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Voltage Drop on High-Rise Buildings Using The Analytical Hierarchy Process (AHP) Method

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ABSTRACT

The AHP modeling method in this study was conducted by weighting six main technical criteria: Voltage Drop Magnitude (C1), Voltage Drop Percentage (C2), Load Magnitude (C3), Distance from Source (C4), Average Current (C5), and Line Impedance (C6). The analysis results show that the most dominant factor influencing voltage drop is voltage quality, with the highest criteria weights being Voltage Drop Percentage (35.7%) and Voltage Drop Magnitude (28.3%). Based on the global score index calculation, the classification of four alternative loads is as follows: The FJM Office (A1) ranks first with a score of 50.9% and is interpreted as an "Influential" load due to its voltage drop of 5.35%, which technically exceeds the standard operational limit. The AJG Office (A2) scored 23.6%, interpreted as "Moderately Influential," while the Workshop (A4) and the Security Post Office (A3) scored 16.9% and 8.2%, respectively, interpreted as "Less Influential".

Keywords: *Voltage Drop, AHP, WSM, Global Scoring Index, Preventive Maintenance.*

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INTRODUCTION

The electrical system plays an important role in supporting modern activities, including in providing reliable electrical energy for various sectors such as industry, offices, and high-rise buildings [1]. One of the crucial problems in the power distribution system of high-rise buildings is the occurrence of voltage drops, namely the difference in voltage between the source point and the load point caused by the impedance of the conductor line [2]. According to the IEEE 1159-2019 standard, the maximum voltage drop allowed in the distribution system is 5% of the nominal voltage, because excessive voltage drops can result in decreased operational efficiency of equipment, damage to sensitive electronic devices, overheating of conductors, and economic losses [3][4].

The electrical installation system in a building includes lighting and power installations that distribute energy throughout the room, electronic devices, air conditioning systems, water pumps, and other important equipment [5]. Installations that are not systematically designed can cause various problems such as voltage disturbances, equipment damage, and even potential work accidents [6]. The voltage received by customers is highly dependent on the distribution power flow which can fluctuate and affect load performance if not properly designed [7]. As electricity demand increases, the load on the distribution system often exceeds capacity, causing increased system losses and poor voltage regulation [8].

Power quality in electrical distribution systems is crucial to maintain a stable and reliable electricity supply, especially for industrial and commercial loads that are sensitive to voltage disturbances [9][10]. Power quality is affected by several factors such as voltage sags, swells, and harmonics that can cause significant damage or failure to loads [11]. Research shows that voltage drops in sensitive industries cause significant economic losses, so better power quality solutions are needed [12].

In an effort to optimize the stability of the electrical system in multi-storey buildings, a decision-making method is needed that is able to analyze various technical parameters comprehensively [13]. The electrical power distribution system in modern buildings has complex characteristics with variations in load conditions, line length, and voltage quality that affect system performance [14]. The Analytic Hierarchy Process (AHP) is an effective multi-criteria decision-making method because it can decompose complex problems into a hierarchical structure and weight them based on the level of importance through pairwise comparisons [15].

Previous studies have applied the AHP method in various power system contexts. Wibisono and Tamaji [15] used AHP to improve power system efficiency with a focus on voltage drop improvement. Xu et al. [16] applied AHP with fuzzy logic for distribution transformer selection based on technical criteria such as energy efficiency and load capacity. Le et al. [18] developed an AHP method for load ranking and load shedding strategies by analyzing load power factor, operational urgency, and system stability. Bobar et al. [20] explored a combined method of AHP, fuzzy logic, and Z-number for efficiency assessment in systems with high uncertainty.

Although various studies have used AHP in electric power systems, no study has specifically integrated six key technical parameters to classify loads based on their contribution to voltage drop in high-rise buildings. The novelty of this study lies in the integration of the parameters of voltage drop percentage, voltage drop magnitude, load distance from the source, load power, line impedance, and average current into the AHP structure. This approach allows for a measurable load classification that can be the basis for technical considerations in improving the stability of high-rise building distribution systems.

This study aims to use the AHP method to classify loads that contribute most to voltage drop in the electrical distribution system of a multi-storey building. Through pairwise comparisons, the priority weight of each criterion is determined systematically and objectively, so that alternative actions for certain loads can be evaluated based on their level of contribution. This study not only produces a measurable load classification, but also provides a methodological contribution in the form of a framework for assessing the influence of loads on voltage drop in the electrical distribution system of a multi-storey building that can be used as a reference in electrical engineering practice.

METHODS

This chapter systematically describes the research methods used in analyzing voltage stability in the electrical distribution system of multi-storey buildings in Factory Area I (FJM Office of PT. Petrokimia Gresik). The discussion includes the applied research approach, location and time of research implementation, data collection techniques that include direct measurements in the field and data collection of technical specifications of the existing electrical system, research variables that are the object, to the analysis of data processing procedures using the Analytical Hierarchy Process (AHP) method as a multi-criteria decision-making framework. All stages of the methodology are structured to ensure that the process of transporting the loads that have the most influence on voltage drops can be carried out objectively, measurably, and can be scientifically accounted for, so that the results of the analysis obtained are able to provide valid technical recommendations for improving the quality of voltage distribution in the electrical system of multi-storey buildings.

This chapter presents a theoretical overview that serves as the foundation for this research. The discussion begins with the concept of voltage drop as the primary phenomenon analyzed, followed by a review of other supporting theories relevant to the analysis of voltage stability in multi-storey building electrical distribution systems. A thorough understanding of these concepts is necessary to provide a scientific basis for identifying factors influencing voltage drop and for applying the Analytical Hierarchy Process (AHP) method as a decision-making analysis tool.

1. Voltage Drop

Voltage drop is a phenomenon of reduced voltage that occurs at certain points in the electrical power distribution process, so that the voltage received by consumers is not the same as the initial voltage transmitted by the power source [21]. Technically, voltage drop is defined as the difference between the voltage at the source (base) and the voltage at the load (end) of an electrical installation.

Several main factors cause voltage drop, including:

(1) the length of the conductor cable, where the longer the conductor, the greater the voltage drop.

(2) the magnitude of the flowing current, which is directly proportional to the magnitude of the voltage drop.

(3) the type of resistance (Rho) of the conductor material.

(4) the cross-sectional area of the conductor, which is inversely proportional to the voltage drop. In addition to these factors, voltage drop is also influenced by line impedance parameters, including resistance and reactance [21]. The magnitude of the voltage loss can be expressed as follows:

$$\Delta V = I \times R \times Cos\varphi + I \times X \times Sin\varphi$$

Description:

ΔV = Voltage drop (Volts)
X = Line reactance (Ohms)
Cos φ = Angle of load power factor
Vs = Transmission voltage (Volts)
R = Line resistance (Ohms)
Vr = Receiving voltage (Volts)
I = Current flowing (Amperes)
Z = Line impedance (Ohms)

To determine whether the service voltage on a line is within the standard category or not, use the following voltage drop percentage formula:

$$\Delta V(\%) = \frac{V_s - V_r}{V_s} \times 100\%$$

Description:
ΔV (%) x 100 % = Voltage drop in % (Volts)

Some frequently used reference standards include IEEE Std 141-1993, IEC 60364-5-52, and the Indonesian national standard through SPLN (State Electricity Company Standard). Each of these standards defines the nominal voltage and voltage drop tolerance limits according to the system type and application, such as industrial systems, high-rise buildings, or domestic installations. A comparison of the nominal voltage and maximum voltage drop limits for these three standards can be seen in the following table [22] [23] [24]:

Table 1. Standard Nominal and Maximum Voltage Drop

Standard	Nominal Voltage	Maksimum *Voltage drop*
IEEE Std 141-1993	208/120V, 480/277V, 600V	Feeder: 3%
		Branch Circuit: 2%
		Total (Feeder + Branch): 5%
		Starting Motor: 15% (Temporary)
IEC 60364-5-52	400/230V, 690/400V	Lighting Installation: 3%
		General Installation: 5%
SPLN	380/220V (TR), 20kV (TM)	TR: 5%
		TM: 10%
		Starting Motor: 15% (Temporary)

2. Amount of Installed Power (Pseudo-Power)

Pseudo-power (total power) is the power that enters the AC circuit or in other words the power that is actually received from the AC current voltage source supplier, and is also the resultant of power between the active power and the reactive power. Power appears to be defined as the result of multiplication of voltage and current in an ac circuit regardless of the difference in phase angle of current and voltage [25]. To find the amount of power installed in the three phases, the formula is obtained as follows.

$$S = \sqrt{3} \times V \times I$$

Description:
S = Pseudo-Power
V= Voltage
I= Current
√3= 1.73 (Three Phases)
3. Average Voltage and Current
To find the average voltage, it can be formulated as follows:

$$V_{average} = \frac{V_R + V_S + V_T}{3}$$

As for finding the average current, it can be formulated as follows:

$$I_{average} = \frac{I_R + I_S + I_T}{3}$$

'4. Channel Impedance

In an electrical power distribution system, line impedance is an important parameter that greatly affects voltage stability, especially in the context of *voltage drop*. Channel impedance consists of resistive and reactive components derived from conductor cables, connections, and other distribution elements. This impedance value determines how much voltage drop occurs along the distribution path from source to load point, which is a major focus in load classification research on high-rise buildings using *the AHP* method. Channel impedance generally consists of two main components, namely the resistive component R and the inductive reactive component X. The total impedance value Z of a channel can be formulated as [26]:

$$Z = R + jX$$

Description:
R = Resistansi Cable
X = Inductive Reactance of Cable
j = Imaginary number

5. Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP*)* is a multicriteria decision-making method developed by Thomas L. Saaty in the 1970s. AHP is used to compile a priority order of various alternatives based on a number of criteria through *a pairwise comparison process.* In this method, decision-makers assess the level of relative importance between criteria and between alternatives quantitatively on a numerical scale (usually a scale of 1–9 according to Saaty).

One of the main advantages of AHP is its ability to simplify complex problems into a hierarchical structure, thus facilitating systematic and logical analysis. In addition, AHP is also equipped with a consistency test through *Consistency Ratio (CR)* to ensure that the assessments given are not contradictory. The end result of this process is the priority weight of each criterion and alternative, which can be used to rank and support objective decision-making based on technical data and rational considerations [27].

Then there is the hierarchical structure where the problem solving of decisions is divided into several tiered levels so that it is easy to assess step-by-step.

1. Level 1 (Goal) The main goal to be achieved.
2. Level 2 (Criteria) Factors that affect the achievement of goals.
3. Level 3 (Alternative) Option to be selected.

In this study, the structure of the decision hierarchy is arranged as follows:
1. Objective: Determine which load has the most effect on the occurrence of *voltage drop* in high-rise buildings.
2. Criteria: Magnitude voltage drop, voltage drop percentage, installed power load (kVA), load distance at voltage source, average current, and line impedance.
3. Alternative: Analyzed load
This hierarchical structure is the basis for the preparation of the paired comparison matrix at the next stage. Based on the basic principles developed by Saaty, the calculation steps include pair-based

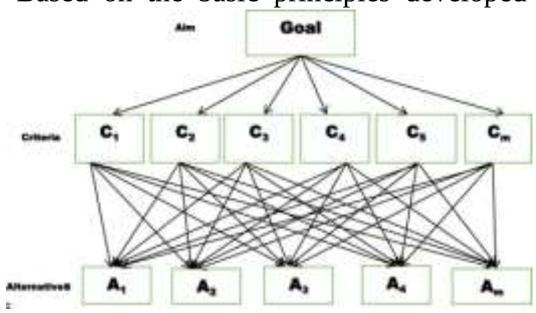

Figure 1. *Structure Hierarchy AHP*

comparison assessment, consistency testing, and priority matrix calculation [28]. Here's the explanation:
1). Preparation of a Paired Comparison Matrix
At this stage, a pairwise comparison is carried out between elements (criteria and alternatives) to assess the level of relative importance of one element to another. This assessment is based on the perception of experts or stakeholders using a scale of 1 to 9 developed by Saaty.
2). Normalization of Comparison Matrix
Matrix normalization is carried out to obtain the relative values of each criterion. Normalization is done by dividing each element of the matrix by the number of values in the same column.
3). Priority Weight Calculation
The priority weight of each criterion is obtained by calculating the average value of each row of the normalization matrix. This priority weight shows the relative importance of each criterion and is used as a weighting factor at the decision-making stage.
4). Consistency Ratio
This stage aims to ensure that the assessment given by the decision-maker is consistent and logical. Consistency is measured using the Consistency Ratio *(CR).* In the CR calculation process, a Random Index (RI) value is required, which is a random consistency value based on the size of the matrix (number of criteria/n) [29]. Here is the table of Random Index Values (RI):

