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Waste analysis of fuselage assembly in panelization group of the 117th NC212i aircraft

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A B S T R A C T

PT. Dirgantara Indonesia (PTDI) is the single source producer of the NC212i Aircraft. Almost every Aircraft is delivered to the customer over the deadline date. The existence of waste is believed to be one of causing the late delivery. Based on observations of the 117th NC212i Aircraft assembly line, which is precisely at the fuselage assembly in the paneling group, six wastes are identified: waiting, transportation, overprocessing, inventory, and motion. Waste of overproduction does not occur because PTDI applies MTO (Make to Order) system. These 6 wastes are then processed using Waste Assessment Model (WAM). The ranking result is: first place is 25% for defects, second place is 23% for waiting, third place is 17% for motion, fourth place is 15% for inventory, fifth place is 13% for transportation, sixth place is 8% for overprocessing, and seventh place is 0% for overproduction. Three critical wastes based Pareto principle can be minimized, so the delay of aircraft delivery can be reduced.

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1. INTRODUCTION

PT. Dirgantara Indonesia is one of the biggest aircraft industry in Asia, which means that Indonesia has been trusted by aerospace and the advancement of science and technology by other countries. According to PT. Dirgantara Indonesia website, in its collaboration with Airbus companies, PTDI produces civilian and military aircraft, one of the examples is the NC212i Aircraft in Fig 1. Word "N" comes from Nusantara (Indonesia) because PTDI is the single producer of the NC212 Aircraft. Number "21" means that NC212i has 21 or up to 28 seat capacity, and the last number "2" means that this Aircraft is set by two turbo-propellers [1]. This Aircraft is one of the Aircraft with the largest number of requests among other Aircraft.

With the increasing demand for NC212i Aircraft, PTDI is trying to increase productivity from the previous two Aircraft per year to 4 aircraft per year. In the NC212i fuselage assembly, a 3-month target cannot be fulfilled yet, where the new fuselage has been completely assembled and sent to the FA (Final Assembly) section within approximately 11 months. This delay was caused by the delay of the finish date on several panels from the initial target. The delay that occurs in the delivery of NC212i fuselage is suspected as a symptom of waste.

The fuselage is the main structure or body of an aircraft, and it can be seen in Fig 2. In its assembly, fuselage itself consists of several parts of groups such as fuselage provisioning, fuselage integration, fuselage union, center fuselage, lower panel center fuselage, upper panel center fuselage (FO), upper panel center fuselage (GO), skin panel rear fuselage LH, skin panel rear fuselage RH, upper panel rear fuselage, rear cone, nose fuselage union, nose lower panel structure, nose upper panel structure, and nose radome. In the 117th NC212i aircraft fuselage assembly, it was found that there were symptoms of waste, such as some defects that occurred, the job stop panel, pending material, and others.

Fig. 1. Civil NC212i aircraft

Fig. 2. Aircraft fuselage (orange part)

Waste is anything that has non added value. Waste is excessive beyond the minimum requirements for equipment, materials, components, places, and work time [2]. According to Ohno [3], waste includes eight types such as defect, overproduction, waiting, non-utilized talent transportation, inventory, motion, and extra processing. The waste consists of seven types, including overproduction, waiting, transportation, overprocessing, inventory, motion, and defect [4], [5]. Because the production process is still often found that there is waste that can inhibit the optimization of the production process, various methods are developed to create an ideal condition such as the absence of waste [6]. According to Ravizar and Rosihin [7], with the lean manufacturing approach, the waste can be reduced.

Lean manufacturing's goal is to advance an industry production system and satisfy the customer with the best quality that uses a minimal amount of energy [8]. Sanchez and Nagi [9] say that lean focuses on the use of resources productively. Lean methodology means to minimize NVA (Non-Value-Added) and change them into VA (Value Added) that concentrates on processes and all employees [10]. Critical types of waste, weighting, and ranking methods are used to find out which waste is the most dominant [11] The stages of identifying, weighing, and classification can be found in the Waste Assessment Model method.

