Integration lean manufacturing and 6R to reduce wood waste in furniture company toward circular economy

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Abstract. The furniture industry is suspected to have triggered global warming. The need for wood as raw material becomes a necessity for cutting down trees. The concept of a circular economy aims to reduce the use of natural resources by utilizing production waste or post-use product waste into raw materials. One strategy that can be used to support the circular economy is by implementing 6R. The application of 6R in a circular economic perspective on the furniture industry will be interesting to do. This study uses value stream mapping as a lean manufacturing analysis tool to identify furniture company waste. Value stream mapping is developed by integrating green manufacturing indicators such as material consumption and waste management. Practically, the furniture company can find out the map of production waste so that it can utilize waste as raw material for derivative products as an effort to reduce tree felling. Theoretically, this research will enrich the integration of green-value stream mapping toward the circular economy by implementing the 6R strategy in furniture companies. Reuse wood waste as a raw material for a variety of table products can reduce the amount of wood waste while reducing the resources of wood logs.

1. Introduction

Circular economy (CE) was first introduced by Ellen MacArthur Foundation [1]. In recent years, the concept of CE has gained significant momentum throughout the world. This concept improves the traditional concept of linear economy, which produces with the "take-make-dispose" model so that it is difficult to answer the challenges of sustainability which simultaneously requires sustainable economic growth, environmental protection, and social welfare [2]. The change from a linear economic model to a circular economy is beneficial for companies: cost efficiency, increased competitive advantage and reduction of negative environmental and community impacts [3]. The definition of CE itself is still being debated [4], but in general many associate it with a combination of reduce, reuse and recycle (3R) activities [5]. In addition to the 3R combination, CE also creates sustainable value that encourages economic growth, better environmental quality and social justice [4]-[6]. With resources steadily depleting at an alarming rate, the world is in serious trouble with its activities of meeting its never-ending needs through extraction, production, and consumption activities where most of the products end up in landfills (linear economy). The CE message is very strong because it is based on reducing resources through efforts to increase resource efficiency through reuse, reduce, recycle, recovery, redesign and remanufacturing [6R]. CE is no longer an option, but it is inevitable to continue economic prosperity and ecological and social balance [2]. Related to the urgency of implementing the CE concept, to date the study is still conceptual (6R). Only a few try to implement on certain commodities and are limited to the application of 3R [7]. Wood-based furniture is a sector that triggers global warming. Tree felling is considered to trigger environmental damage. This can be reduced by saving wood and utilizing its wood waste. Wood waste is a mass of wood that cannot be utilized at a stage of production. Wood waste can be distinguished based on the location of the occurrence of waste, namely waste from timber harvesting in the forest and wood processing waste that is in the industry. Timber harvesting waste is wood that is not brought from the forest because it is considered to be of no economic value by the company or the one that is cutting down. The types of wood waste in the form of non-commercial wood,
decorative wood with certain uses, round wood with a diameter of less than 30 cm without length limit and round wood with a length of less than two meters. Wood processing waste is wood waste that is not utilized in the form of sawdust, slabs, bark, pieces, shavings, off-cut of logs and wood dust. The sawmill waste was 50.8% and wood processing industry waste was 61.0%. Sawmill waste consists of sawdust (19.6%), slabs (25.9%), and cuts (14.3%). Wood processing industry waste consists of log cuts (5.6%), sawdust (0.7%), wet veneer waste (24.8%), dry veneer waste (12.6%), peeled residues (11.0%) and wood edge cutting (6.3%). This wood waste problem poses unique challenges to eliminate, reduce, or manage effectively. A satisfactory solution to these challenges calls for a systematic integrated approach to minimize wood waste to reduce its concomitant environmental impacts [8]. In the last decade, interest has been growing in utilizing this resource and millions of tons of solid wood waste are available for recycling into a myriad of products. Reuse in the wood waste brings not only important benefits in terms of material and energy savings but also avoidance of GHG emissions in the forest and landfill [9].

Wood waste identification must be carried out throughout the production process to be able to utilize waste using the 6R strategy. Lean manufacturing uses value stream mapping to identify 7 types of waste. Value stream map is a collection of all value-added activities and non-value added ones, ranging from raw materials to end customers, that involves information flows, materials flow, and decision-making flows [10]. The purpose of VSM is to identify value-added and non-value-added activities in a value streams so that non-value-added activities can be eliminated [11]. Integrating VSM and other concepts had been done to improve their capability. For example, VSM was combined with supply chain management [12]-[13], product development methodologies [14]-[15], agent-based systems [16]. Value stream mapping as a mean to evaluate the sustainability indicator was introduced by Simon and Mason. A number of studies have addressed the extension of VSM to incorporate additional criteria [17].

The study of the circular economy in the furniture industry has been carried out by previous researchers. There are investigate how much furniture companies know about Circular Economy practices, barriers and drivers of CE [18], the expansion of the circular economy by identifying the challenges and opportunities for a furniture cluster [19], design a business model for the furniture industry to address the circular economy concept using game theory [20], investigate the relationship between varying ESCC practices on the CE-targeted performances [21]. Empirical studies of the potential waste from the furniture production process and the challenges of utilizing the waste in a circular economy perspective are still rarely conducted. The Circular Economy, a new economic framework, can be combined with the 6R-based elements of sustainable manufacturing in order to relieve these challenges by establishing a closed-loop material flow [22]. This study aims to develop a framework that integrates value stream mapping with indicators that can identify potential waste throughout the production process while also involving the 6R strategy to realize a circular economy. By integrating 6R into VSM, activities that have the potential to reduce, reuse, recycle, recovery, redesign and remanufacture are more easily identified. To achieve this goal, this research will be carried out in stages. In the first stage, this research will develop a VSM that involves indicators of quality and material consumption. Potential defects that still occur in the production process lead to waste. Likewise with material consumption that is not optimal, the remaining material will potentially become waste. The next step is to identify the type of waste as the basis for the 6R design. