other than that feeder behaves well in transient fault conditions.



Fullerton Gantry is situated very close to Fullerton consumer service center. Therefore in emergency situations feeder can be switched off from the gantry very easily without switching off the whole feeder.

Few Autoreclosures are situated in WPS-I, out of them three Autoreclosures are situated in this feeder. Those are the reasons for this feeder to become robustly efficient when compared to other feeders of the province.

This feeder does not needed to be given good attention in doing system augmentations as this feeder is robustly efficient.

5.5 Improvements to be done

To develop relatively inefficient feeders various improvement methods can be identified. Out of them most beneficial proposals needed to be identified because all the identified proposal cannot be implemented in short time period due to limitations of resources like funds, labor, tools, material & etc.

After doing the DEA analysis, most needed improvements can be identified by doing in-depth analysis on inefficient feeders considering technical, environmental and practical issues.

Following improvements can be done considering weaknesses of feeders.

- To reduce Auto trippings, Auto reclosures and Sectionalisers can be installed and can introduce better maintenance practices.
- To reduce Feeder off durations Fault locaters can be fixed in the network (at present identifying fault location is a major issue faced by field staff).
- Manual trippings can be reduce by introducing Remote operating switches and on-load switches and can introduce better operation practices.
- Power losses & voltage drops can be improved by feeder re-conductoring and transferring load to other feeders, installing capacitors, improving joints and connections.
- By improving the line maintenance programs and improving the wayleaves clearance programs number of auto trippings occurs and feeder off durations can be reduced.

Medium voltage Distribution development plan is implemented by all Distribution Development licensees in every two years. Through that study various proposals are identified to keep the system in stipulated limits (focused mainly on maintaining the loadings levels and voltage drops within stipulated limits) [19]. Other than that some proposals are identified to improve the reliability of the network.

If this benchmarking study is carried out parallel to preparation of Medium voltage Distribution development plan most beneficial improvements can be identified easily and utility and can improve their network in most beneficial way by utilizing limited resources well.

CHAPTER SEVEN

6 CONCLUSION & RECOMMENDATIONS

It is often assumed that benchmarking or performance evaluation is an essential technique only used in small number of businesses. But it can be used in all types of businesses. It allows the businesses or the company to strive for continuous improvement.

In this research various benchmarking methods were investigated for their pros and cons and Data Envelopment Analysis (DEA) method was selected. Table 6.1 shows the selected Input Variables and Output variables for the DEA base model.

Table 6.1 Selected Input and output Variables for the DEA base model

Input Variables	**Output Variables**
Number of Auto trippings	Feeder length
Feeder off duration due to auto trippings	
Number of manual trippings	
Peak Power loss	
maximum Voltage Drop percentage	

Thirty two medium voltage feeders of Western Province South –I of CEB were evaluated in this research. Feeders were categorized into two categories as urban and rural considering the Homogeneity of feeders. After the evaluation feeders were categorized into five categories called robustly efficient, marginally efficient, marginally inefficient, significantly inefficient and distinctly inefficient. Table 6.2 shows the feeders in each category.

Table 6.2 Feeders in each feeder category

Item	Nos. Of Feeders	Feeders of Urban category	Feeders of Rural category
Robustly efficient	9	Dehi F1, Dehi F3,Panni F3, Panni F5, Rath F1,	Matu F2, Matu F3,Matu F4,Matu F7
Marginally efficient	5	Dehi F5, Dehi F8, Rath F6,	Pana F5, Matu F5,
Marginally inefficient	0		
Significantly inefficient	2	Rath F2, Rath F8	
Distinctly inefficient	16	Dehi F6, Dehi F7, Panni F6, Rath F3, Rath F4, Rath F7, Rath F9,	Pana F1, Pana F2, Pana F3, Pana F4, Matu F1,Matu F6 , Matu F8, Matu F9, Matu F10

Other than that, obtained results from the study for few feeders were compared with the real condition of the feeder.

Finally it is recommended to do in-depth analysis for inefficient feeders considering the practical constraints, field issues and the efficiency targets assigned by the study to improve their relative performances.

Same study is recommend for all Distribution provinces in Sri Lanka & give targets to feeders to be achieved. The studies can be done annually or once in two years (Parallel to Medium voltage Distribution Development Plan).

Steps shown in following flow chart (figure 6.1) can be used as a guide line/methodology for benchmark medium voltage feeders in Sri Lanka.

