Waste analysis in aircraft production process

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Abstract. Waste is any type of work activity that does not provide added value and it is eliminated, because it can have a negative impact on the company. During the production process, waste can occur due to the operator, the machine, nature, etc. In the production process of aircraft manufacturing at one of Indonesian-aircraft Industries, there are many factors that influence the occurrence of waste; therefore, there is a need to minimize or even eliminate the waste, one of them by using lean manufacturing. In this company, there are three of the biggest waste that occurs during the production process of aircraft, namely Defects, Inventory and Motion waste. From those three wastes, they will be identified which causes the greatest impact on other waste using the Waste Relationship Matrix (WRM) method. The results of the calculation of WRM, found that defect waste has a considerable impact when compared to inventory waste and motion waste, with an average value of 44.02%. So, the company needs to focus on eliminating these wastes, by improving the condition of the production floor, both from the people, methods, machines, or even from the environment.

Keywords: lean, waste, WRM, Pareto, fishbone diagram

1. Introduction

The rapid industrial growth and technological development has made competition among companies more competitive. One of the toughest challenges is the ability to adopt and introduce approaches and improvement techniques so that overall improvement can be achieved [1]. Increasing efficiency on the production line is proven to be able to reduce the level of downtime and be able to meet high market demands [5]. Therefore, companies must know which activities can provide added value so they can improve product quality [1]. Many methods can be used to reduce activities that have no value/waste in the production process, one of which is lean manufacturing. Lean manufacturing was developed by Eiji Toyoda and Taichi Ohno in the 1950s and 1960s in which they continually identified and eliminated waste from the system [4]. There are 7 types of waste that must be removed from the system, namely Transportation, Inventory, Motion, Waiting, Overprocessing, Overproduction, and Defects [6]. Elimination waste is known as one of continuous improvement in the manufacturing world [11]. Elimination waste is the application of lean manufacturing with the 4P category (Problem Solving, People and Partners, Process, and Philosophy) [12]. Waste has a negative effect on companies such as Inventory tends to increase production costs because of the additional costs to handle and storage space availability, Delays can...
cause work-in-process accumulation, and Overprocessing will increase operating redundancy [5]. In industry, production costs can be minimized and profits can be obtained by eliminating waste that occurs [13].

Lean can describe in more detail of the process in a company, providing information related to process activities that give value or not [19]. Lean should become a culture in the company, because the value added processes can be achieved through constant evaluation on the improvement process [20]. During the production process, waste can occur due to the operator, machinery, nature, etc., which can cause the company's inability to meet customer demands [6]. Implementation of lean manufacturing is one of the efforts that can be carried out by a company to make improvements toward the waste that occurs in the company. Lean manufacturing is an approach to identify and minimize continuous or sustainable waste, so that it can attract the attention of consumers with a smooth production flow [10].

One of Indonesian-aircraft Industry companies must be able to compete with other international aircraft industry companies. Therefore, it must pay attention to the aircraft production process in detail in order to know the type of waste that occurs when the production process takes place and the impact caused by the waste. Problems that often occur on the production floor are caused by disturbed production flow, which has an impact on increasing customer waiting time [7]. The process of producing aircraft parts at one of Indonesian-aircraft Industry companies involves several divisions, namely Detail Part Manufacturing, Component Assembly, Final Assembly Line, and Flight Delivery [8]. Subsequently, there will be many factors that influence the occurrence of waste when the aircraft production process is carried out. Thus, the implementation of lean manufacturing is expected to provide company consideration for eliminating waste that has the greatest impact on other waste first. Lean manufacturing techniques may allow the aerospace defense industry to remain healthy and profitable [16].

2. Material and Method
2.1. Material
Literature review to support the conducted research compose the basic concepts of lean manufacturing, Waste Relationship Matrix (WRM), Fishbone Diagrams.

2.1.1. Lean Manufacturing Basic Concept
Terminologically, lean means a series of activities or solutions to eliminate waste, reduce non-value added (NVA) operations and increase value added (VA) operations [15]. Lean can be defined as a systemic and systematic approach to identifying and eliminating waste, or non-value-added activities through continuous improvement by flowing products (material, work in process, output) and information using a pull system and internal and external to pursue excellence and perfection [10]. Implementation of lean is expected to gain three results, namely: better processes, better working conditions, fulfill the needs and goals of the organization [14]. Simply lean, is a systematic method to create more value for customers with fewer resources, it reduces non-value-added resources, including space, material, tooling, and labour [17].