Waste Assessment Model (WAM) is a model that can resolve and eliminate waste [12]. There are three steps in WAM: the Seven Waste Relationship (SWR), Waste Relationship Matrix (WRM), and Waste Assessment Questionnaire (WAQ). SWR is the initial identification stage of the lean problem that is identifying the waste that exists on the production line [13]. WRM is used to find the relationship between the seven wastes. WAQ is used to assess the types of waste that occurs and dominant while confirming the findings at the time of observation [14]. According to Mughni [15], Henny, and Budiman [16], the WAM method is accurate to identify waste. According to Utama et al. [17] and Sayyida et al. [18], the calculation result, such as waste ranks, is then identified using Pareto Diagram to find the critical wastes so they can be analyzed.

This study aims to minimize the waste that occurs in the production of the fuselage assembly line from NC212i based on the results of ranking with WAM. The ranking makes it easy to determine the improvement strategy to be carried out. The improvement results are expected to increase work effectiveness by eliminating the causes of seven wastes.

2. RESEARCH METHODS

The research was carried out for 30 days in the NC212i Aircraft assembly panelization group. Identification of the problem is made by interviewing and discussing with Lean Manufacturing Supervisors, NC212i Aircraft Assembly Board Supervisors, employees, and

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mechanics. The collection of flawed data and layout data aims to simplify and strengthen the identification of problems at the beginning of the study. Data defects are used to determine the effect of the issue. The data layout is used to analyze the airframe assembly flow process.

The identification phase is to decide what wastes occur in the 117th NC212i Aircraft's fuselage assembly on the panelization group. The identification phase of waste uses the lean manufacturing approach and seven waste. Its identification includes transportation, inventory, motion, waiting, overproduction, overprocessing, and defects.

The WAM method decides the waste rank that occurs as a basis for corrective steps. Processing data by recapitulating a questionnaire from the respondent regarding the waste that occurred. This questionnaire involved six persons from the NC212i aircraft assembly line, each from Engineering, Quality Assurance, Production Engineering, Kitting, Production Control, and Component Assembly departments. This assessment questionnaire consists of 65 different questions.

The WAM method has three steps in determining waste ranking, namely the Seven Waste Relationship (SWR), Waste Relationship Matrix (WRM), and Waste Assessment Questionnaire (WAQ) [12]. SWR describes the interrelated relationships between waste that occur. For example, waste that arises in inventory influences the likelihood of waste resulting in defects. Overproduction that occurs on the production floor can cause quality problems [19]. WRM as a measurement of the level of relationship between waste is displayed in rows and columns [16]. WRM and WAQ are questionnaire-based measurement models that require expert opinions to get maximum results [20]. The relationship results between waste are converted in the form of 1-20 values, which indicate the level of strength of the relationship waste (Table 1).

The WRM stage is conducting an interview process and discussion, which is involved the Supervisor of the Lean Manufacturing CA Section and the Supervisor of NC212i Aircraft fuselage assembly. Whereas in the WAQ stage, data processing of the waste analysis questionnaire recapitulation. The results of processing data with this method in the form of a percentage rating of each waste.

Table 1. Conversion range between waste

Range	Type of relationship	Symbol
17—20	Absolutely necessary	A
13—16	Especially important	E
9—12	Important	I
5—8	Ordinary closeness	O
1—4	Unimportant	U
0	No relationship	X

3. RESULTS AND DISCUSSION

The result of the Fuselage Assembly in Panelization Group of the 117th NC212i Aircraft research that contains waste identification and data processing using the Waste Assessment Model.

3.1 Seven waste relationship

Waste identification that occurs in the Fuselage Assembly in the Panelization Group of the 117th NC212i Aircraft process consists of seven wastes. Waste of transportation that occurs is the far distance between the painting area and assembly area, which is ± 500 meters. Besides, in Production Zone IV, there is only one kitting car for material transportation. This has led to a struggle over the use of kitting cars between one management and other management. As a result, painting time delays two until three days from the initial target time.

Waste of inventory was found with the presence of defect materials and damaged equipment, which are still in the production aisle area. In addition, there is no temporary or unique storage space for parts or panels that have been assembled, so that the part is placed on the inspection table and disturb the inspection process of many parts. Waste of motion occurs when the work process is carried out by several operant mechanics from other series aircraft assembly to pursue the lead time. The mechanics do some unnecessary repetitive movements because they not have to get used to assembly NC212i aircraft yet. Besides, due to the lack of a drilling machine, some mechanics have to move the drill position from the right side to the left or from one mechanic to another mechanic in one panel continuously to take turns.

