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Analysis of Waste Material Using Lean Construction and Fault Tree Analysis Approaches

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ABSTRACT

This research analyzes waste material in construction projects using Lean Construction and Fault Tree Analysis approaches. The study was conducted on three building projects: Building X in Makassar, Building Y in Batam, and Building Z in Kediri. The objectives are to estimate waste cost from material waste during structural and architectural work, identify the highest waste material indicators, and determine optimization strategies to improve waste cost efficiency. The Waste Assessment Model method was used to identify waste variables, while Fault Tree Analysis was employed to determine root causes and calculate the probability of waste occurrence. Data collection was conducted through direct field observations, interviews with contractors, and questionnaires. Results showed that waste costs in Building X project amounted to Rp. 1,371,690,630 (4.93% of contract value), Building Y project Rp. 1,434,910,750 (3.75% of contract value), and Building Z project Rp. 1,573,029,639 (3.36% of contract value). Waste Assessment Model analysis revealed three critical waste types across all projects: Defects (19.95-20.09%), Overproduction (18.19-18.32%), and Inventory (16.16-16.27%). Fault Tree Analysis identified that the highest probability variable causing waste material was A1 "Human or Group Failure" (0.6066-0.6565), while the lowest was C2 "Storage Capacity and Method" (0.3040-0.3623). This research provides strategies for waste cost efficiency through identification of dominant causes and probability calculations of waste occurrence.

Keywords:
Lean Construction, Waste Material, Fault Tree Analysis, Waste Assessment Model, Construction Management

INTRODUCTION

The construction industry is one of the most important sectors for infrastructure development in Indonesia. However, the development of this industry still faces various challenges, especially in terms of suboptimal project management. The main problem in Indonesia's construction industry is poor project management, which often results in waste of resources, both materials, labor, and time, according to (R. S. Sanusi, Sulistyoweni 2014). This waste has an impact on increased costs, decreased productivity, and project delays, delaying the completion of the targeted project (Allo and Bhaskara 2022).

Lean Construction is a management technique that adopts the principles of lean manufacturing and aims to increase value-added while eliminating non-value-added activities in construction projects (Allo and Bhaskara 2022). By implementing lean construction, waste management becomes more effective and projects run more efficiently in terms of cost, quality, and time. The current implementation of Lean Construction is quite effective, but the sustainability of the implementation of this method depends on the commitment between stakeholders in encouraging the reduction of material waste during construction work. The calculation of material waste in this study uses the Lean Construction approach by applying the principle of Eliminate Waste to obtain the calculated waste cost value. By implementing Lean Construction, it is hoped that more optimal solutions can be found to reduce waste and increase the efficiency of material use in construction projects. In addition, using a combination of the Waste Assessment Model and Fault Tree Analysis methods, this study identified the factors that produce the most waste (Huang et al., 2021, 2025; Masalegooyan et al., 2022; Taheriyoun & Moradinejad, 2015). The use of the Waste Assessment Model is used to obtain a model that will be simplified to facilitate the search for waste problems and identify for the waste elimination process (Harsa et al. 2024). The Fault Tree Analysis method is a method used to identify the cause of failures in a system (Hariadi, Termawut, and Hafid 2023). The Fault Tree Analysis method is used to find the root cause of material waste occurring.

The construction projects of Building X, Building Y, and Building Z have a fairly high number of waste materials. This requires good material waste management to reduce project costs and can increase productivity. In the construction process, of course, it is not uncommon for these production products to have a low waste material rate, where a high amount of waste material will affect development costs. Research (Harsa et al. 2024), (Aritonang and Saptadi 2023), (Faisal Afriandi and Joumil Aidil Saifuddin 2023), (Jufrijal and Fitriadi 2022), (Irawan and Putra 2021) explains that the causes of waste material can be caused by several variables, namely overproduction, inventory, defect, motion, transportation, process, and waiting. Through the application of the Lean Construction method, it is hoped that it can reduce the material waste produced, increase development efficiency, and reduce existing costs.

Based on the root of the problem that occurs, it is necessary to conduct waste material analysis research to identify the highest type of waste material, analyze the impact of waste material on project costs and can minimize waste material in construction projects. Referring to references to literature studies that use the Lean Construction method approach to reduce material waste in the implementation of building construction projects at the University of Riau using the Lean Construction concept (Harsa et al. 2024), the identification of Crude Palm Oil waste using the Waste Assessment Model method (Jufrijal and Fitriadi 2022), the application of Lean Manufacturing using the Waste Assessment Model method in an effort to reduce waste in the steel production process structure (Faisal Afriandi and Joumil Aidil Saifuddin 2023), waste identification using the Waste Assessment Model in raw material warehouses carried out at *PT* XYZ (Naziihah, Arifin, and Nugraha 2022), proposed improvements to the shoulder for e-clip production process using the Waste Assessment Model method (Aritonang and Saptadi 2023).