2.1.2. Waste Relationship Matrix (WRM)
Every waste has a relationship with each other, this is caused by the influence of each waste can appear directly or indirectly. The relationship between waste is very complex because the impact of each type of waste to other waste can be seen directly or indirectly. Therefore, [9] developed a framework for assessing the level of waste impact based on its effect on other waste. Each waste type is abbreviated with a letter, (O: Overproduction, I: Inventory, D: Defect, M: Motion, P: Process, T: Transportation, W: Waiting), and each relationship is marked with an underscore symbol " _ ". The relationship of seven waste can be seen in figure 1.
Waste Relationship Matrix (WRM) is used as an analysis of measurement criteria for the relationship between waste that occurs. WRM is a matrix consist of rows and columns. The row shows the effect of each waste on the other six types of waste. The column shows the waste affected by the other six wastes. Diagonal matrix shows the highest relationship value.

To calculate the score from the waste relationship matrix, a measurement is developed using a questionnaire. Waste relationship questionnaire with each weight score on each answer that has been provided in each of the questionnaire questions can be seen in Table 4.3.

![Figure 1. Waste Relationship Matrix][9]

**Table 1. Waste Relationship Matrix [9]**

| From/To | O | I | D | M | T | P | W |
|---------|---|---|---|---|---|---|---|
| O       | A | O | O | O | I | X | E |
| I       | I | A | U | O | I | X | X |
| D       | I | I | A | U | E | X | I |
| M       | X | O | O | A | X | I | A |
| T       | U | O | I | U | A | X | I |
| P       | I | U | I | I | X | A | I |
| W       | O | A | O | X | X | X | A |

**Table 2. WRM’s Score [9]**

| Range     | Relation             | Symbol |
|-----------|----------------------|--------|
| 17-20     | Absolutely Necessary | A      |
| 13-16     | Especially Important | E      |
| 9-12      | Important            | I      |
| 5-8       | Ordinary Closeness   | O      |
| 1-4       | Unimportant          | U      |
Table 3. List of Questions for WRM Analysis [9]

| No. | Questions                                                                 | Answer choices                                         | Score |
|-----|---------------------------------------------------------------------------|--------------------------------------------------------|-------|
| 1   | Did i cause or produce j                                                 | Always, Sometimes, Rarely                               |       |
| 2   | What is the type of relationship between i and j                          | If i rise then j rise, If i rise, then j remain, Uncertain, depending on circumstances |       |
| 3   | The impact on j caused by i                                               | Seen directly & clearly, It takes time to be seen, Not visible |       |
| 4   | Eliminating the impact of i on j can be achieved by ...                   | Engineering method, Simple and direct, Instructional Solution |       |
| 5   | I’s impact on j mainly affects ...                                        | Product quality, Resource productivity, Lead time, Quality and productivity, Quality and lead time, Productivity and lead time, Quality, productivity and lead time |       |
| 6   | How big i’s impact on j will increase lead time                           | Very high, Medium, Low                                  |       |

2.1.3. Pareto Diagram
The Pareto diagram was first introduced by an economist from Italy named Vilfredo Pareto (1848-1923). In general, the Pareto diagram is used to show problems that are arranged from the highest priority to the lowest to determine the problem that must be addressed first. The Pareto principle states that for many events, around 80% of the effect is caused by 20% of the cause [21]. Pareto diagrams are in the form of a vertical bar chart that ranks measurements from highest to lowest.

2.1.4. Fishbone diagram
Fishbone diagram was developed in 1943 by Prof. Kaoru Ishikawa so this causal diagram is also often referred to as the Ishikawa diagram or fish bone diagram. Fishbone diagrams are structured diagrams to identify the causes of problems and cause-effect relationships based on the experience and expertise of a group of people by structured brainstorming. The way to explore the causes of a problem is to use the 5 why principle, it aims to explore the true root causes and stimulate the team to make optimal improvements [2]. The most important factors in making fishbone diagrams are 5M & 1E which consists of man, machine, method, materials, measurement, and environment.