Table 2. Random Index Value

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

To validate the weighting results, a consistency level calculation is required which involves searching for the Consistency Index (CI) and Consistency Ratio (CR) values. The calculation is carried out using equation (7) (8) as follows:

$$\text{Consistency Ratio (CI)} = \frac{(\lambda\text{max}-\text{n})}{(n-1)}$$

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

Description:
CI: Consistency Index
RI: Random Index
CR: Consistency Ratio
λmaks: Maximum Eigenvalue, which is the average value of the matrix multiplication by the priority weights.
n: Number of elements or criteria being compared (matrix order)

5). Global Index Score Calculation
The calculation of the Global Index Score uses the *Weighted Sum Model (WSM) method* by multiplying the priority weight between the AHP outcome criteria by the priority weight between alternatives in each AHP result criterion [30].

$$S_i = \sum_{j=1}^{n} W_j \times X_{ij}$$

Description:
S_i = the final result showing the total value for the alternative (A1, A2, A3, or A4)
W_j = Weight of the j criterion (AHP result)
X_{ij} = Alternative Priority weight i at criterion j (AHP result)
$\sum_{j=1}^{n}$ = Sum of multiplication results for all priority weights

RESULT AND DISCUSSION

1. Voltage Measurement Data for Each Phase

Table 3. shows the results of three-phase voltage measurements over a one-week period (January 5–January 9, 2026), taken at 11:00 a.m. Western Indonesian Time (Peak Load Time). The data was collected manually using a multimeter from each outgoing feeder panel.

Table 3. 3 Phase Voltage Measurement Data

FJM OFFICE			
DATE	R-S	R-T	S-T
05/01/2026	359,2	360,5	359,2
06/01/2026	358,3	360,1	361,7
07/01/2026	356,8	358,2	359,6
08/01/2026	358,2	364,4	362,6
09/01/2026	359,2	365,6	361,1
AJG OFFICE			
DATE	R-S	R-T	S-T
05/01/2026	362,4	366	365
06/01/2026	363,6	365,7	364,8
07/01/2026	362,7	365,8	365,7
08/01/2026	363,5	366,8	365,3
09/01/2026	368,9	366,2	365,2
WORKSHOP			
DATE	R-S	R-T	S-T
05/01/2026	367,4	371,6	371,5
06/01/2026	367,5	371,3	372,5
07/01/2026	366,7	370,3	371,5
08/01/2026	367,4	371,6	371,8
09/01/2026	368,9	372,4	372,7
SECURITY POST OFFICE			
DATE	R-S	R-T	S-T
05/01/2026	370,4	371,7	371,8
06/01/2026	370,2	371,6	372,4
07/01/2026	371,3	370,5	372,5

08/01/2026	370,6	370,1	372,9
09/01/2026	370,6	370,1	372,9
VOLTAGE SOURCES			
DATE	R-S	R-T	S-T
05/01/2026	381,2	380,8	380,5
06/01/2026	380,6	380,5	380,7
07/01/2026	381,5	380,7	380,2
08/01/2026	380,5	381	380,5
09/01/2026	380,5	380,6	380,3

2. Current measurement data per phase

Table 4. shows the results of current measurements for each phase over a one-week period (January 5–January 9, 2026), taken at 11:00 a.m. WIB (Peak Load Time). The data was collected manually using a multimeter from each outgoing feeder panel.

Table 4. Current Measurement Data

FJM OFFICE			
DATE	R	S	T
05/01/2026	65,8	36,78	54,6
06/01/2026	62,3	34,96	57,99
07/01/2026	62,4	34,96	57,99
08/01/2026	70,1	39,11	33,75
09/01/2026	65,1	36,06	53,3
AJG OFFICE			
DATE	R-S	R-T	S-T
05/01/2026	66,7	53,4	54,8
06/01/2026	61,4	56,8	55,7
07/01/2026	63,4	58,7	48,9
08/01/2026	61,3	57,8	45,6
09/01/2026	62,9	53,4	48,7
WORKSHOP			
DATE	R-S	R-T	S-T
05/01/2026	75,8	50,8	56,7

06/01/2026	70,11	53,4	55,4
07/01/2026	72,5	56,8	46,7
08/01/2026	69,8	55	54,6
09/01/2026	70,9	52,3	50,7
SECURITY POST OFFICE			
DATE	R-S	R-T	S-T
05/01/2026	4,25	1,23	1,45
06/01/2026	4,2	1,43	1,07
07/01/2026	4,17	1,5	1,32
08/01/2026	4,28	1,4	1,88
09/01/2026	4,56	1,39	1,86

3. Data on distance and cross-sectional area of the cable.

Table 5. Cable Cross-Sectional Distance and Area Data

FROM VOLTAGE SOURCES TO FJM OFFICE	
CABLE CROSS-SECTIONAL AREA	**DISTANCE**
$240mm^2$	276m
$25mm^2$	90m
$25mm^2$	110m
TOTAL	476m
FROM VOLTAGE SOURCES TO FJM OFFICE	
CABLE CROSS-SECTIONAL AREA	DISTANCE
$240mm^2$	276m
$25mm^2$	90m
$25mm^2$	110m
TOTAL	476m
FROM VOLTAGE SOURCES TO AJG OFFICE	
CABLE CROSS-SECTIONAL AREA	DISTANCE
$240mm^2$	276m
$70mm^2$	40m
$70mm^2$	60m
TOTAL	376m
FROM VOLTAGE SOURCES TO SECURITY POST OFFICE	
CABLE CROSS-SECTIONAL AREA	DISTANCE
$240mm^2$	276m

$25mm^2$	90m
TOTAL	366m
FROM VOLTAGE SOURCES TO WORKSHOP	
CABLE CROSS-SECTIONAL AREA	DISTANCE
$240mm^2$	276m
$70mm^2$	40m
$25mm^2$	90m
TOTAL	406m

Table 5. shows the results of measuring the cable distance and cross-sectional area from the voltage source to each feeder. Distance measurements were performed using Google Earth.

