PYROLYZER PRODUCTION SYSTEM FOR WASTE MANAGEMENT USING GROUP TECHNOLOGY APPROACH

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Abstract

Waste management methods in Indonesia largely rely on unsustainable practices such as open dumping and landfills which urgently need transformation. Pyrolysis is one alternative solution for waste problems as it can process waste into other products. As the existing production system was not set up to manufacture this machine, we proposed a production system to produce a pyrolizer so that a more effective and efficient production process can be achieved. In this study, we employed Group Technology approach using Rank Order Clustering (ROC) method to create cell manufacturing groups. Based on our evaluation on the shortest material movement, we produced 2 different cells to manufacture the pyrolyzer. Cell, I contained plate cutting, drilling, pipe cutting, and bending machines (M2, M5, M3, M4), whilst Cell 2 contained rolling and lathe machines (M1, M6). It also contained main reactor, pyrolyzer reactor burner, middle condenser, upper access door, bottom access door, upper condenser, bottom condenser components (A, F, H, B, C, G, I). Out of the sixteen components to be made, seven components were in Cell I whereas the other nine were in Cell II (N, P, J, E, D, K , L, M, O) comprising burner case, access ladders, separators, firewalls, reactor base frames, condenser frames, gas piping, water piping, and sprinklers components. By applying this group technology method to the pyrolyzer production system, the production process could be carried out in a more efficient and organized manner.

Keywords: *group technology; rank order clustering; production system; waste management; pyrolysis machine*

1. Introduction

Indonesia is one of the largest plastic waste producers in the world. It is the second largest contributor of plastic waste to the ocean, after China. At least 16 percent of plastic waste in the oceans comes from Indonesia (Jambeck et al., 2015).On average there are around 182.7 billion plastic bags used in Indonesia each year (Making Oceans Plastic Free, 2017). Based on the data from Central Statistics Agency (BPS), Indonesia plastics waste reached 66 million tons in 2021 (Liputan6.com, 2021). Plastic is a versatile product, light, flexible, moisture resistant, strong, and relatively inexpensive. Because of the convenience they provide, plastic products are still widely used in the world. However, plastics in general cannot be recycled and they are not naturally biodegradable, thus causing waste and pollution issues, harming the ecosystem, and threating our oceans and wildlife.

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It is paramount to reduce the amount of plastic waste, so it does not have detrimental impacts on the environment. In Indonesia, waste management mostly uses open dumping and controlled landfill methods. Though simple, these methods are not environmentally friendly. Other methods such as incineration, composting, sorting, and recycle are not widely used. Only around 10% of plastic waste in Indonesia ends up in recycling centers and only 2% can be recycled effectively (ZeroWaste Center, 2021) Waste issues in Indonesia are worsened by the fact that the waste at source is not separated. An ample amount of waste is dumped directly into open dumping or landfills every day, causing excessive waste accumulation in the landfill. A number of landfills in Indonesia are on the verge of overcapacity. Several landfills have closed temporarily as they are full and cannot accommodate more waste coming in (Kompas.com, 2022; waste4change, 2019) There is an urgent need to shift waste management model from merely dumping and piling up to processing the waste. One potential alternative solution is use pyrolysis method for waste management in landfills in Indonesia. We proposed the manufacture of pyrolyzer which is a waste processing machine using pyrolysis method. The machine can convert plastic waste into oil which can be processed into other products. Pyrolysis is a material decomposition process at high temperatures that takes place in the absence of air or with limited air (Chhiti & Kemiha, 2013). The decomposition process in pyrolysis is also often referred to as devolatilization. The pyrolysis process produces products in the form of solid fuel, i.e., carbon, liquids in the form of a mixture of tar, and several other substances. Other products are gases in the form of carbon dioxide (CO_2), methane (CH_4), and several gases that contain small amounts. The results of pyrolysis are in the form of three types of products, namely solids (charcoal), gas, and liquid (bio-oil).

This study is a case-based study, focusing on, PT Hari Mukti Teknik (HMT), an industrial partner involved in machinery production. PT HMT is a company engaged in manufacturing machinery, especially industrial scale washing machines, as well as engineering research, one of which is designing and developing pyrolyzer machines. In the production process of pyrolyzer machines, there are various factors that affect company productivity, including the problem of production facilities and equipment layout. Currently, the facility layout at PT Hari Mukti Teknik is not suitable to produce pyrolysis machines. It is because the existing production system is a product layout that is focused to produce industrial scale washing machines and several other similar products (dryers, rollers, etc.). In the current layout, there are considerable distances between facilities within the production area, leading to extensive material handling during the production process. Several actions can be taken to increase productivity for the manufacture of pyrolyzer, including minimizing material handling costs and optimizing the layout of facilities. Therefore, we need to design the layout of production facilities and systems to obtain an effective and efficient condition that can support the production process of pyrolyzer machines.

Group Technology (GT) is a method applied in facility layout design that involves categorizing similar components into families. This allows for standardized processes, reduced material handling, shorter lead times, efficient resource use, and cost savings (Benitez, Da Silveira, & Fogliatto, 2019; Pérez-Gosende, Mula, & Díaz-Madroñero, 2021). GT-driven layouts enhance productivity and flexibility while improving quality control in manufacturing operations. This study employed the Rank Order Clustering (ROC) algorithm method which is a technique that falls under the umbrella of GT. The ROC focuses on the clustering of machines or components based on their similarities or dissimilarities. Facility layout design using the ROC method will produce manufacturing cell that groups machines and components in the production process into one group that has the same shape as well as the same processing process. This method It is expected that this grouping can have a positive impact on the production process system, namely increasing efficiency and productivity, one of which is because it reduces the value of components material handling in the production process.

1.1 Facility Layout

Facility layout can be defined as a procedure for setting up factory facilities to support the swift production process (Wignjosoebroto, 2009). Increasing productivity and cost efficiency can be achieved by facility layouts planning. Facilities must be properly managed so that they can achieve the goal of producing products or providing services at low cost, high quality, and using minimal resources (Rajagopalan & Heragu, 1997). Layout planning includes setting up the layout of operating facilities by utilizing the available area for placing machines, equipment for operations, and all equipment used in the operation process (Wahyudi, 2010).

Several types of facility (machine or equipment) layouts are as follows (Purnomo, 2004):

1) Product Layout
   Is a method of managing and placing all the necessary production facilities into a particular department. In this layout, machines or tools are arranged based on the process of a product. Products will move continuously in an assembly line.
2) Process Layout
   Is a method of managing all production facilities that have the same characteristics that will be grouped into the same department. In other words, the material is moved to the department in accordance with the order in which the process is carried out.
3) Group Technology Layout
   Is a layout based on the grouping of products or components to be made. This type of layout is usually used for components that are grouped based on the similarities in the shape of the components, machines, or equipment used.
4) Fixed Position Layout
   Based on this layout, the main product components will remain in the same position or location for facilities such as tools, machines, people, and other components moving towards the main product materials.

Facility layout has a lot of strategic impact because facility layout determines the competitiveness of the company in terms of capacity, process, flexibility, cost, quality of work environment, contact with customers and corporate image (Maheswari & Dany, 2015). Layout redesign can optimize operator workload (Tarigan, Tarigan, & Dalimunthe, 2017). According to

Apple (Apple, 1990) the purpose of designing a facility layout is as follows:

1) Simplify the manufacturing process.
2) Minimize material handling.
3) Maintain high work-in-process goods turnover.
4) Save the use of building space.
5) Increase the efficiency of the use of labor.

1.2 Group Technology

Group technology is a management philosophy that seeks to group products that have similar design or manufacturing characteristics or both (Assauri, 1980). In this case similar components are identified and grouped together to gain advantages in the manufacturing process and component design (Heragu, 2018). Group Technology (GT) is a philosophy in manufacturing that identifies and groups similar parts into part groups (part families) by taking advantage of similarities in terms of product design and fabrication processes in the manufacturing cycle (Tarigan et al., 2017).

That there are 2 methods that can be used in the group technology approach (Kusiak, 1990), namely:

1) Classification Method, this method is used to group parts based on their design characteristics.
2) Clustering Method, this approach can be used to group products into product groups and machines into machine cells. Grouping is done based on the similarity of the production process.

The group technology method has the goal of reducing material activity time, setup time, throughput time, in-process inventory, machine idle time and space requirements so that it can increase production efficiency.

1.3 Manufacturing Cell

Manufacturing cell is a new concept that has been successfully applied in many manufacturing environments and can achieve significant advantages (Assauri, 1980). Manufacturing cells aim to minimize the movement of parts between cells to reduce material handling costs by identifying machine cells and part families of their components.

There are two approaches known so far in applying group technology to form manufacturing cells (Fauizia, 2008), namely:

1) Clarification and coding approach
   Clarification and coding techniques used in manufacturing environments provide users to group parts easily based on attributes such as shape, dimensions, material composition, tolerances, and operating requirements. In particular, each part is given a 10-to-30-digit code to represent its different attributes. More than 75 systems have been created and used in the system.
2) Clustering approach
   The clustering approach tries to find and create simple clusters or groups in the input data matrix of objects or attribute objects. This technique attempts to rearrange the rows and columns of the input matrix to indicate whether a part is processed on the corresponding machine. There are several known clustering techniques, such as the use of the Similarity Coefficient (SC).
3) Production Flow Analysis
   Production Flow Analysis (PFA) also known as incidence matrix is a systematic procedure that analyzes information from the route of the part manufacturing process used to be able to identify part families. PFA displays information about the type of machine needed by each component during production activities in the form of a matrix.
   This PFA consists of inputs of 0 and 1, where (1) indicates that the part requires processing in a particular machine and (0) indicates that the machine is not used for processing the part in question (Singh, 1996). The PFA steps are as follows:
   a) List of all the parts created horizontally.
   b) List of all machines used to process the part created vertically.
   c) Enter the number 1 in the coordinates of the meeting between the part and the machine if the part in question is processed on that machine.

1.4 Rank Order Clustering

Rank Order Clustering (ROC) is an algorithm that classifies part-machines introduced by (King, 1980). ROC focuses on grouping machines or components to create manufacturing cells using evaluation criteria such as shortest material movement. ROC has the concept of forming diagonal blocks by re-allocating columns and rows of machine component matrices repeatedly which are expressed in binary values. This method is easier, more effective, and more efficient grouping of components compared to other cluster analysis methods. ROC is easy to design component groups (part families) and machine groups (machine cells)(Saragih, 2012).

The processing steps using the Rank Order Clustering method are as follows (Heragu, 2018):

1) For each row of the machine-part incidence matrix a binary weight is assigned, and the decimal equivalent (Wj) is calculated. For example, the component-machine relationship value for row 1 is 0 1 1 0 0 0, then the decimal equivalent value is $Wj = (0 \times 2^5) + (1 \times 2^4) + (1 \times 2^3) + (0 \times 2^2) + (0 \times 2^1) + (0 \times 2^0) = 24$
2) The row equivalent decimal values are sorted from the largest to the smallest order (decreasing order).
3) The matrix is transformed by changing the rows and columns.
4) The column equivalent decimal values are sorted from the largest order to the smallest (decreasing order).

Table 1. Machine Requirements

Code	Machine
M1	Rolling Machine
M2	Plate Cutting Machine
M3	Pipe Cutting Machine
M4	Bending Machine
M5	Drilling Machine
M6	Lathe Machine

Table 2. Part Requirements

Code	Machine
A	Main Reactor
B	Upper Access Door
C	Bottom Access Door
D	Reactor Base Frame
E	Firewall/Isolator
F	Pyrolyzer Reactor Burner
G	Upper Condencer
H	Middle Condencer
I	Bottom Condensor
J	Separator
K	Condensor Frame
L	Gas Piping
M	Water Piping

5) Note whether the ranking or order of the row and column decimal equivalent values is different. If yes, go to step 6. Otherwise, calculation stops.
6) Repeat steps 1 through 4 until the order or ranking of each element in the row and column is not different.

2. Methods

Research at PT Hari Mukti Teknik was carried out in the following steps:

2.1 Problem Identification

The first step was to identify the problems at PT HMT. Here, observation and evaluation were conducted to analyze existing facilities layout. This included gathering information on the production process at PT HMT.

2.2 Literature Review

This stage was conducted to find out the right research method in solving the problems found. Here, the method used to resolve the problem is the Rank Order Cluster (ROC) Algorithm. Literature review that has been done consisted of facility layout, types of facility layout design methods, Group Technology, Manufacturing Cell, Production Flow Analysis, and ROC.

2.3 Problem Solving Method

The method used for problem solving in this study is the Rank Order Cluster Algorithm (ROC). The ROC method is a facility or machine grouping method based on row and column sorting of the machine-part incidence matrix. Facility layout design using the ROC method will produce manufacturing cells that group machines and components in the production process into one group that has the same shape as well as the same processing process. This grouping can have a positive impact on the production process system, namely increasing efficiency and productivity, one of which is because it reduces the value of material handling components in the production process.

2.4 Data Collection

The data needed was observed and interviewed directly with PT HMT. Some of the data collected for this study included the Operation Process Chart (OPC), data of facilities and tools, and an overview of the existing layout.

2.5 Data Processing

The obtained data were processed and analyzed to produce a layout design of the new facility. Some of the data processing carried out included the following.

a) Data of machine and component requirement for the pyrolyzer machine production process.
b) Process Flow Analysis of Every Component.
c) Making Part-Machine Incidence Matrix.
d) Data Processing using ROC Method.
e) Analysis of Data Processing Results

3. Result and Discussion

3.1 Machine and Component Requirement Data

Data of machines (**Table 1**) and components requirements (**Table 2**) along with the details for building a pyrolyzer machine were obtained from the Operation Process Chart (OPC) of the pyrolyzer machine and the existing layout from PT HMT. OPC is used to determine the flow of material movement and the sequence of the production process from the beginning of the manufacturing process to the end as well as inspections at each manufacturing step. OPC also provides other information related to the production process including standard time, processing time, operating time, facilities used, and process information. Based on the existing layout, the flow of production process for the pyrolysis machine is illustrated in **Figure 1**.

3.2 Process Flow Analysis of Every Components

The production process flow for the manufacture of pyrolyzer was analyzed based on the existing OPC as shown in **Table 3**. The stages of the manufacturing process and the machine used by each part are shown in **Table 4.**

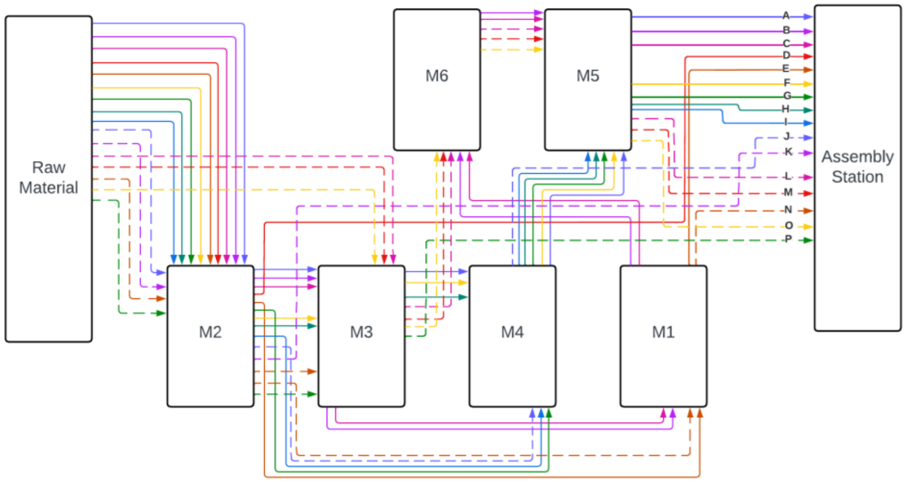

Figure 1. Flowchart of Initial Pyrolysis Machine Production Process

Table 1. Production Process Flow of Every Parts

Num	Parts	Process
A	Main Reactor	Plate cutting, pipe cutting, bending, drilling
B	Upper Access Door	Plate cutting, pipe cutting, rolling, turning, drilling
C	Bottom Access Door	Plate cutting, pipe cutting, rolling, turning, drilling
D	Reactor Base Frame	Plate cutting
E	Firewall/Isolator	Plate cutting, rolling
F	Pyrolyzer Reactor Burner	Plate cutting, pipe cutting, bending, drilling
G	Upper Condensor	Plate cutting, bending, drilling
H	Middle Condensor	Plate cutting, pipe cutting, bending, drilling
I	Bottom Condensor	Plate cutting, bending, drilling
J	Separator	Plate cutting, bending
K	Condensor Frame	Plate cutting
L	Gas Piping	Pipe cutting, drilling, bending
M	Water Piping	Pipe cutting, drilling, bending
N	Burner Case	Plate cutting, pipe cutting, rolling
O	Sprinkler	Pipe cutting, drilling, bending
P	Access Ladder	Plate cutting, pipe cutting

Table 2 Sequence of Machining Process of Pyrolyzer Machine Components

Num	Parts	Machining Process
A	Main Reactor	M2-M3-M4-M5
B	Upper Access Door	M2-M3-M1-M6-M5
C	Bottom Access Door	M2-M3-M1-M6-M5
D	Reactor Base Frame	M2
E	Firewall/Isolator	M2-M1
F	Pyrolyzer Reactor Burner	M2-M3-M4-M5
G	Upper Condensor	M2-M4-M5
H	Middle Condensor	M2-M3-M4-M5
I	Bottom Condensor	M2-M4-M5
J	Separator	M2-M4
K	Condensor Frame	M2
L	Gas Piping	M3-M6-M5
M	Water Piping	M3-M6-M5
N	Burner Case	M2-M3-M1
O	Sprinkler	M3-M6-M5
P	Access Ladder	M2-M3

Table 5 Part-Machine Incidence Matrix for Pyrolyzer Machine Manufacture

Machine	Part															
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**
M1		1	1		1									1		
M2	1	1	1	1	1	1	1	1	1	1	1			1		1
M3	1	1	1			1		1				1	1	1	1	1
M4	1					1	1	1	1	1						
M5	1	1	1			1	1	1	1			1	1		1	
M6		1	1									1	1		1	

Table 6. Weight Calculation (row)

Machine	Wj	Rank
M1	26628	5
M2	65509	1
M3	58655	3
M4	34752	4
M5	59290	2
M6	24602	6

Table 7. Weight Calculation (column)

Part	Wi	Rank
A	60	1
B	59	4
C	59	4
D	32	12
E	34	11
F	60	1
G	52	6
H	60	1
I	52	6
J	36	10
K	32	12
L	25	14
M	25	14
N	42	8
O	25	14
P	40	9

3.3 Making Part-Machine Incidence Matrix

Part-Machine Incidence Matrix is a matrix that describes the relationship between machines and components in a production process. If a component corresponds with a machine in its production process, then the matrix will have a value of 1. Conversely, if a component is not given any machining treatment by a machine, then the matrix will have a value of 0. **Table 5** shows The Part-Machine Incidence Matrix.

The value 1 in Table 5 indicates that the part (A, B, C, etc) is processed in the machine (M1, M2, M3, etc). For example, cell (M1, B) has value 1 since part B is processed by machine 1. Meanwhile, cell (M1, A) is empty since part A is not processed by machine 1.

3.4 Data Processing with ROC Method

In data processing using the ROC method, a Part-Machine Incidence Matrix was transformed so that the binary values form a group of machines and components. The data processing was done in several steps. The weighting process follows the rank order clustering (ROC) method to group the parts and machines by King (1980).

1) Weighting each row and calculating its decimal equivalent value as shown in **Table 6**.
2) Sorting the weight from the largest to the smallest order. The sequence of the machine in decreasing order was M2-M5-M3-M4-M1-M6.
3) Weighting each column and calculating its decimal equivalent values as shown in **Table 7**.
4) Sorting the column equivalent values from the largest order to the smallest. The rank obtained was A-F-H-B-C-G-I-N-P-J-E-D-K-L-M-O.
5) Recalculating the row and column equivalent values and resorting the values from largest to smallest. It was found that there was no change in the sequence

Table 8. Final Grouping

Machine	Part															
	A	**F**	**H**	**B**	**C**	**G**	**I**	**N**	**P**	**J**	**E**	**D**	**K**	**L**	**M**	**O**
M2	1	1	1	1	1	1	1	1	1	1	1	1	1			
M3	1	1	1	1	1	1	1							1	1	1
M4	1	1	1	1	1			1	1					1	1	1
M5	1	1	1			1	1			1						
M1				1	1			1			1					
M6				1	1									1	1	1

Table 9. Final Machine-Component Grouping Arrangement

Cell	Machine	Part
I	2, 5, 3, 4	A, F, H, C, G, I
II	1, 6	N, P, J, E, D, K, L, M, O

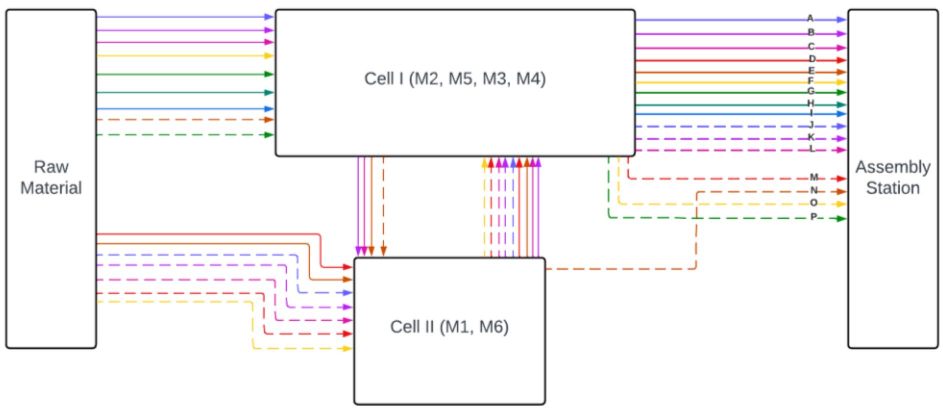

Figure 2. Flowchart of Pyrolysis Machine Production Process with Group Technology Approach

from before, so the calculation and data processing with the ROC method was completed.

3.5 Data Processing Analysis

Cells were formed to classify machines and components based on similarities in shape and machining processes. The final grouping can be seen in **Table 8** and **Table 9**. At the formation of the group, only two cells were made considering the economic feasibility of the company if it wanted to build facilities to produce pyrolyzer machines. The more cells that are formed means the nature of the existing cells is more specialist which also requires more machines in the production process so that it will increase the initial cost. On the other hand, the fewer cells that are formed means that the properties of the cells are more general, so that it can reduce the initial cost of building a pyrolyzer machine production plant.

Apart from that, in the formation of the cell, there are still several components that must be machined by tools or machines in different groups. To overcome this, the company can do two things:

1) Adding the machine needed by the components into the cell, but this means the company must spend extra to buy the machine.
2) Transferring components that require machining to other cells that have these machines, which means adding value to material handling in the production process.

By applying the group technology method to the pyrolyzer machine production system, the production process can be carried out in a more efficient and organized manner as illustrated in **Figure 2**.

4. Conclusion

This study has designed the production system to manufacture pyrolysis machines using group technology approach. The initial layout of the facilities at the shop floor was not designed to produce pyrolysis machines hence the process was not optimal. Machines and components with similar shapes and machining processes were grouped together to reduce the level of material handling in a production process. Cell manufacturing grouping using the ROC algorithm for the pyrolysis machine production process produced 2 different cells. Cell I contained plate cutting, drilling, pipe cutting, and bending machines (2, 5, 3, 4), and contains main reactor, pyrolyzer reactor burner, middle condenser, upper access door, bottom access door, upper condenser, bottom condenser components (A, F, H, B, C, G, I). Meanwhile, cell II contained rolling and lathe machines, as well as burner case, access ladders, separators, firewalls, reactor base frames, condenser frames, gas piping, water piping, and sprinklers components (N, P, J, E, D, K , L, M, O).

Implementation of the proposed method for the pyrolysis machine production system can improve the production flow. Thus, the production process can be carried out in a more efficient and organized manner.

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6. References

Apple, J. M. (1990). Tata Letak Pabrik dan Penanganan Bahan Terjemahan Nurhayati. *Mardiono, MT Bogor: Penerbit Institut Teknologi Bogor*.

Assauri, S. (1980). Manajemen Produksi. In *Manajemen Produksi. FEUI. Jakarta*. FEUI.

Benitez, G. B., Da Silveira, G. J. C., & Fogliatto, F. S. (2019). Layout planning in healthcare facilities: a systematic review. *HERD: Health Environments Research & Design Journal*, *12*(3), 31–44.

Chhiti, Y., & Kemiha, M. (2013). Thermal conversion of biomass, pyrolysis and gasification. *International Journal of Engineering and Science (IJES)*, *2*(3), 75–85.

Fauizia, E. N. (2008). Aplikasi Group Technology Dalam Perancangan Ulang Tata Letak Fasilitas Produksi Pada Pembuatan Mesin Plastik. *Simposium Nasional RAPI VII 2008*.

Heragu, S. S. (2018). *Facilities design*. Crc Press.

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., … Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science*, *347*(6223). https://doi.org/10.1126/science.1260352

King, J. R. (1980). Machine-component grouping in production flow analysis: An approach using a rank order clustering algorithm. *International Journal of Production Research*, *18*(2). https://doi.org/10.1080/00207548008919662

Kompas.com. (2022, October 28). TPA Piyungan Sempat Tutup, Antrean Gerobak Sampah di Kota Yogyakarta hingga Tepi Jalan . Retrieved January 1, 2023, from https://yogyakarta.kompas.com/read/2022/10/28/074738878/tpa-piyungan-sempat-tutup-antrean-gerobak-sampah-di-kota-yogyakarta?page=all

Kusiak, A. (1990). *Intelligent Manufacturing System*. New Jersey: Prentice-Hall.

Liputan6.com. (2021, November 9). Indonesia Produksi Limbah Plastik 66 Juta Ton per Tahun, Apa Solusinya? Retrieved January 1, 2023, from https://www.liputan6.com/bisnis/read/4706371/indonesia-produksi-limbah-plastik-66-juta-ton-per-tahun-apa-solusinya

Maheswari, H., & Dany, F. A. (2015). Evaluasi Tata Letak Fasilitas Produksi Untuk Meningkatkan Efisiensi Kerja Pada Pt. Nusa Multilaksana. *Jurnal Ilmiah Manajemen Dan Bisnis*, *1*(3).

Making Oceans Plastic Free. (2017, November 12). The Hidden Cost of Plastic Bag Use and Pollution in Indonesia. Retrieved January 1, 2023, from https://makingoceansplasticfree.com/hidden-cost-plastic-bag-use-pollution-indonesia/

Pérez-Gosende, P., Mula, J., & Díaz-Madroñero, M. (2021). Facility layout planning. An extended literature review. *International Journal of Production Research*, *59*(12), 3777–3816.

Purnomo, H. (2004). Perencanaan dan perancangan Fasilitas. *Yogyakarta: Graha Ilmu*.

Rajagopalan, S., & Heragu, S. S. (1997). Advances in discrete material handling system design. *Sadhana*, *22*(2). https://doi.org/10.1007/BF02744493

Saragih, M. H. (2012). *Perancangan Ulang Tataletak Fasilitas dengan Pendekatan Group Technology Berdasarkan Rank Order Clustering (ROC) dan Algoritma BLOCPLAN di PT. Apindowaja Ampuh Persada*.

Singh, N. (1996). *Cellular Manufacturing Systems: Design, Planning and Control*. London: Chapman and Hall Press.

Tarigan, U., Tarigan, U. P. P., & Dalimunthe, Z. A. (2017). Aplikasi Algoritma Block Plan dan ALDEP dalam Perancangan Ulang Tata Letak Fasilitas Produksi Pabrik Pengolahan Karet. *Seminar Nasional Teknik Industri [SNTI2017, September, 313–322*.

Wahyudi, E. S. (2010). *Perancangan ulang tata letak fasilitas produksi di cv. dimas rotan gatak sukoharjo*.

waste4change. (2019). Indonesia’s Waste Emergency: Indonesia’s Landfills are on the Verge of Overcapacity. Retrieved January 1, 2023, from https://waste4change.com/blog/indonesias-waste-emergency-indonesias-landfills-are-on-the-verge-of-overcapacity/

Wignjosoebroto, S. (2009). Tata letak pabrik dan pemindahan bahan. *Surabaya: Guna Widya*.

ZeroWaste Center. (2021, July 21). Plastics Waste Facts in Indonesia. Retrieved January 1, 2023, from https://zerowastecenter.org/plastics-waste-facts-in-indonesia/17678/