In the 117th NC212i Aircraft fuselage assembly, waste waiting takes place in the form of mutual waiting between the mechanics in the use of a drilling machine. In the skin panel rear fuselage LH assembly, waste waiting is found in the way of a job stop caused by the material pending because the material has not been painted (painting material has not available yet in the painting section). Besides, the mechanics in the panel are passed to the other panel assembly process to pursue the completion target. PT. Dirgantara Indonesia sets MTO (Make to Order) system so that the quantity of Aircraft is according to the customer's order quantity. That's the reason why the waste of production does not occur.

This waste occurs when some defect materials are found, where over-processing such as rework and repair must be done. The activities categorized as overprocessing waste because they do not add the value of the product and do not need to be done if the materials are in good condition. In the fuselage assembly of the 117th NC212i Aircraft panelization section, there are still defect materials (rework and repair) and materials that cannot be used (scrap). Defects that occur cause a variety of rework or repairs, so delaying one or two days from the target.

Seven waste that occurs in the process of fuselage assembly of the 117th NC212i Aircraft has a mutually influential relationship. Measurement of the relationship between waste that occurs using criteria developed by Rawabdeh [12]. This criterion has a weight value of 0 to 4 with six questions. Words i and j mean the waste that can influence each other in every criteria (Table 2). The higher weight obtained, the greater the level of waste relationships that occur per the results of the opinion of experts.

Table 2. Criteria of interrelation between waste [12]

	i-j	Alphabet	Weight
1	*Does i cause j?*		
	Always	A	4
	Sometimes	b	2
	Rare	c	0
2	*What is the type of relationship between i and j?*		
	if i increases then j increase	a	2
	if i increases, j is at a constant level	b	1
	random, does not depend on the condition	c	0
3	*The impact of j that caused by i :*		
	can be seen directly and clearly	a	4
	need time to be seen	b	2
	can not be seen	c	0
4	*Eliminate the impact of i on j can be reached by :*		
	technical method	a	2
	simple and direct	b	1
	instruction solution	c	0
5	*The impact of j that caused by i can influence :*		
	product quality	a	1
	resource productivity	b	1
	lead time	c	1
	quality and productivity	d	2
	productivity and lead time	e	2
	quality and lead time	f	2
	quality, productivity, and lead time	g	4
6	*At what level does the impact i on j increase manufacturing lead time :*		
	high level	a	4
	medium level	b	2
	low level	c	0

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Table 3. Answer and scores of interrelation between waste

No.	Question Relation	1		2		3		4		5		6		Total Score	Relationship
		A	W	A	W	A	W	A	W	A	W	A	W		
1	I-D	c	1	c	0	c	0	C	0	a	1	c	0	2	U
2	I-M	c	1	c	0	c	0	C	0	b	1	c	0	2	U
3	I-T	c	1	c	0	c	0	B	1	b	1	c	0	3	U
4	D-I	b	2	a	2	a	4	A	2	b	1	b	2	13	E
5	D-M	b	2	a	2	a	4	A	2	e	2	a	4	16	E
6	D-T	b	2	a	2	a	4	A	2	e	2	c	0	12	I
7	D-W	a	4	a	2	a	4	C	0	e	2	a	4	16	E
8	M-I	c	1	b	1	c	0	A	2	b	1	c	0	5	O
9	M-D	c	1	b	1	c	0	C	0	a	1	c	0	3	U
10	M-P	b	2	a	2	b	2	C	0	b	1	c	0	7	O
11	M-W	b	2	a	2	b	2	C	0	b	1	c	0	7	O
12	T-I	c	1	c	0	c	0	B	1	b	1	c	0	3	U
13	T-D	c	1	c	0	c	0	B	1	a	1	c	0	3	U
14	T-M	c	1	a	2	c	0	B	1	b	1	c	0	5	O
15	T-W	a	4	a	2	a	4	B	1	c	1	a	4	16	E
16	P-I	c	1	c	0	b	2	C	0	b	1	c	0	4	U
17	P-D	c	1	b	1	c	0	C	0	a	1	c	0	3	U
18	P-M	c	1	a	2	c	0	A	2	b	1	c	0	6	O
19	P-W	c	1	a	2	c	0	B	1	b	1	c	0	5	O
20	W-I	a	4	a	2	a	4	A	2	c	1	a	4	17	A
21	W-D	c	1	b	1	c	0	A	2	a	1	c	0	5	0

Weight results based on the interview process, and discussion with the Supervisor of the Lean Manufacturing CA Section, and the Supervisor of NC212i Aircraft fuselage assembly is done for weighting every waste that occurs. The results of the second opinion of the Supervisor shows that W-I has the highest relationship weight (Table 3). The waiting process that occurs makes more goods accumulate in certain operations. This excess inventory will result in additional storage costs [21] and will reduce the level of quality of raw materials.

3.2 Waste relationship matrix

WRM is a matrix that describes the level of waste relations. The highest value is given to waste that affects the waste itself (Table 4). Values in the pattern will illustrate improving the waste relationship that occurs. The W-I relationship has an A, which indicates that both of these wastes have a strong and mutually influential relationship.

Table 4. Waste relationship matrix

F/T	O	I	D	M	T	P	W
O	X	X	X	X	X	X	X
I	X	A	U	U	U	X	X
D	X	E	A	E	I	X	E
M	X	O	U	A	X	O	O
T	X	U	U	O	A	X	E
P	X	U	U	O	X	A	O
W	X	A	O	X	X	X	A

The matrix is converted to a percentage. WRM is converted into numbers by reference A: 10; E: 8; I: 6; O: 4; U: 2 and X: 0. Waste Matrix Value results show that defects have the highest percentage (26%) in the fuselage assembly of the 117th NC212i Aircraft process. Defects that occur cause rework and slow down the production process. Other wastes have an effect of around 14% of defects (Table 5).

Table 5. Waste matrix value

F/T	O	I	D	M	T	P	W	Score	%
O	0	0	0	0	0	0	0	0	0%
I	0	10	2	2	2	0	0	16	11%
D	0	8	10	8	6	0	8	40	26%
M	0	4	2	10	0	4	4	24	16%
T	0	2	2	4	10	0	8	26	17%
P	0	2	2	4	0	10	4	22	14%
W	0	10	4	0	0	0	10	24	16%
Score	0	36	22	28	18	14	34		
%	0%	24%	14%	18%	12%	9%	22%		

3.3 Waste assessment questionnaire

WAQ aims to allocate waste based on 68 questions. In this study, waste overproduction does not occur. Three questions related to waste overproduction are eliminated, so the number of questions becomes 65 items. The value in Table 5 will use next in the waste assessment questionnaire calculation. For category A, the score is one if "Yes", 0.5 if "Medium", and 0 if "No. For category B, the score is 0 if" Yes ", 0.5 if" Medium ", and one if" No " Here the recapitulation of the questionnaire answers Questions are categorized into aspects of man, machine, material and method (Table 6).

The weight of each question is based on the waste relationship matrix is then inputted in Table 7. Each weight in a row is divided by the number of the grouped items (Ni). The sum of the scores for each column of waste (Sj) and frequency (Fj) from the appearance of the value in each waste column is calculated by ignoring the value of 0 (Table 8). The weight of the questionnaire (1; 0.5; or 0) is then inputted into each weight value by the multiplication system (Table 9).

Table 6. Recapitulation of the waste assessment questionnaire

No.	Question Type	Question category	Production engineering	Engineering liaison	Kitting	Production control	Quality inspection	Component assembly	Average
Category 1: *Man*									
1	To motion	B	0.5	0	1	0	1	0	0.42
2	From motion	B	0	1	0	0	0.5	0.5	0.33
3	From defects	B	0.5	0	0	0	1	0.5	0.33
4	From motion	B	0	0	0	0.5	0.5	0	0.17
5	From motion	B	0	0.5	0	0	0.5	0.5	0.25
6	From defects	B	0	0.5	0	0	1	0.5	0.33
7	From process	B	0.5	1	0	0.5	1	0.5	0.58
:	:	:	:	:	:	:	:	:	:
Category 4: *Method*									
65	From defects	B	0	0	0	0	0.5	0	0.08

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Table 7. Question weight based on waste relationship matrix

No	Question Aspect	Question Type	Initial Weight for Each Type of Waste						
			O	**I**	**D**	**M**	**T**	**P**	**W**
1	Man	To motion	0	2	8	10	4	4	0
2		From motion	0	4	2	10	0	4	4
3		From defects	0	8	10	8	6	0	8
4		From motion	0	4	2	10	0	4	4
5		From motion	0	4	2	10	0	4	4
6		From defects	0	8	10	8	6	0	8
7		From process	0	2	2	4	0	10	4
:	:	:	:	:	:	:	:	:	:
65	Method	From defects	0	8	10	8	6	0	8

Table 8. Weight divided results with Ni

No	Ni	Initial Weight for Each Type of Waste						
		Wo.k	**Wi.k**	**Wd.k**	**Wm.k**	**Wt.k**	**Wp.k**	**Ww.k**
1	9	0.00	0.22	0.89	1.11	0.44	0.44	0.00
2	11	0.00	0.36	0.18	0.91	0.00	0.36	0.36
3	8	0.00	0.89	1,11	0.89	0.67	0.00	0.89
4	11	0.00	0.44	0.22	1.11	0.00	0.44	0.44
5	11	0.00	0.36	0.18	0.91	0.00	0.36	0.36
6	8	0.00	1.00	1.25	1.00	0.75	0.00	1.00
7	7	0.00	0.29	0.29	0.57	0.00	1.43	0.57
:	:	:	:	:	:	:	:	:
65	8	0.00	1.00	1.25	1.00	0.75	0.00	1.00
	Sj	0.00	41.97	53.90	44.09	33.92	24.08	47.97
	Fj	0	60	65	54	39	36	47

Table 9. Multiplication weight results with WAQ recapitulation

No	Average	Initial weight for each type of waste						
		Wo.k	**Wi.k**	**Wd.k**	**Wm.k**	**Wt.k**	**Wp.k**	**Ww.k**
1	0.42	0.00	0.09	0.37	0.46	0.19	0.19	0.00
2	0.33	0.00	0.12	0.06	0.30	0.00	0.12	0.12
3	0.33	0.00	0.30	0.37	0.30	0.22	0.00	0.30
4	0.17	0.00	0.07	0.04	0.19	0.00	0.07	0.07
5	0.25	0.00	0.09	0.05	0.23	0.00	0.09	0.09
6	0.33	0.00	0.33	0.42	0.33	0.25	0.00	0.33
7	0.58	0.00	0.17	0.17	0.33	0.00	0.83	0.33
:	:	:	:	:	:	:	:	:
65	0.08	0.00	0.08	0.10	0.08	0.06	0.00	0.08
	Sj	0.00	15.86	21.69	16.35	13.01	8.95	18.74
	Fj	0	54	59	48	36	31	43

Table 10. The final result of the waste assessment model

	O	I	D	M	T	P	W
Score (Yj)	0.0000	0.3400	0.3653	0.3296	0.3541	0.3201	0.3574
Pj Factor	0.0000	0.0249	0.0381	0.0291	0.0203	0.0133	0.0353
Final Result	0.0000	0.0080	0.0140	0.0100	0.0070	0.0040	0.0130
Final Result (%)	0%	15%	25%	17%	13%	8%	23%
Ranking	7	4	1	3	5	6	2

Frequency (fj) aims to count the number of cells that have no value of 0. The answer value of questions sometimes does not show a relationship, so the value becomes 0, or the answer has a value of 0. Equation (1) is used to calculate the initial indicators for each waste (Yj). The final value of the waste factor (Yj final) is then calculated by putting the probability factor of influence between types of waste (Pj) based on the total "From" and "To" in WRM (equation 2)

$$Yj = sj\ Sj\ x\ fj\ Fj \quad (1)$$
$$Yj\ final = Yj\ x\ Pj \quad (2)$$

The final result of WAM (Table 10) defects has the most significant percentage cause of waste in the fuselage assembly of the 117th NC212i Aircraft process. The waste rank that has been prioritized using the WAM method then identified to find critical waste using the Pareto diagram (Fig. 3). The results shown by the Pareto Diagram above are that three of the highest types of waste that can be taken based on the 80/20 principle are defecting, waiting, and motion.

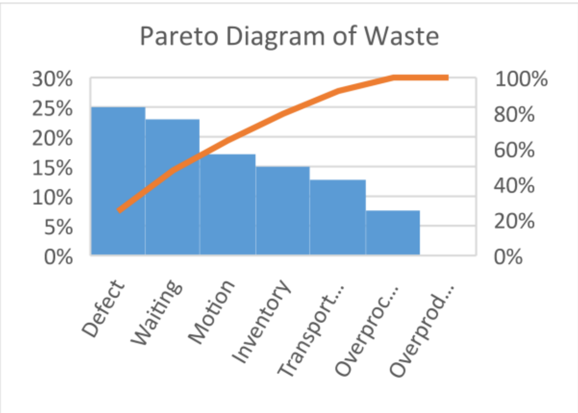

Fig. 3. Pareto diagram of waste

The waste defect has an effect of 25%. Defects that occur influence the needs of raw materials, workers, and production process time [22]. It requires rework that has an impact on workers' needs and processing time. The results of rework, sometimes the quality is not the same as products that do not experience the rework process. This rework process makes waiting for the next process.

Factors that cause defects are the unclear drawing part. This obscure drawing causing the size does not match what has been set. Besides, the pressure to complete the work affects worker overtime and creates a reduced level of accuracy. To keep the process going according to plan, the principle of Just in Time has a huge role in providing the right parts in each production process [23]. Errors such as unclear drawings can be minimized at the supervisory level so that pictures that have entered the production area are final drawings.

The waste is waiting for around 23% of WAM results. The limited number of mechanics caused the cessation of work on several panels. This happened because the mechanic was instructed to install another panel to pursue the target completion date. Another factor is the occurrence of defects that cause the time to wait for rework and repair. Besides, the waste of waiting is also caused by the workload imbalance in one panel with other panels that have an impact on some processes having to wait for other panels that have many operations for final integration. Waiting that occurs is also caused by delays in material supply from Detail Part Manufacturing (DPM) and the amount of equipment in assembly, for example, drilling machines. This causes the mechanic to have to wait to take turns using a drilling machine.

Waste motion is caused by mechanical motion originating from other types of Aircraft. The NC212i fuselage is different from their fuselage, so mechanics make unnecessary movements due to unusual assembly. Lack of

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numbers of machines makes mechanics have to take turns in using machines. This situation causes the mechanics to make unnecessary movements such as moving the machine from the other side to the side.

With the cause factors from each waste, the company can solve the problem accurately. The solution should involve every person in the fuselage assembly's management, especially the mechanics. Mechanics have the most important role because they are the direct executors of the product. The company should give the skill training or the routine training for mechanics every three months so their skills are qualified. Besides that, the company should increase the quality awareness so the most dominant waste, defect, can be minimized. If the three dominant scraps are solved immediately, PTDI can reduce the problem of Aircraft's late delivery and fulfill productivity.

Waste elimination has a considerable role in getting an effective production process. Defect in several studies contributed to the most significant waste in the production process [14], [24]. Implementation of lean manufacturing on an ongoing basis can reduce waste that occurs in achieving the zero-defect target [25]. This research is still from the perspective of experts, so it requires quantitative data to make implementation effective in the production process.

4. CONCLUSION

From this study, Based on the results of the research, it can be concluded that wastes that occur in the fuselage assembly of the 117th NC212i Aircraft panelization are the waste of transportation, waste of inventory, waste of motion, waste of waiting, waste of overprocessing, and waste of defects. Three critical wastes based Pareto principle include waste of defect, waste of waiting, and waste of motion. For further improvement, the defect problem can be resolved by using the six sigma method, and the problem of waiting and motion can be solved by using ECRS (Eliminate, Combine, Rearrange, Simpifly) method.

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