2.2. Method
The data that has been collected, in the form of data from the questionnaire about waste that has been distributed to the production division of Sub Assy All Programs and historical waste data that occur, will be processed to find out the optimal results for problem solving. The following is a type of data processing from existing data to achieve research objectives.
- Recap the results of questionnaires that have been filled out by workers
- Processing data from questionnaire results using the Waste Relationship Matrix (WRM) method.
- Discussion of the largest waste based on the results of the Waste Relationship Matrix (WRM) method using the Pareto Diagram.
- Finding the root cause of the biggest waste based on previous Pareto Diagram analysis using the Fishbone Diagram tools.
3. Result and Discussion

3.1. Result

Based on the results of Inventory interviews that have occurred is excess components because the number of components made is more than the number of components needed to make aircraft at a later stage. Consequently, the components that are not used will be put into a warehouse with a specified expiration date. Whereas the waste motion that has occurred is that there are operators who do not do a job because the components that should be assembled experience defects and the sustainability of the components must be analyzed first by the engineering workers. So that the waiting time arises which causes the operator does not provide added value to the product or process. In addition, the large number of operators on one workstation can also lead to waste motion because not all operators do a certain work on the workstation. The following is a recapitulation of the value obtained for each waste defect, inventory, and motion relationship with other waste based on respondents' answers. From the recapitulation of respondents’ answers, the total value of each waste relationship will be converted into a WRM symbol based on the range of values previously described. The following is the conversion of the total score obtained from the questionnaire results of each respondent into the WRM symbol.

Table 4. WRM Symbol Conversion

| No | Relationship Question | Respondent 1 Score | Relationship | Respondent 2 Score | Relationship | Respondent 3 Score | Relationship |
|----|------------------------|--------------------|--------------|--------------------|--------------|--------------------|--------------|
| 1  | D_O                   | 5                  | O            | 14                 | E            | 11                 | I            |
| 2  | D_W                   | 13                 | E            | 13                 | E            | 20                 | A            |
| 3  | D_T                   | 4                  | U            | 14                 | E            | 1                  | U            |
| 4  | D_I                   | 6                  | O            | 12                 | I            | 11                 | I            |
| 5  | D_M                   | 17                 | A            | 18                 | A            | 10                 | I            |
| 6  | I_O                   | 6                  | O            | 11                 | I            | 10                 | I            |
| 7  | I_D                   | 12                 | I            | 7                  | O            | 12                 | I            |
| 8  | I_M                   | 8                  | O            | 5                  | O            | 5                  | O            |
| 9  | I_T                   | 7                  | O            | 4                  | U            | 4                  | U            |
| 10 | M_I                   | 4                  | U            | 4                  | U            | 8                  | O            |
| 11 | M_D                   | 1                  | U            | 8                  | O            | 4                  | U            |
| 12 | M_P                   | 6                  | O            | 8                  | O            | 8                  | O            |
| 13 | M_W                   | 12                 | I            | 10                 | I            | 19                 | A            |

After knowing the symbol of the relationship from waste defect, inventory, and motion to other waste, the relationship symbol can be integrated into the waste relationship matrix table as follows.

WRM has a function as a matrix to analyze the criteria for each measurement consisting of rows that show the effect that occurs in a waste to the other six wastes [3].

Table 5. WRM Respondent 1

| From/To | D | O | W | T | I | M | P |
|---------|---|---|---|---|---|---|---|
| D       | D | A | O | E | U | O | X |
| I       | I | O | X | O | A | O | X |
| M       | M | U | X | I | X | U | A | O |

Table 6. WRM Respondent 2

| From/To | D | O | W | T | I | M | P |
|---------|---|---|---|---|---|---|---|
| D       | D | A | E | E | E | I | A | X |
| I       | I | O | I | X | U | A | O | X |
| M       | M | O | X | I | X | U | A | O |
Table 7. WRM Respondent 3

| From/To | D | O | W | T | I | M | P |
|---------|---|---|---|---|---|---|---|
| D       | A | I | A | U | I | I | X |
| I       | I | I | X | U | A | O | X |
| M       | U | X | X | O | A | O |   |

From the waste relationship matrix above, then the score of the level of influence of waste defect, inventory, and motion is calculated on the other waste (waste matrix value). This can be performed by converting the results of the relationship waste matrix into percentages [9]. The results of the percentage of the level of influence of waste with other waste can be sought by first converting the results of the relationship waste matrix into numbers with references A = 10, E = 8, I = 6, O = 4, U = 2, and X = 0. The following is a comparison table that shows the ranking of waste from waste defects, inventory, and motion that can cause the largest to the smallest impact on other waste.

Based on the above calculation results, it can be concluded that of the three respondents assume that waste defects have a considerable influence when compared to waste inventory and waste motion. This can be proved by the large percentage of the effect of defects on other waste that is equal to 42.22% in respondents 1, 49.02% in respondents 2, and 40.82% in respondents 3. The percentage figures are almost close to half of the total 100% of the overall effect of waste defects, inventory, and motion on other waste. If waste defects occur during the production process, the waste that is most affected is waste motion and waste waiting. It can be seen in the waste relationship matrix that the relationship of defect to motion and defect to waiting is on average I (Important) to A (Absolutely Necessary), where the relationship is obtained based on the results of respondents' questionnaire answers. In addition, the magnitude of the effect of waste inventory and motion on other waste can be said to be almost the same as the percentage difference between the two wastes of approximately 1%.

Table 8. Comparison of WRM Respondent 1, 2, and 3

| Ranking | Waste | Value | %  | Waste | Value | %  | Waste | Value | %  |
|---------|-------|-------|----|-------|-------|----|-------|-------|----|
| 1       | D     | 38    | 42.22 | D     | 50    | 49.02 | D     | 40    | 40.82 |
| 2       | I     | 28    | 31.11 | I     | 26    | 25.49 | M     | 30    | 30.61 |
| 3       | M     | 24    | 26.67 | M     | 26    | 25.49 | I     | 28    | 28.57 |

It can be concluded that the waste that needs to be minimized first is the waste defect in the Sub Assy All Programs section. This can be proven by the Reject Tag data which contains information about defect components in the past so that it can affect the production process. In addition, workers in the Sub-Assy All Programs production division also said that the biggest waste was caused by defects in aircraft components, resulting in longer aircraft manufacturing lead times. Therefore, companies need to pay attention to the waste defect which has a major influence on the course of the production process. It starts by identifying which defects should be addressed first so that the quality of aircraft products will also be maintained and seen by consumers.

3.2. Discussion

To identify or select the most important type of defect, a Pareto diagram is used. This diagram can show how much frequency various types of defects have occurred. The total components in the Reject Tag Sub Assy All Programs are 11 components, but the number of defects is 13 because there are several components that experience more than one types of defects. Furthermore, defect type data is sorted from the largest to the smallest, then the percentage of defect types and the cumulative percentage is made.
Table 9. Type of Defect

| No | Type of Defect          | Number of Defect | Percentage (%) | Cumulative Percentage (%) |
|----|-------------------------|------------------|----------------|---------------------------|
| 1  | Incorrect diameter holes| 5                | 38.46          | 38.46                     |
| 2  | Incorrect length        | 3                | 23.08          | 61.54                     |
| 3  | Incorrect drilling position | 2            | 15.38          | 76.92                     |
| 4  | Damage to components    | 2                | 15.38          | 92.31                     |
| 5  | Incorrect material      | 1                | 7.69           | 100                       |
|    | Total                   | 13               | 100            |                           |

From table 13 it can be seen that the type of defect in the previous period were incorrect diameter holes of 38.5%, incorrect length of 23.1%, damage to components of 15.4%, incorrect drilling position by 15.4%, and incorrect material by 7.7%. Based on the principle of the Pareto diagram, repairs should be focused on the type of defect that reaches 20% in the overall type of defect that occurs, namely incorrect diameter holes. It is intended that the company can improve the quality of aircraft production and increase customer satisfaction.

![Pareto Chart of Description Defect](image)

**Figure 2. Defect Pareto Diagram**

Manpower and facility are the key elements for the shop floor of aerospace manufacturer [18], therefore, a fishbone diagram are used to seek the factors that cause the wrong diameter hole defects. These causative factors are divided into 5 namely man, machine, method, measurement, and environment.

Based on discussion with the head of production floor and observation on the production floor, the causes of the defects are:

- **Man:** Lack of operator accuracy in working on aircraft sub-assy components can lead to errors in workmanship. This can be caused by the operator's lack of concentration due to the large workload borne by the operator during the production process. This can be caused by the number of human resources that are lacking in the production of Sub Assy All Programs. In addition, the skills possessed by the operator also affect the performance of the operator himself. The lack of operator skills can be caused by operator work experience that is still less than five years and the lack of procurement of internal company training.
Figure 3. Fishbone Diagram Defect Incorrect Diameter Holes

- **Machine/tools:** the tools used are often damaged due to lack of checking tools that will be used before the assembly process is carried out. Tool damage can also be caused by the frequency of using a tool quite often because there are no other tools that can replace it to do the job.

- **Method:** errors that are often experienced are the results of working on parts that will be combined not in accordance with the design provided so that it must be reworked on that part or immediately discarded and replaced with new ones. This is related to the incorrect measurement method due to the lack of operator accuracy in the measurement process. In addition, the component working process can also be hampered if there is a tool to be used that is broken and there are no replacement tools that can be used.

- **Measurement:** the error is caused by the measurement scale of the measuring instrument which is not suitable and the lack of operator accuracy during the measurement process. The scale of measurement that is not appropriate indicates that the gauge has been damaged due to lack of regular checking of the gauge.