Similar type of model can be developed to Benchmark 132/ 220 kV Transmission Lines of the country.

6.1 Future work:

Practical solutions needed to be obtained for inefficient feeders and needed to implement those solutions. After that same benchmarking study shall be carried out and shall find the relative performance increment of those feeders.

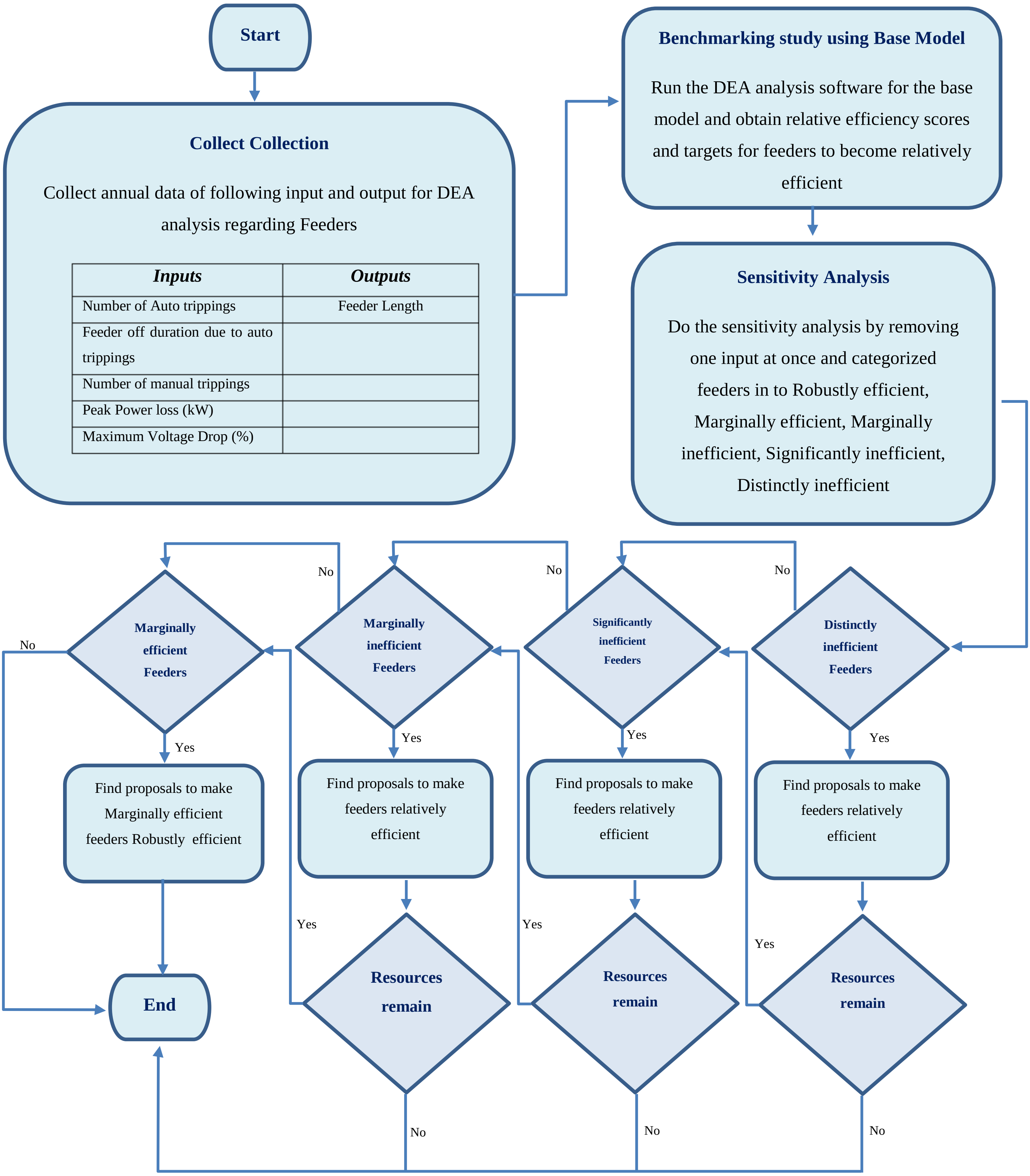


Figure 6.1: recommended methodology to carry out the Benchmarking study

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