Praprocessing Data

1. Average Voltage

The following is an example of calculating the average voltage data on an Voltage Source on Monday, January 5, 2026.

$$Vavg = \frac{VR + VS + VT}{3}$$
$$Vavg = \frac{381{,}2 + 380{,}8 + 380{,}5}{3}$$
$$Vavg = \frac{1.142{,}5}{3}$$
$$Vavg = 380{,}83\ V$$

Below is a summary of the average current at the FJM Office, AJG Office, Workshop, Security Post Office taken on January 5-9, 2026, during peak load times.

Table 6. Average Voltage Data Results Wekly

VOLTAGE SOURCE				
DATE	R-S	R-T	S-T	**AVERAGE**
05/01/2026	381,2	380,8	380,5	380,83
06/01/2026	380,6	380,5	380,7	380,6
07/01/2026	381,5	380,7	380,2	380,8
08/01/2026	380,5	381	380,5	380,67
09/01/2026	380,5	380,6	380,3	380,67
AVERAGE WEEKLY = 380,67 V				

DATE	R-S	R-T	S-T	AVERAGE
05/01/2026	359,2	360,5	359,2	359,63

06/01/2026	358,3	360,1	361,7	360
07/01/2026	356,8	358,2	359,6	358,2
08/01/2026	358,2	364,4	362,6	361,73
09/01/2026	359,2	365,6	361,1	361,97
AVERAGE WEEKLY = 360,31 V				

DATE	R-S	R-T	S-T	AVERAGE
05/01/2026	362,4	366	365	364,47
06/01/2026	363,6	365,7	364,8	364,7
07/01/2026	362,7	365,8	365,7	364,73
08/01/2026	363,5	366,8	365,3	365,2
09/01/2026	363,4	366,2	365,2	364,93
AVERAGE WEEKLY = 364,81 V				

DATE	R-S	R-T	S-T	AVERAGE
05/01/2026	367,4	371,6	371,5	370,17
06/01/2026	367,5	371,3	372,5	370,43
07/01/2026	366,7	370,3	371,5	369,5
08/01/2026	367,4	371,6	371,8	370,27
09/01/2026	368,9	372,4	372,7	371,33
AVERAGE WEEKLY = 370,34 V				

DATE	R-S	R-T	S-T	AVERAGE
05/01/2026	370,4	371,7	371,8	371,3
06/01/2026	370,2	371,6	372,4	371,4
07/01/2026	371,3	370,5	372,5	371,43
08/01/2026	370,6	370,1	372,9	371,2
09/01/2026	370,6	370,1	372,9	371,2
AVERAGE WEEKLY = 371,31 V				

2. Average Current

The following is an example of calculating the average current data on an FJM Office on Monday, January 5, 2026.

Below is a summary of the average current at the FJM Office, AJG Office, Workshop, Security Post Office taken on January 5-9, 2026, during peak load times.

FJM OFFICE

DATE	R (A)	S (A)	T (A)	AVERAGE (A)
05/01/2026	65,8	36,78	54,6	52,39

06/01/2026	62,3	34,96	57,8	51,75
07/01/2026	62,4	34,96	56,7	51,78
08/01/2026	70,1	39,11	33,75	47,65
09/01/2026	65,1	36,06	53,3	51,49
AVERAGE WEEKLY = 51,01 A				

AJG OFFICE

DATE	R (A)	S (A)	T (A)	AVERAGE (A)
05/01/2026	65,8	36,78	54,6	52,39
06/01/2026	62,3	34,96	57,8	51,75
07/01/2026	62,4	34,96	56,7	51,78
08/01/2026	70,1	39,11	33,75	47,65
09/01/2026	65,1	36,06	53,3	51,49
AVERAGE WEEKLY = 51,01 A				

WORKSHOP

DATE	R (A)	S (A)	T (A)	AVERAGE (A)
05/01/2026	75,8	50,8	56,7	61,1
06/01/2026	70,11	53,4	55,4	59,64
07/01/2026	72,5	56,8	46,7	58,67
08/01/2026	69,8	55	54,6	59,8
09/01/2026	70,9	52,3	50,7	57,97
AVERAGE WEEKLY = 59,44 A				

SECURITY POST OFFICE

DATE	R (A)	S (A)	T (A)	AVERAGE (A)
05/01/2026	4,25	1,23	1,45	2,31
06/01/2026	4,2	1,43	1,07	2,23
07/01/2026	4,17	1,5	1,32	2,33
08/01/2026	4,28	1,4	1,88	2,52
09/01/2026	4,56	1,39	1,86	2,6
AVERAGE WEEKLY = 2,4 A				

Technical Calculation Results

After field data collection and initial calculations of the electrical power distribution system at each load point, technical variables were obtained which included the parameters of magnitude and percentage of *voltage drop*, installed power load (kVA), average current, load distance from the voltage source, and channel impedance value. The recapitulation of the technical values for the 6 criteria in each alternative can be seen in the following table:

Table 7. Recapitulation of Technical Calculation Results

	K1 (V)	K2 (%)	K3 (KVA)	K4 (m)	K5 (A)	K6 (Ω)
A1 (FJM Office)	20,36	5,35	31,83	476	51,01	0,174
A2 (AJG Office)	15,86	4,17	35,78	376	56,63	0,064
A3 (Security Guard Post Office)	10,33	2,71	1,54	366	2,4	0,094
A4 (Fabrication Workshop)	9,36	2,46	38,13	406	59,44	0,056

Application of the AHP Method

Table 8. Scale AHP

Intensity	Definition	Explanation
1	Equally important	Both criteria are equally important
3	A little more important	One criterion is a little more important than the other
5	More important	One criterion is clearly more important
7	Very much more important	One criterion is clearly more important
9	Absolutely more important	Evidence in support of one criterion is absolutely more important
2,4,6,8	Intermediate values	The value of compromise between two assessments

Table 8. is a table of the AHP scale which will later be used to form a paired comparison matrix for the priority weighting process of each criterion and alternative. The weighting was carried out using the Analytical Hierarchy Process (AHP) method with a scale of 1-9. This scale is used to compare the level of importance between the criteria in pairs. A value of 1 indicates both criteria are equally important, a value of 3 indicates a little more important, a value of 5 indicates more important, a value of 7 indicates a lot more important, and a value of 9 indicates absolute more important. While the values of 2, 4, 6, and 8 are compromise values between two adjacent considerations.

The weighting of criteria in this study is carried out based on experience judgment or assessment based on experience and knowledge in the field of electric power distribution systems. This assessment also considers the impact of each parameter (criterion) on its effect on voltage drop based on applicable standards.

$$A = \begin{pmatrix} 1 & 1/2 & 5 & 3 & 3 & 5 \\ 2 & 1 & 5 & 3 & 3 & 5 \\ 1/5 & 1/5 & 1 & 1/2 & 1/2 & 2 \\ 1/3 & 1/3 & 2 & 1 & 1 & 3 \\ 1/3 & 1/3 & 2 & 1 & 1 & 3 \\ 1/5 & 1/5 & 1/2 & 1/3 & 1/3 & 1 \end{pmatrix}$$

Table 9. Comparison Matrix Between Criteria

	C1	C2	C3	C4	C5	C6
C1	1	½	5	3	3	5
C2	2	1	5	3	3	5
C3	1/5	1/5	1	1/2	½	2
C4	1/3	1/3	2	1	1	3
C5	1/3	1/3	2	1	1	3
C6	1/5	1/5	1/2	1/3	1/3	1

Reason for Expert Judgement:
C2 (Percentage Voltage Drop)
It is considered the most important because it is directly compared to the IEEE/IEC standard which sets a maximum limit of 5%.

C1 (Magnitude Voltage Drop)
It is important because it shows the actual amount of losses, but it is derived from C2

C4 and C5 (Distance and Current)
Equally important because they both have a direct effect on voltage drop.

C3 (kVA Load)
It has less direct effect than current, because large loads are not necessarily high VD at close distances.

C6 (Impedance)
Relatively fixed for the same cable, the effect is already covered in the calculation of voltage drop.

Matrix Normalization

The matrix normalization process below is carried out by converting each element of the matrix into a decimal value first, followed by adding each column of the comparison matrix. The number of columns for 1 is 4,583 then C2 is 2,616 and so on.

$$A = \begin{pmatrix} 1{,}000 & 0{,}500 & 5{,}000 & 3{,}000 & 3{,}000 & 5{,}000 \\ 2{,}000 & 1{,}000 & 5{,}000 & 3{,}000 & 3{,}000 & 5{,}000 \\ 0{,}200 & 0{,}200 & 1{,}000 & 0{,}500 & 0{,}500 & 2{,}000 \\ 0{,}333 & 0{,}333 & 2{,}000 & 1{,}000 & 1{,}000 & 3{,}000 \\ 0{,}333 & 0{,}333 & 2{,}000 & 1{,}000 & 1{,}000 & 3{,}000 \\ 0{,}200 & 0{,}200 & 0{,}500 & 0{,}333 & 0{,}333 & 1{,}000 \end{pmatrix}$$

Table 10. Convert Matrix to Decimal Number

	C1	C2	C3	C4	C5	C6
C1	1,000	0,500	5,000	3,000	3,000	5,000
C2	2,000	1,000	5,000	3,000	3,000	5,000
C3	0,200	0,200	1,000	0,500	0,500	2,000
C4	0,333	0,333	2,000	1,000	1,000	3,000
C5	0,333	0,333	2,000	1,000	1,000	3,000
C6	0,200	0,200	0,500	0,333	0,333	1,000
Quantity	4,063	2,566	15,500	8,833	8,833	19,000

After the matrix is converted to a decimal value and each column is summed as in table 10. the next step is to divide each element of the matrix by the number of columns each to get the normalized matrix. As in the example in table 10. in column C1 the first row of the value of 1,000 is divided by the total number (column C1) of 4.063 which will result in 0.246 as in table 4.24

$$A = \begin{pmatrix} 0{,}246 & 0{,}194 & 0{,}322 & 0{,}339 & 0{,}339 & 0{,}263 \\ 0{,}492 & 0{,}389 & 0{,}322 & 0{,}339 & 0{,}339 & 0{,}263 \\ 0{,}049 & 0{,}077 & 0{,}064 & 0{,}056 & 0{,}056 & 0{,}105 \\ 0{,}081 & 0{,}129 & 0{,}129 & 0{,}113 & 0{,}113 & 0{,}157 \\ 0{,}081 & 0{,}129 & 0{,}129 & 0{,}113 & 0{,}113 & 0{,}157 \\ 0{,}049 & 0{,}077 & 0{,}032 & 0{,}056 & 0{,}056 & 0{,}052 \end{pmatrix}$$

Table 11. Matrix Normalization Results

	C1	C2	C3	C4	C5	C6
C1	0,246	0,194	0,322	0,339	0,339	0,263
C2	0,492	0,389	0,322	0,339	0,339	0,263
C3	0,049	0,077	0,064	0,056	0,056	0,105
C4	0,081	0,129	0,129	0,113	0,113	0,157
C5	0,081	0,129	0,129	0,113	0,113	0,157
C6	0,049	0,077	0,032	0,056	0,056	0,052
Quantity	1	1	1	1	1	1

The normalization results in table 11. show that the sum of each column in the normalized matrix is already worth 1 which indicates that the normalization process has been carried out correctly. After that, the normalization results that have been determined will be summed up each line and generated at table 12.

Table 12. Criterion Line Summing Results

	C1	C2	C3	C4	C5	C6	$\sum Bar$
C1	0,246	0,194	0,322	0,339	0,339	0,263	1,703

C2	0,492	0,389	0,322	0,339	0,339	0,263	2,144
C3	0,049	0,077	0,064	0,056	0,056	0,105	0,407
C4	0,081	0,129	0,129	0,113	0,113	0,157	0,722
C5	0,081	0,129	0,129	0,113	0,113	0,157	0,722
C6	0,049	0,077	0,032	0,056	0,056	0,052	0,322

After adding to each line. The result of the sum of each row will be divided by the total number of criteria (n=6). As an example in table 12. in column C1, there is a result of the sum of each row, namely 1.703 which will later be divided by n=6 (the number of alternatives) and will produce an eigenvector value or commonly called priority vector (the relative importance level of each criterion or alternative to the objective) of 0.283 as in table 13.

Priority Weighting Results Between Criteria

Table 13. Priority Weighting Results Between Criteria

Criteria	Priority Weights
C1 (Magnitude Voltage Drop)	0,283
C2 (Percentage Voltage Drop)	0,357
C3 (Installed Power Load)	0,067
C4 (Distance from source)	0,120
C5 (Average current)	0,120
C6 (Channel Impedance)	0,053

After obtaining the priority weight in table 13, the summing results of each row will be divided by the priority results to find the Consistency Vector (CX) or consistency values per criterion. This value will later be used to calculate λ the max (maximum eigenvalue) to determine whether the comparison matrix is consistent or not (matrix consistency test).

$$CX = \frac{\sum line}{Priority}$$

$$\text{C1} = \frac{1{,}703}{0{,}283} = 6{,}017$$

$$\text{C2} = \frac{2{,}144}{0{,}357} = 6{,}005$$

$$\text{C3} = \frac{0{,}407}{0{,}067} = 6{,}074$$

$$C4 = \frac{0{,}722}{0{,}120} = 6{,}016$$

$$C5 = \frac{0{,}722}{0{,}120} = 6{,}016$$

$$C6 = \frac{0{,}322}{0{,}053} = 6{,}075$$

Total = 36,203

So from the results above, it is obtained to find the max, namely: λ

$$\lambda\text{max} = \frac{Total}{n}$$

$$\lambda\text{max} = \frac{36{,}057}{6} = 6.033$$

Matrix Consistency Test

Then the formula to find the consistency ratio (CI) is as follows:

$$\text{Consistency Index (CI)} = \frac{(\lambda\text{maks}-\text{n})}{(n-1)}$$

$$\text{Consistency Index (CI)} = \frac{(6{,}033-6)}{(6-1)}$$

$$\text{Consistency Index (CI)} = \frac{0{,}033}{5}$$

Consistency Index (CI) = 0,0066

For n = 6, the Random Consistency is 1.24

CR = CI / RI

CR = 0,0066/ 1,24

CR = 0,005

Since CR $\leq$ is 0.1, the consistency ratio of the calculation is acceptable.

Weight Calculation Between Alternatives Each Criterion

Alternative Comparison Matrix on Criterion 1 (C1)

Below is the actual data obtained from the calculation of the data above. Where the FJM Office has the largest voltage difference, which is 19V with the voltage in the Interconnect Transformer (voltage source).

Table 14. Actual Data Magnitude Voltage Drop (C1)

Alternate	Magnitude Voltage Drop (C1)
A1 (FJM Office)	20,36 V
A2 (AJG Office)	15,6 V
A3 (Security Post Office)	9,36 V
A4 (Workshop)	10,33 V

From the actual data above and assisted by expert judgment, a 4x4 comparison matrix between alternatives to C1 was compiled, as follows:

$$B = \begin{pmatrix} 1 & 3 & 7 & 5 \\ 1/3 & 1 & 5 & 3 \\ 1/7 & 1/5 & 1 & 1 \\ 1/5 & 1/3 & 2 & 1 \end{pmatrix}$$

Table. 15 Comparison Matrix Between C1 Alternatives

	A1	A2	A3	A4
A1	1	3	7	5
A2	1/3	1	5	3
A3	1/7	1/5	1	1/2
A4	1/5	1/3	2	1

The assessment on the paired comparison matrix for the Magnitude Voltage Drop (C1) criterion is based on the magnitude of the absolute voltage drop value in units of Volts (V) in each alternative. In accordance with the 380V distribution system standard, the maximum permissible voltage drop limit is 5%, which is nominally equivalent to 19V. Loads that have a voltage drop value close to or exceeding the 19V threshold are considered to have the most critical influence on the power quality of the system.

A1 (FJM Office) has the highest magnitude voltage drop value of 20.36 V. This value is very far apart (more than double) compared to A3 (Security Guard Post Office) and A4 Workshop). Therefore, A1 is considered to have a very strong/dominant influence and is given a high importance scale to other alternatives. A2 has a voltage drop of 15.6 V. Although it is lower than A1, this value is still significant and is in the second highest position. A2 is considered to have a greater influence than A3 and A4, but remains under the dominance of A1.

While A3 (9.36V) and A4 (10.33V) are well below the standard limit of 19V, so their voltage profiles are considered relatively safe. Since both are in the same low category, their importance is considered to be close to equivalent, where A4 is slightly higher in influence because it has a numerically larger drop magnitude than A3.

Furthermore, the comparison matrix that has been determined is changed to a decimal value and the sum of each column is added (Table 16.) for later normalization process.

$$B = \begin{pmatrix} 1{,}000 & 3{,}000 & 7{,}000 & 5{,}000 \\ 0{,}333 & 1{,}000 & 5{,}000 & 3{,}000 \\ 0{,}143 & 0{,}200 & 1{,}000 & 0{,}500 \\ 0{,}200 & 0{,}333 & 2{,}000 & 1{,}000 \end{pmatrix}$$

Table. 16 Conversion of Comparison Matrix Between Alternatives in C1

	A1	A2	A3	A4
A1	1,000	3,000	7,000	5,000
A2	0,333	1,000	5,000	3,000
A3	0,143	0,200	1,000	0,500
A4	0,200	0,333	2,000	1,000
Quantity	1,676	4,533	15,000	9,500

After the matrix is converted to a decimal value and each column is summed as in the table above, the next step is to divide each element of the matrix by the number of columns each to get the normalized matrix. As in the example in table 4.29, in the first row of the first column (A1) the value of 1,000 is divided by the total number (column A1) of 1,676 which will result in 0.597 as in table 17.

$$B = \begin{pmatrix} 0{,}597 & 0{,}662 & 0{,}467 & 0{,}526 \\ 0{,}199 & 0{,}221 & 0{,}333 & 0{,}316 \\ 0{,}085 & 0{,}044 & 0{,}067 & 0{,}053 \\ 0{,}119 & 0{,}073 & 0{,}133 & 0{,}105 \end{pmatrix}$$

Table. 17 Results of Normalization of Alternative Inter-Matrix for C1

	A1	A2	A3	A4
A1	0.597	0.662	0.467	0.526
A2	0.199	0.221	0.333	0.316
A3	0.085	0.044	0.067	0.053
A4	0.119	0.073	0.133	0.105
Quantity	1	1	1	1

The normalization results show that the sum of each column in the normalized matrix is already worth 1 which indicates that the normalization process has been carried out correctly as shown in table 17. After that, the normalization results that have been determined will be summed up by each row and generated in table 18.

Table. 18 Results of Row Summation of Alternative Inter Matrices for C

	A1	**A2**	**A3**	**A4**	$\sum Baris$
A1	0.597	0.662	0.467	0.526	2.252
A2	0.199	0.221	0.333	0.316	1.069
A3	0.085	0.044	0.067	0.053	0.249
A4	0.119	0.073	0.133	0.105	0.430

After adding to each line. The sum of each row will be divided by the total number of alternatives (n = 4). As an example in table 18, in column A1 of the fifth row, there is a result of the sum of each row, namely 2.252 which will later be divided by n=4 (the number of alternatives) and will produce an eigenvector value or commonly called priority vector (the relative importance of each criterion or alternative to the goal) of 0.563 as in table 18.

Table. 19 Priority Weights Between Alternatives For C1

Alternate	**Priority Weights**
A1 (FJM Office)	0,563
A2 (AJG Office)	0,267
A3 (Security Post Office)	0,062
A4 (Workshop)	0,107

After obtaining the priority weight between alternatives in C1. The result of summing each row will be divided by the priority result to look for the Consistency Vector (CX) or consistency value per criterion. This value is later used to calculate λ the max (maximum eigenvalue) to determine whether the comparison matrix is consistent or not (ratio consistency test). Here is the calculation:

$$CX = \frac{\sum baris}{Prioritas}$$

$$\text{C1} = \frac{2{,}252}{0{,}563} = 4$$

$$\text{C2} = \frac{1{,}069}{0{,}267} = 4{,}003$$

$$\text{C3} = \frac{0{,}249}{0{,}062} = 4{,}016$$

$$\text{C4} = \frac{0{,}430}{0{,}107} = 4{,}018$$

Total = 16,037

So from the results above, it is obtained to find the max, namely: λ

$$\lambda\text{maks}=\frac{Total}{n}$$

$$\lambda\text{maks}=\frac{16{,}037}{4}=4{,}009$$

Then the formula to find the consistency ratio (CI) is as follows:

$$\text{Consistency Index (CI)}=\frac{(\lambda\text{maks}-\text{n})}{(n-1)}$$

$$\text{Consistency Index (CI)}=\frac{(4{,}009-4)}{(4-1)}$$

$$\text{Consistency Index (CI)}=\frac{0{,}009}{3}$$

$$\text{Consistency index (CI)}=0{,}003$$

For n = 4, the Random Index is 0.90

CR = CI / RI

CR = 0,003/ 0,90

CR = 0,003

Since CR ≤ is 0.1, the consistency ratio of the calculation is acceptable

Global Score Index Calculation

The global score index is calculated using the Weighted Sum Model (WSM) method by multiplying the priority weight between the criteria by the priority weight between the alternatives in each criterion (AHP Results). In accordance with the formulation in equation (9), it can be calculated for the calculation of the global score index, which is as follows:

1. Global Score Index A1 (FJM Office)

Table. 20 Global Score Index Results A1

	Prioritization of Criteria	Priority Weighting Between Alternatives
Magnitude VD	0,283	0,563
Persentase VD	0,357	0,606
Installed Power Load	0,067	0,222
Distance	0,120	0,583

Average Current	0,120	0,211
Channel Impedance	0,053	0,449

$S_{A1} = (W_1 \times X_{11}) + (W_2 \times X_{12}) + (W_3 \times X_{13}) + (W_4 \times X_{14}) + (W_5 \times X_{15}) + (W_6 \times X_{16})$

$= (0.283 \times 0.563) + (0.357 \times 0.606) + (0.067 \times 0.222) + (0.120 \times 0.583) + (0.120 \times 0.211) + (0.053 \times 0.449)$

$= 0{,}159329 + 0{,}216342 + 0{,}014874 + 0{,}069960 + 0{,}025320 + 0{,}023797$

$= 0{,}509$

So it was obtained for the global score index at the FJM Office (A1) with the result = 0.509 × 100% = 50.9%

2. Global Score Index A2 (AJG Office)

Table. 21 Global Score Index Results A2

	Prioritization of Criteria	**Priority Weighting Between Alternatives**
Magnitude VD	0,283	0,267
Persentase VD	0,357	0,229
Installed Power Load	0,067	0,234
Distance	0,120	0,111
Average Current	0,120	0,342
Channel Impedance	0,053	0,170

$S_{A2} = (W_1 \times X2_1) + (W_2 \times X2_2) + (W_3 \times X2_3) + (W_4 \times X2_4) + (W_5 \times X2_5) + (W_6 \times X2_6)$

$= (0.283 \times 0.267) + (0.357 \times 0.229) + (0.067 \times 0.234) + (0.120 \times 0.111) + (0.120 \times 0.342) + (0.053 \times 0.170)$

$= 0{,}075561 + 0{,}081753 + 0{,}015678 + 0{,}013320 + 0{,}041040 + 0{,}009010$

$= 0{,}236$

So it was obtained for the global score index at the AJG Office (A2) with the result = 0.236 × 100% = 23.6%

3. Global Score Index A3 (Security Post Office)

Table. 22 Global Score Index Results A3

	Prioritization of Criteria	Priority Weighting Between Alternatives
Magnitude VD	0,283	0,062
Persentase VD	0,357	0,081
Installed Power Load	0,067	0,106
Distance	0,120	0,091
Average Current	0,120	0,032
Channel Impedance	0,053	0,266

$S_{A3} = (W_1 \times X_{31}) + (W_2 \times X_{32}) + (W_3 \times X_{33}) + (W_4 \times X_{34}) + (W_5 \times X_{35}) + (W_6 \times X_{36})$

$= (0.283 \times 0.062) + (0.357 \times 0.081) + (0.067 \times 0.106) + (0.120 \times 0.091) + (0.120 \times 0.032) + (0.053 \times 0.266)$

$= 0{,}017546 + 0{,}028917 + 0{,}007102 + 0{,}010920 + 0{,}003840 + 0{,}014098$

$= 0{,}082$

So it was obtained for the global score index at the Security Guard Post Office (A3) with the result = 0.082 × 100% = 8.2%

4. Global Score Index A4 (Workshop)

Table. 23 Global Score Index Results A4

	Prioritization of Criteria	Priority Weighting Between Alternatives
Magnitude VD	0,283	0,107
Persentase VD	0,357	0,081
Installed Power Load	0,067	0,434
Distance	0,120	0,213
Average Current	0,120	0,411
Channel Impedance	0,053	0,119

$S_{A4} = (W_1 \times X_{41}) + (W_2 \times X_{42}) + (W_3 \times X_{43}) + (W_4 \times X_{44}) + (W_5 \times X_{45}) + (W_6 \times X_{46})$

$= (0.283 \times 0.107) + (0.357 \times 0.081) + (0.067 \times 0.434) + (0.120 \times 0.213) + (0.120 \times 0.411) + (0.053 \times 0.119)$

$= 0{,}030281 + 0{,}028917 + 0{,}029078 + 0{,}025560 + 0{,}049320 + 0{,}006307$

= 0,169

So it was obtained for the global score index at Workshop (A4) with the result = 0.169 × 100% = 16.9%

Global Score Index Results

Table. 24 Global Score Index Ranges and Categories

Range	Category	Remarks
81 - 100%	Very Critical	The load has the impact of a fatal system failure or exceeds operational safe limits.
61 - 80%	Critical	The load is in a condition close to the maximum capacity limit which can interfere with the stability of the system.
41 - 60%	Influential	Load makes a significant contribution to the system
21 - 40 %	Quite Influential	Expenses have a moderate impact that is usually still within normal limits of daily operations.
0 – 20%	Less Influential	Loads have minimal impact or very small contribution to the risk of system failure.

The results of the calculation of the global score index in table 24. are interpreted using an assessment scale with a range of 0-100% which refers to the international standard voltage drop. This scale is compiled to provide an idea of how much the load affects the occurrence of voltage drop and the necessary actions based on the index value obtained. The division of categories consists of five levels, namely very critical, critical, influential, moderately influential and less influential.

The very critical category with a range of 81-100% indicates that the load is in a very critical condition and is the highest category where the load has a fatal impact that can lead to a complete system failure because it has exceeded the operational safe limit.

Critical categories with a range of 61-80% indicate that loads have a significant contribution to the deterioration of voltage quality in the distribution network. The load at this stage is very close to maximum capacity, so it has the potential to disrupt the stability of the system if not handled immediately.

Furthermore, the influential category with a range of 41-60% of the category shows that the load contributes significantly to the voltage drop that occurs, so it requires regular supervision so that the system's performance remains stable. For the category of quite influential with a range of 21-40%, the load is considered to have a moderate influence so that the recommended action is enough in the form of routine maintenance.

Finally, the less influential category with a range of 0-20% indicates that the load has a very small impact on the stability of the voltage drop globally. Therefore, the priority of handling it is at the lowest level with minimal supervision.

Table. 25 Final Results of AHP Calculation

Rank	Load (Alternative)	Global Score Index	Categories (Classification)	Voltage Drop
1	FJM Office	50,9%	Influential	5,35% (Exceeds Standard Limit)
2	AJG Office	23,6%	Quite Influential	4,17% (Below the standard threshold)
3	Workshop/ Fabrication Workshop	16,9%	Less Influential	2,71% (Below the standard threshold)
4	Security Post Office	8,2%	Less Influential	2,46% (Below the standard threshold)

Based on the results of calculation and ranking (Table 25.) using the Analytic Hierarchy Process (AHP) method, the classification of the level of influence of each load on the occurrence of voltage drop in the electrical distribution system of multi-storey buildings was obtained. FJM Office Load ranks first with a global score index of 50.9%, so it is classified as the most "influential" load on voltage reduction. This is due to a voltage drop value of 5.35%, which has technically exceeded the limit of operational standards (maximum 5% according to IEEE, IEC or PLN standards).

In addition, it shows that the characteristics of load, current, and distance to the source at the FJM Office make a dominant contribution to the occurrence of voltage drops, so periodic monitoring and technical improvement actions are needed to maintain voltage quality. Furthermore, the AJG Office ranks second with a global score index of 23.6% and its voltage drop value of 4.17% is still below the standard threshold of 5%, so it is classified as "quite influential". This load still contributes significantly to voltage reduction, but it is not as dominant as the FJM Office, so the recommended technical action is routine maintenance to prevent an increase in voltage drop in the future.

Meanwhile, the Fabrication Workshop/Workshop and the Security Guard Post Office ranked third and fourth respectively with a global score index of 16.9% and 8.2% with a voltage drop value of 2.71% and 2.46% respectively, which made the two companiescategorized as "less influential" to the occurrence of voltage drop. Therefore, the recommended technical action for the Fabrication Workshop/Workshop and the Security Guard Post Office is minimal supervision, without the need for special repair intervention, as long as the operational conditions are still within the permissible standard limits.

Overall, the results of this classification show that the AHP method is able to provide a quantitative and systematic picture of the degree of influence of each load on voltage drop. The classification results show that the load of the FJM Office has the largest contribution to the voltage drop. The technical implications of these findings are the need to evaluate the cross-section area of the cable, the length of the channel, and the possibility of load redistribution to minimize voltage drop in the distribution system of high-rise buildings. By grouping the load into an influential, moderate, and less influential interpretation scale, local electricity distribution system managers can determine technical handling priorities in a more directed, effective, and data-driven manner.

CONCLUSION

Based on the research results, the following conclusions were drawn:

1. The AHP modeling method in this study was conducted by integrating six technical criteria: Voltage Drop Magnitude (C1), Voltage Drop Percentage (C2), Load Magnitude (C3), Distance from Source (C4), Average Current (C5), and Line Impedance (C6). The modeling process involved the preparation of a pairwise comparison matrix, which was validated with a Consistency Ratio (CR) value below 0.1, thus declaring the model consistent and valid for use as a tool for analyzing load influence levels.
2. The factors influencing voltage drop in high-rise buildings were determined through weighted criteria, with voltage quality being the most dominant factor. The weighting results show that the Voltage Drop Percentage (C2) has the greatest influence, with a weighting of 35.7%, followed by the Voltage Drop Magnitude (C1) at 28.3%. Distance and load factors have a lower influence on the priority index.
3. Load classification results obtained from the AHP model WSM ranked the FJM Office (A1) first with a global score of 50.9%, which falls into the "Influential" category, as its voltage drop reached 5.35% (exceeding the standard limit of 5%). The AJG Office (A2), with a score of 23.6%, falls into the "Moderately Influential" category, while the Workshop (A4) with a score of 16.9% and the Security Post Office (A3) with a score of 8.2% are classified as loads that have a "Less Influential" impact on the overall system stability.

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