- **Environment:** a less supportive work environment can be seen from the lack of neatness of the work table or workstation. This can be caused by the number of tools and components scattered on the table.

4. **Conclusion**

- There are three biggest wastes that occur during the aircraft production process, namely waste defect, inventory, and motion. The results of the calculation of Waste Relationship Matrix (WRM) can be concluded that the waste defect has a considerable influence when compared to waste inventory and waste motion. If there is a waste defect during the production process, then the waste that most affected are waste motion and waste waiting. Classification of waste defects that have occurred in the sub assy component are incorrect drilling position, incorrect diameter holes, incorrect length, damage to components, and incorrect material. Based on the analysis of the Pareto diagram that has been made, the improvement must be focused on the type of defect that reaches 20% in the overall type of defect that occurs is the incorrect diameter holes.

- The causes of incorrect diameter hole type defects can be identified through the fishbone diagram tools. Based on the results of the fishbone diagram analysis, it was found that the most dominant factor occurred was the man factor. In man factors, the lack of operator accuracy in working on aircraft sub-assy components can lead to errors in workmanship. This can be caused by the operator's lack of concentration due to the large workload borne by the operator during
the production process. Workloads that accumulate can be caused by insufficient human resources in the production division of the Sub Assy All Programs. In addition, the skills possessed by the operator also affect the performance of the operator himself. The lack of operator skills can be caused by operator work experience that is still less than five years and the lack of procurement of company training.

5. References

[1] Amrina E and Lubis A A A 2017 Minimizing waste using lean manufacturing: a case in cement production Proceedings of 2017 4th International Conference on Industrial Engineering and Application (ICEA)

[2] Alfiansyah R and Nani K 2018 Jurnal Teknik ITS 7 165 – 170

[3] Ratlalan R M, Tama I P, dan Sugiono 2017 Penerapan lean manufacturing untuk meminimise waste pada proses perakitan plastic box 260 menggunakan metode VSM Proceeding of 2017: Seminar Nasional Multi Disiplin Ilmu & Call for Papers Unisbank

[4] Womack J P, Jones D J, and Roos D 1990 The machine that changed the world (New York: Rawson Associates)

[5] Khalil R A, Stockton D J, Tourki T, dan Mukhongo L M 2013 International Journal of Scientific & Engineering Research (IJISER) 4

[6] Saifuddoha A M, Habib M A, Sumi S Y, Jennurine M, and Islam M S 2013 IOSR Journal of Business and Management (IOSR-JBM) 9 79-84

[7] Henny H and Budiman H R 2018 Implementation lean manufacturing using Waste Assessment Model (WAM) in shoes company IOP Conference Series: Materials Science and Engineering 407

[8] Triyatna, Rakhendi dkk 2013 Perjalanan anak bangsa menguasai teknologi dirgantara (Bandung: PT. Dirgantara Indonesia (Persero))

[9] Rawabdeh I 2005 International Journal of Operations & Production Management 25 800-822

[10] Gaspersz V, 2011 Lean six sigma for manufacturing and service industries (Jakarta: PT Gramedia Pustaka Utama)

[11] Mostafa S and Dumrak J 2015 Waste Elimination for Manufacturing Sustainability (Adelaide: University of South Australia)

[12] Liker J K 2010 The Toyota Way (United States: McGraw-Hill Publication)

[13] Canel C, Rosen D, and Anderson E A 2000 Industrial Management dan Data System 100 51-60

[14] Tischler L 2006 Bringing lean to the office Quality Progress 39 32-38

[15] Wee H M and Wu S 2009 Supply Chain Management: An International Journal 14 335-341

[16] Bharadwaj V V S, Shashank P S, Harish M, and Garre P 2015 International Journal of Engineering Research and General Science 3 429-439

[17] Garre P, Bharadwaj V V S, Shashank P S, Harish M, and Dheeraj M S 2017 Applying lean in aerospace manufacturing materialstoday: Proceeding 8439-8446

[18] Chang H-M, Chikong H, and Torng C-C 2013 International Journal of Innovation, Management and Technology 4

[19] Nuruddin A W, Surachman, Setyanto N W, and Soenoko R 2013 Jurnal Rekayasa Mesin 4 147-156

[20] Ikatrinasari Z F and Haryanto E I 2014 Journal of Service Science and Management 7 291-301

[21] Juran J M 1994 Merancang mutu (Jakarta: PT. Pustaka Binaman Pressindo)