The problem analysis method in the five projects uses the Lean Construction method approach in determining the highest material waste. The five studies used the Waste Assessment Model method and only took into account the percentage of variables that caused material waste and did not take into account waste costs. The preparation of mitigation designs in the five studies used several methods, including fishbone, fault tree analysis, and failure mode and effects analysis. The use of these methods has disadvantages such as the fishbone method which only takes into account the root cause without taking into account the probability of waste occurring, the fault tree analysis method which only identifies the root cause without calculating the probability, and the failure mode and effects analysis method which cannot consider the dependence between the causes of waste material and is less efficient in analyzing complex systems. The research on the analysis of the causative factors and mitigation of waste in building construction projects in the city of Medan by (Simamora et al. 2024) and the analysis of waste material on concrete barrier work using the Fault Tree Analysis method by (Silaban and Pamungkas 2023) produced outputs in the form of basic factors that can cause material waste without taking into account the probability of material waste and calculating the costs incurred. The difference between this study and the previous research is that there is a calculation of waste costs caused by material waste, there is a process of identifying variables that cause waste using the Waste Assessment Model method so that it can determine the relationship between waste variables, and the use of the Fault Tree Analysis method to find the root cause of the waste so that the probability of the occurrence of the waste material can be calculated. This study only discusses waste materials because the main purpose of this research is to find out the causes of waste and how to efficiently waste costs occur. There is a relevance between waste cost and waste time where the delay in implementation time will also have an impact on the increase in costs in the sense that waste time can be shown in the form of waste cost. Waste time in this study can be reflected through waste cost analysis even though it does not discuss waste time in a complex way (D'Onza et al., 2016; Kurdve et al., 2015; Martinez-Sanchez et al., 2015; Reynolds et al., 2019).

The formulation of the problem in this study includes determining the value of waste costs in structural and architectural work with a waste level approach, identifying the highest indicators of the cause of material waste using the Waste Assessment Model method, and the formulation of a strategy for optimizing the efficiency of waste cost materials through the Fault Tree Analysis method. In line with the formulation of the problem, the purpose of this study is to estimate the waste cost due to waste material during the implementation of structural and architectural work, identify the highest indicators of material waste in the construction projects of Building X, Building Y, and Building Z, and determine optimization strategies in increasing the efficiency of material waste costs in structural work. The expected benefits of this study include the ability to identify the amount of waste cost material, knowing the dominant indicators of the cause of waste material in the project being studied, and obtaining effective strategies in efforts to save material cost efficiency during the implementation of structural and architectural work.

METHOD

The case studies used in this study are the X Building Project in the city of Makassar, the Y Building in the city of Batam, and the Z Building in the city of Kediri. This research was conducted to find out the highest material waste. The results of the analysis were obtained from direct observation at the location and distribution of questionnaires to the contractor. In the analysis of this waste material, the Lean Construction method is used. The data obtained is based on the results of direct surveys in the field and conducting interviews with the contractor. In this study, the data collected was in the form of primary data and secondary data.

a. Data Primer

Primary data is the main source of research data whose collection is carried out by conducting interviews with related parties. In addition to interviews, data collection was also carried out by distributing questionnaires containing questions about the variables that cause material waste to the contractor to obtain the factors that cause material waste.

b. Data Seconds

Secondary data is a source of research data whose collection is obtained from analyzing existing project data. Secondary data used in this study include:

1) Volume Material
2) Monitoring waste material
3) Monitoring the Arrival of Materials

The existence of these 3 data can be used as material to identify the factors that cause waste material.

RESULT AND DISCUSSION

Analisa Waste Cost Material

The analysis of waste cost material begins with calculating the waste level of work and continues with the calculation of waste cost material. The work is calculated regarding structural and architectural work by taking into account the main materials used. The analysis of material waste cost can be described as follows:

1. **Waste Level *Calculation***

Waste level calculation requires data on the material needs used as well as material purchase data which is then calculated using the waste level equation formula. The results of the waste level calculation can be obtained with the following formula.

$$\text{Waste Level} = \frac{Volume\ Waste}{Volume\ Material\ Terpakai} \times 100\%$$

2. **Waste Cost *Calculation***

The *waste cost* calculation can be continued after getting the *waste level* figure. The results of the analysis of *the waste cost calculation* of the Building X Project, Building Y Project, and the Z Building Project are in Table 1.

Table 1 Waste Cost Analysis Results

	X	And	Z
Total Waste Cost (IDR)	1,508,859,693	1,578,401,825	1,573,029,639
Waste Cost Percentage (%)	4.93	3.75	3.36

An example of calculating *waste cost* on materials in the table above can be calculated using the following formula.

Volume *Waste* = 54.51
Waste Level = 2.30
Contract Value = 27,800,000,000
Unit Price = 1,168,000
Total Price = 54.51 × 1,168,000 = 63,663,129
Weight of Work= 63,663,129 / 27,800,000,000 = 0.00229
Waste Cost = *Waste Level* × Weight of Work × Total Contract Value

Waste Cost = 2.30 × 0.00229 × 27,800,000,000
Waste Cost = 146,425,196

Analisa Waste Assessment Model

Waste material has seven variables that can be identified, namely *overproduction, inventory, defects, motion, transportation, process,* and *waiting*. The process of identifying critical *waste* variables can be carried out using the *Waste Assessment Model* (WAM) method which is carried out by distributing a questionnaire consisting of two types of questionnaires. The first stage is the filling out of the *Seven Waste Relationship* questionnaire which is used to obtain the *Waste Relation Matrix* (WRM) number. The second stage is by filling out the *Waste Assessment Questionnaire* (WAQ) to determine the order of variables that cause *the highest* waste material.

1. Analisa *Seven Waste Relationship*

The analysis of the Seven Waste Relationship began with the distribution of a questionnaire consisting of six types of questions. The purpose of this questionnaire is to determine the total score between *waste* material. The scoring in the questionnaire follows the conditions described below, namely the first, third, and sixth types of questions with 3 answer choices with a = 4 points, b = 2 points, and c = 0 points, respectively. The second and fourth types of questions have 3 answer options with a = 2 points, b = 1 point, c = 0 points respectively. The fifth question has 7 answer choices with a score of a, b, c = 1 point, d, e, f = 2 points, and answer choice g = 4 points (Jufrijal & Fitriadi, 2022).

The number of relationships between waste has 31 relationships consisting of O – I, which is the relationship between *Overproduction* and *Inventory,* O – D, which is the relationship between *Overproduction* and *Defect,* O – M which is the relationship between *Overproduction* and *Motion* and so on until all the relationships between the seven *wastes are* formed.

The total score of the relationship between waste can be shown in table 4.8 for the SWR analysis of Building X, table 4.9 for the SWR analysis of Building Y, and table 4.10 for the SWR analysis of Building Z.

Table 2 Inter-Waste Analysis Score of Building X Project

Relationship	Total Building Project Score		
	X	And	Z
O - I	10	10	10
O – D	10	10	10
:	:	:	:
O – W	10	10	10
I – O	12	12	12
I – D	10	10	10
:	:	:	:
I – T	10	10	10
D – O	13	13	13
D – I	10	10	10
:	:	:	:
M – D	12	12	12
T – O	10	10	10
:	:	:	:

Relationship	Total Building Project Score		
	X	And	Z
T – W	13	13	13
P – O	10	10	10
:	:	:	:
P - W	10	10	2
W – O	13	13	3
:	:	:	:
W - D	10	10	2

(Source: Author, 2025)

2. Analisa Waste Relationship Matrix

Waste Relationship Matrix is a matrix table used for the analysis of measurement criteria. Waste Relationship Matrix useful for describing the real relationships between variables waste (Faisal Afriandi & Joumil Aidil Saifuddin, 2023).

The result of the total score between waste converted by converting the score into a symbol. The rules for converting score scores into symbols can be explained in table 4.11 as follows (Jufrijal & Fitriadi, 2022):

Table 3 Table of Score Conversion Criteria for Symbols

Range	Types of Relationships	Symbol
17 – 20	*Absolutely Necessary*	A
13 – 16	*Especially Important*	And
9 – 12	*Important*	I
5 – 8	*Ordinary Closeness*	Or
1 – 4	*Unimportant*	In the

(Source: (Jufrijal & Fitriadi, 2022)

The result of the symbol conversion that has been obtained will be simplified in the form of numbers where each symbol has a score. The A symbol has a score of 10, the E symbol has a score of 8, the I symbol has a score of 6, the O symbol has a score of 4, the U symbol has a score of 2, and the X symbol has a score of 0 (Jufrijal & Fitriadi, 2022). The conversion results can be shown in tables 4 for Building X, 1.16 for Building Y, and 1.17 for Building Z.

Table 4 Building X Project Symbol Simplification Table

F/T	Or	I	D	M	T	P	W	SHOES	%
Or	10	6	6	8	6	0	6	42	15.67
I	6	10	6	6	6	0	0	34	12.69
D	8	6	10	6	6	0	6	42	15.67
M	0	6	6	10	0	6	6	34	12.69
T	6	8	6	6	10	0	8	44	16.42
P	6	6	8	6	0	10	6	42	15.67
W	8	6	6	0	0	0	10	30	11.19
SHOES	44	48	48	42	28	16	42	268	100.00
%	16.42	17.91	17.91	15.67	10.45	5.97	15.67	100.00	

(Source: Author, 20205)

Table 5 Building Symbol Simplification Table Y

F/T	Or	I	D	M	T	P	W	SHOES	%
Or	10	6	6	8	6	0	6	42	15.67
I	6	10	6	6	6	0	0	34	12.69
D	8	6	10	6	6	0	6	42	15.67
M	0	6	6	10	0	6	6	34	12.69
T	6	8	6	6	10	0	8	44	16.42
P	6	6	8	6	0	10	6	42	15.67
W	8	6	6	0	0	0	10	30	11.19
SHOES	44	48	48	42	28	16	42	268	100.00
%	16.42	17.91	17.91	15.67	10.45	5.97	15.67	100.00	

(Source: Author, 20205)

Table 6 Building Z Project Symbol Simplification Table

F/T	Or	I	D	M	T	P	W	SHOES	%
Or	10	6	6	8	6	0	6	42	15.67
I	6	10	6	6	6	0	0	34	12.69
D	8	6	10	6	6	0	6	42	15.67
M	0	6	6	10	0	6	6	34	12.69
T	6	8	6	6	10	0	8	44	16.42
P	6	6	8	6	0	10	6	42	15.67
W	8	6	6	0	0	0	10	30	11.19
SHOES	44	48	48	42	28	16	42	268	100.00
%	16.42	17.91	17.91	15.67	10.45	5.97	15.67	100.00	

(Source: Author, 20205)

The percentage of values in the table above is obtained from the total calculation between *wastes*. An example of the calculation on line O is as follows.

Total score O = 42
Total overall score = 268
Percentage O = 42 / 268 × 100 % = 15.67%

3. Analisa *Waste Assessment Question*

Waste Assessment Question is a questionnaire made with the aim of identifying *material waste* that occurs during the production process. This questionnaire consists of 68 questions with seven *waste* variables divided into four aspects, namely *man, method, material,* and *machine*, which has two types of questions "*From Waste"* and "*To waste*". The determination of the initial weight value for each *waste with the "*Form Waste" *question type* was obtained from the row score in the symbol simplification table, while for each *waste* with the question type "*To Waste*" was obtained from the column score in the symbol simplification table.

Initial weighting is done by grouping each type of question. Question grouping is done for each *waste* like, 3 questions *from overproduction*, 6 questions *from inventory*, 8 questions *from defects*, 12 questions *from motion*, 4 questions *from transportation*, 7 questions *from process*, 7 questions *from waiting*, 4 questions *to defects*, 9 questions *to motion*, 3 questions *to transportation*, and 4 questions *to waiting* (firmansyah, 2025).

The next stage after the initial weighting is to do weighting for each question. There is a symbol Wj.k which means W is *waste*, j is a type of *waste*, and k is a question number. The Ni symbol is a symbol that indicates the number of questions. The following is a weighting table with the number of questions in table 5 for the Building X project, table 6 for the Building Y project, and table 7 for the Building Z project.

Examples of calculations of Wo.k, Sj, FJ can be described as follows:

Wo.k $= \frac{Bobot\ Awal}{Ni}$

Sj $= \sum_{k=1}^{k} \frac{Wj.k}{Ni}$

Fj = Number of Questions – Questions are worth 0

After the weighting with the number of questions (Ni) was obtained, the final weighting calculation was carried out by reviewing the results of the WAQ questionnaire consisting of 68 questions with a choice of answers "Yes" with a score of 1, "Medium" with a score of 0.5, and "No" with a score of 0 (Jufrijal & Fitriadi, 2022).

The results of the average are obtained from the average results of the questionnaire answers with the answer score.

Wo.k = Average × of the first weighting results in Wo.k

sj $= \sum_{k=1}^{k} Xk \times \frac{Wj.k}{Ni}$

Fj = value found in the type of waste that is not 0

The final result is carried out by looking for the score value (Yj), Pj *Factor*, and Final Yj value to get the highest percentage and *ranking of waste*. The final results can be seen in table 4.27 for the Building X project, table 7 for the Building Y project, and table 8 for the Building Z project.

Table 7 Final Results of WAQ Building X Project

	Or	**I**	**D**	**M**	**T**	**P**	**W**
Score (Yj)	1.62	1.64	1.63	1.64	1.63	1.65	1.63
Pj Factor	257.30	227.22	280.69	198.82	171.53	93.56	175.43
(Yj Final)	417.42	373.32	457.74	327.01	278.99	154.18	285.58
Percentage	18.19%	16.27%	19.95%	14.25%	12.16%	6.72%	12.45%
Rank	**2**	**3**	**1**	**4**	**6**	**7**	**5**

(Source: Author, 2025)

Table 8 Final Results of WAQ Building Y Project

	Or	**I**	**D**	**M**	**T**	**P**	**W**
Score (Yj)	1.66	1.66	1.67	1.64	1.67	1.68	1.65
Pj Factor	257.30	227.22	280.69	198.82	171.53	93.56	175.43
(Yj Final)	427.19	376.96	468.50	326.36	286.30	156.78	290.30
Percentage	18.32%	16.16%	20.09%	13.99%	12.27%	6.72%	12.45%
Rank	**2**	**3**	**1**	**4**	**6**	**7**	**5**

(Source: Author, 2025)

Table 9 Final Results of WAQ Building Z Project

	Or	I	D	M	T	P	W
Score (Yj)	1.62	1.64	1.63	1.64	1.63	1.65	1.63
Pj Factor	257.30	227.22	280.69	198.82	171.53	93.56	175.43
(Yj Final)	417.42	373.32	457.74	327.01	278.99	154.18	285.58
Percentage	18.19%	16.27%	19.95%	14.25%	12.16%	6.72%	12.45%
Rank	**2**	**3**	**1**	**4**	**6**	**7**	**5**

(Source: Author, 2025)

The calculation of the final results *of the Waste Assessment Questionnaire* was obtained in the following way, as an example of a case study of the Building X project:

Score (Yj) = $= 1.62 \frac{Sj}{sj} \times \frac{Fj}{fj} \frac{70}{43.15} \times \frac{56}{56}$

Pj *Factor* = % Row O table 4.15 × % Column O table 4.15
= 15.67 × 16.42
= 257.30

Yj Final = Score (yj) × Pj *Factor*
= 1.62 × 257.30
= 417.42

Percentage = $= 18.19\% \frac{Yj\ Final}{Total\ Yj\ Final} \frac{417.42}{2294.24}$

The final results in table 4.27 for the Building X project, table 4.28 for the Building Y project, and table 10 for the Building Z project can be found that the first rank *of waste* is caused by *Defects*, the second rank is caused by *Overproduction*, and the third rank is due to *Inventory* with a recap of the results in table 10 below:

Table 10 Recapitulation of the Highest Waste Ranking

No	Variables/Locations	Building X	Building Y	Building Z
1	*Defects*	19.95%	20.09%	19.95%
2	*Overproduction*	18.19%	18.32%	18.19%
3	*Inventory*	16.28%	16.16%	16.27%

(Source: Author, 2025)

Analisa Fault Tree Analysis

The step after obtaining the variable data that causes *the highest material* waste through the *Waste Assessment Model* analysis is to create *a Fault Tree Analysis* diagram using *logic gate* rules. The *logic gate* principle in *Fault Tree Analysis* has two types that are influential in determining the *minimum Cut Set* formula. The *logic gate* types are *OR GATE* and *AND GATE.* The use *of OR GATE* is used in the determination of probability formulas by summation, while *AND GATE* is used for the determination of probability formulas by means of multiplication.

The Minimum Cut Set is a combination of *basic events* obtained from the *Fault Tree Analysis* chart. The Minimum *Cut Set* probability calculation process is carried out by filling out a questionnaire by respondents to get the probability value of an event. The description of *Fault Tree Analysis* and probability calculation in Building X, Building Y, and Z Projects can be described as follows:

Fault *Tree Analysis* Method Analysis Variable A1

The analysis of the variable causing waste code A1 with the *variable Defect* is "Human or Group Failure" which is shown in the chart with the following figure number 4.1:

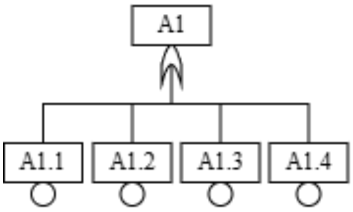

Figure 1 FTA Chart Model of Variable Causes of Waste A1
(Source: Author, 2025)

The description of *the event* description of the variable cause *of waste* code A1 with the *Defect* variable "Human or Group Failure" is as follows:

Table 11 Occurrence Description of FTA Code Chart Model

Yes	Event	Description of Occurrence
1	A1	Human or group failures
2	A1.1	Lack of exposure and training to workers that can increase the risk of defects
3	A1.2	Lack of supervision during the implementation of work causing defects
4	A1.3	Errors in the material production process or the application of work methods (e.g. wrong measurements, wrong cuts, incorrect applications, etc.)
5	A1.4	Lack of coordination regarding the work drawings used to work on the field work

(Source: Author, 2025)

Table 11 shows the event data in the chart shown in Figure 4.1. Top *Event* is the dominant event variable that causes *material waste*. The basic event (*Baisc Event*) is the event that causes the formation of *the Top Event*. Here is the Boolean Algebra method and the minimum cut *set combination* of figure 2.

$$A1 = A1.1 + A1.2 + A1.3 + A1.4$$
$$A1 = (A1.1 + A1.2 + A1.3 + A1.4) – (A1.1 \times A1.2 \times A1.3 \times A1.4)$$

Boolean algebra is obtained from the combination of *the minimum cut set* result with the following probability calculation results:

Table 12 Basic Event Probability Calculation Code A1

Basic Event	Probability of Occurrence		
	Building X	Building Y	Building Z
A1.1	0.1838	0.1131	0.1714
A1.2	0.2132	0.2262	0.2429
A1.3	0.1213	0.1548	0.1214
A1.4	0.1213	0.1131	0.1214
Total	0.6391	0.6066	0.6565

(Source: Author, 2025)

Fault *Tree Analysis* Method Analysis Variable A2

The analysis of the variable cause *of* waste code A2 with the *variable Defect* is "Material Suppliers and Quality Problems" which is shown in the chart with the following figure number 2:

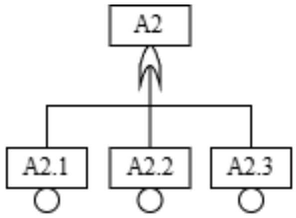

Figure 2 FTA Chart Model of Variable Causes of Waste A2
(Source: Author, 2025)

The description of *the event description* of the variable cause *of waste* code A2 with the *Defect* variable "Material Supplier and Quality Problems" is as follows:

Table 13 Incident Description of the FTA Code Chart Model A2

No	Event	Description of Occurrence
1	A2	Material suppliers and quality problems
2	A2.1	Delivery of materials that do not meet the specifications and quality ordered
3	A2.2	Changes in material quality caused by supplier inconsistency in material production
4	A2.3	The occurrence of unwanted things during the delivery of materials such as collisions, raining materials, contaminated materials

(Source: Author, 2025)

Table 13 shows the event data in the chart shown in Figure 4.2. Top *Event* is the dominant event variable that causes *material waste*. The basic event (*Baisc Event*) is the event that causes the formation of *the Top Event*. Here is the Boolean Algebra method and the *minimum cut set* combination of figure 3.

$$A2 = A2.1 + A2.2 + A2.3$$
$$A2 = (A2.1 + A2.2 + A2.3) - (A2.1 \times A2.2 \times A2.3)$$

Boolean algebra is obtained from the combination of *the minimum cut set* result with the following probability calculation results:

Table 14 Calculation of Probability Basic Event Code A2

Basic Event	Probability of Occurrence		
	Building X	Building Y	Building Z
A2.1	0.0919	0.1131	0.1714
A2.2	0.1213	0.1548	0.1214

A2.3	0.2757	0.2262	0.2429
Total	0.4854	0.4900	0.5308

(Source: Author, 2025)

Fault *Tree Analysis* Method Analysis Variable A3

The analysis of the variable causing waste code A3 with the *variable Defect* is "Material Reception and Storage" shown in the chart with the following figure number 3:

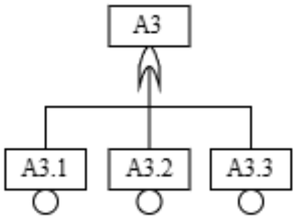

Figure 3 FTA Chart Model of Variable Causes of Waste A3

(Source: Author, 2025)

The description of *the event description* of the variable cause *of waste* code A3 with the *Defect* variable "Material Reception and Storage" is as follows:

Table 15 Occurrence Description of the FTA Code Chart Model A3

No	Event	Description of Occurrence
1	A3	Material reception and storage
2	A3.1	Available storage space in poor or inadequate condition
3	A3.2	Absence of labeling and segregation processes (separation based on characteristics) of materials
4	A3.3	Damage occurs during the removal of materials

(Source: Author, 2025)

Table 15 shows the event data in the chart shown in Figure 4.3. Top *Event* is the dominant event variable that causes *material waste*. The basic event (*Baisc Event*) is the event that causes the formation of *the Top Event*. Here are the Boolean Algebra method and the *minimum cut set combination* from Figure 4.

A3 = A3.1 + A3.2 + A3.3

A3 = (A3.1 + A3.2 + A3.3) – (A3.1 × A3.2 × A3.3)

Boolean algebra is obtained from the combination of *the minimum cut set* result with the following probability calculation results:

Table 16 Basic Event Probability Calculation Code A3

Basic Event	Probability of Occurrence		
	Building X	Building Y	Building Z
A3.1	0.0919	0.1131	0.1214
A3.2	0.1838	0.1548	0.1929
A3.3	0.2132	0.2262	0.2429
Total	0.4845	0.4900	0.5503

(Source: Author, 2025)

Fault *Tree Analysis* Method Analysis Variable A4

The analysis of the variable causing waste code A4 with the *variable Defect* is "Work Implementation Method" shown in the chart with the following figure number 4.4:

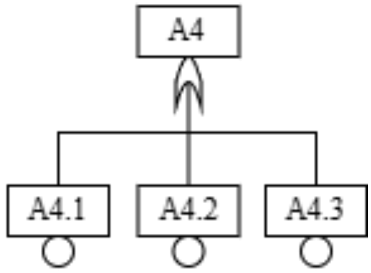

Figure 4 FTA Chart Model of Variable Causes of Waste A4
(Source: Author, 2025)

The description of *the event description* of the variable cause *of* waste code A4 with the *Defect variable* "Work Implementation Method" is as follows:

Table 17 Occurrence Description of the Model FTA Chart Code A4

No	Event	Description of Occurrence
1	A4	Method of work implementation
2	A4.1	No quality control inspection before finishing the work
3	A4.2	Implementation of work processes that are not in accordance with existing SOPs
4	A4.3	No checking or calibration of work aids

(Source: Author, 2025)

Table 17 shows the event data in the chart shown in Figure 4. Top *Event* is the dominant event variable that causes *material waste*. The basic event (*Baisc Event*) is the event that causes the formation of *the Top Event*. Here are the Boolean Algebra method and the *minimum cut set* combination of figure 5.

A4 = A4.1 + A4.2 + A4.3

A4 = (A4.1 + A4.2 + A4.3) – (A4.1 × A4.2 × A4.3)

Boolean algebra is obtained from the combination of *the minimum cut set* result with the following probability calculation results:

Table 18 Basic Event Probability Calculation Code A4

Basic Event	Probability of Occurrence		
	Building X	Building Y	Building Z
A4.1	0.1544	0.1131	0.1214
A4.2	0.0919	0.1131	0.1214
A4.3	0.0919	0.1131	0.1214
Total	0.3362	0.3375	0.3623

(Source: Author, 2025)

Fault *Tree Analysis* Method Analysis Variable B1

The analysis of the variables that cause *waste* code B1 with the variable Overproduction *is* "Planning and Estimation" which is shown in the chart with the following figure number 4.5:

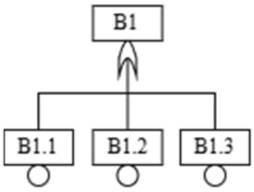

Figure 5 FTA Chart Model of Variable Causes of Waste B1
(Source: Author, 2025)

The description of *the event information* on the variable cause *of waste* code B1 with *the variable Overproduction* "Planning and Estimation" is as follows:

Table 19 Occurrence Description of FTA Code Chart Model B1

No	Event	Description of Occurrence
1	B1	Planning and Estimation
2	B1.1	Lack of precision in the calculation of material estimation so that the volume of material is excessive
3	B1.2	Excessive planning of spare materials
4	B1.3	Excessive material ordering without any confirmation process with the field

(Source: Author, 2025)

Table 19 shows the event data in the chart shown in Figure 5. Top *Event* is the dominant event variable that causes *material waste*. The basic event (*Baisc Event*) is the event that causes the formation of *the Top Event*. Here is the Boolean Algebra method and the *minimum cut set* combination of figure 4.5.

B1 = B1.1 + B1.2 + B1.3

B1 = (B1.1 + B1.2 + B1.3) – (B1.1 × B1.2 × B1.3)

Boolean algebra is obtained from the combination of *the minimum cut set* result with the following probability calculation results:

Table 20 Calculation of Probability Basic Event Code B1

Basic Event	Probability of Occurrence		
	Building X	Building Y	Building Z
B1.1	0.2757	0.1964	0.2214
B1.2	0.1544	0.1845	0.1214
B1.3	0.0919	0.1131	0.1214
Total	0.5159	0.4903	0.4613

(Source: Author, 2025)

Fault *Tree Analysis* Method Variable B2

The analysis of the variable causing *waste* code B2 with the variable Overproduction is "Production Process" shown in the chart with figure number 4.6 below:

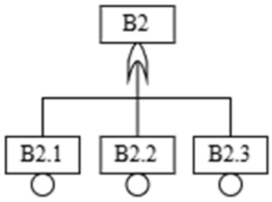

Figure 6 FTA Chart Model of Variable Causes of Waste B2
(Source: Author, 2025)

Fault *Tree Analysis* Method Analysis Variable C2

The analysis of the variable causing *C2 code* waste with the *Inventory* variable is "Capacity and Storage Methods" shown in the chart with the following figure number 7:

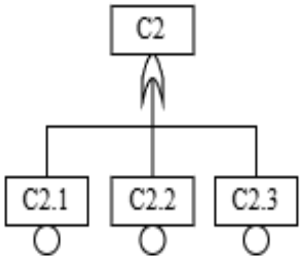

Figure 7 FTA Chart Model of Variable Causes of Waste C2
(Source: Author, 2025)

The description of *the event description* of the variable cause of waste code C2 with the *Inventory* variable "Capacity and Storage Method" is as follows:

Table 21 Occurrence Description of the FTA Code Chart Model C2

No	Event	Description of Occurrence
1	C2	Capacity and Storage Method
2	C2.1	Inadequate material storage space availability
3	C2.2	Irregular storage of materials according to type, quality, label, etc.
4	C2.3	Labeling or coding is not done correctly so that there is a lot of confusion

(Source: Author, 2025)

Table 21 shows the event data in the chart shown in Figure 4.9. Top *Event* is the dominant event variable that causes *material waste*. The basic event (*Baisc Event*) is the event that causes the formation of *the Top Event*. Here is the Boolean Algebra method and the *minimum cut set* combination of figure 8.

C2 = C2.1 + C2.2 + C2.3

C2 = (C2.1 + C2.2 + C2.3) – (C2.1 × C2.2 × C2.3)

Boolean algebra is obtained from the combination of *the minimum cut set* result with the following probability calculation results:

Table 22 Calculation of Probability Basic Event Code C2

Basic Event	Probability of Occurrence		
	Building X	Building Y	Building Z
C2.1	0.0919	0.1131	0.1214
C2.2	0.1213	0.1131	0.1214
C2.3	0.0919	0.1131	0.1214
Total	0.3040	0.3375	0.3623

(Source: Author, 2025)

Fault *Tree Analysis* Method Variable C3

The analysis of the variable causing waste code C3 with the *Inventory* variable is "Storage Control Process" shown in the chart with the following figure number 8:

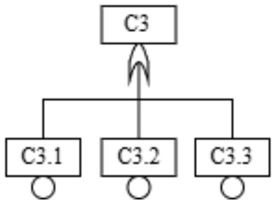

Figure 8 FTA Chart Model of Variable Causes of Waste C3
(Source: Author, 2025)

The description of *the event description* of the variable cause *of waste* code C3 with the *Inventory* variable "Storage Control Process" is as follows:

Table 23 Occurrence Description of the FTA Code Chart Model C3

No	Event	Description of Occurrence
1	C3	Storage Control Process
2	C3.1	No checks are carried out on existing stock manually or digitally
3	C3.2	Difference in the amount of materials/tools in the field with warehouse stock data
4	C3.3	Not checking inventory/stock materials regularly

(Source: Author, 2025)

Table 9 shows the event data in the chart shown in Figure 4.10. Top *Event* is the dominant event variable that causes *material waste*. The basic event (*Baisc Event*) is the event that causes the formation of *the Top Event*.

Fault *Tree Analysis* Method Analysis Variable C4

The analysis of the variables that cause waste code C4 with the *Inventory variable* is "Logistics Management and Delivery Time" which is shown in the chart with the following figure number 9:

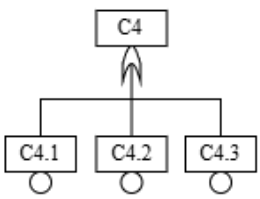

Figure 9 FTA Chart Model of Variable Causes of Waste C4
(Source: Author, 2025)

The description of *the event information* on the variable causes of waste code C4 with the *Inventory* variable "Logistics Management and Delivery Time" is as follows:

Table 24 Occurrence Description of the FTA Code Chart Model C4

No	Event	Description of Occurrence
1	C4	Logistics Management and Delivery Time
2	C4.1	Improper work time planning so that materials arrive too early
3	C4.2	There is a change in the work schedule so that materials accumulate
4	C4.3	There is a policy that has been determined by the supplier regarding the minimum material delivery limit

(Source: Author, 2025)

Table 24 shows the event data in the chart shown in Figure 4.11. Top *Event* is the dominant event variable that causes *material waste*. The basic event (*Baisc Event*) is the event that causes the formation of *the Top Event*. Here is the Boolean Algebra method and the *minimum cut set* combination of figure 10.

$$C4 = C4.1 + C4.2 + C4.3$$

$$C4 = (C4.1 + C4.2 + C4.3) - (C4.1 \times C4.2 \times C4.3)$$

Boolean algebra is obtained from the combination of *the minimum cut set* result with the following probability calculation results:

Table 25 Basic Event Probability Calculation Code C4

Basic Event	Probability of Occurrence		
	Building X	Building Y	Building Z
C1.1	0.0919	0.1131	0.1214
C1.2	0.1213	0.1131	0.1214
C1.3	0.2132	0.2262	0.2429
Total	0.4239	0.4489	0.4818

(Source: Author, 2025)

The *minimum cut set* probability obtained from the combination of *the basic event* variable is obtained as follows:

Table 26 Basic Event Probability Recapitulation

Code	Variable Dominance	Probability of Occurrence		
		Building X	Building Y	Building Z
A1	Human or Group Failure	0.6391	0.6066	0.6565
A2	Material Suppliers and Quality Issues	0.4854	0.4900	0.5308
A3	Material Reception and Storage	0.4845	0.4900	0.5503
A4	Method of Work Implementation	0.3362	0.3375	0.3623
B1	Planning and Estimation	0.5159	0.4903	0.4613
B2	Production Process	0.5136	0.5311	0.5308
B3	Rework Process and Change of Work	0.5136	0.5996	0.5993
C1	Planning and Procurement	0.5738	0.5174	0.5308
C2	Capacity and Storage Method	0.3040	0.3375	0.3623
C3	Storage Control Process	0.3655	0.3789	0.4118
C4	Logistics Management and Delivery Time	0.4239	0.4489	0.4818

(Source: Author, 2025)

The results of the probability analysis of the *minimum cut set* pad table of 4.53 have the highest variable that results in material *waste* in the Project of Building X, Building Y, and

Building Z, which is found in the variable A1 "Human or Group Failure", while the lowest variable is found in the variable C2 "Capacity and Storage Methods".

CONCLUSION

The conclusions that can be drawn from the results of the research that has been carried out on the Building X, Building Y, and Z Projects are: The results of the calculation of material waste costs incurred in the Building X project amounted to Rp. 1,371,690,630 with a waste cost percentage of 4.93% of the contract value. The value of material waste costs incurred in the Building Y project is Rp. 1,434,910,750 with a waste cost percentage of 3.75% of the contract value. The material waste cost incurred in the Z Building project amounted to Rp. 1,573,029,639 with a waste cost percentage of 3.36% of the contract value. Waste Assessment Model analysis shows that there are three types of critical waste in the Building X project, namely Defect 19.95%, Overproduction 18.19%, and Inventory 16.27%. Building Y projects are Defect 20.09%, Overproduction 18.32%, and Inventory 16.16%. Building Z projects are Defect 19.95%, Overproduction 18.19%, and Inventory 16.27%. Broadly speaking, the occurrence of material waste is caused by defect variables, overproduction, and inventory with different solutions for handling waste costs.

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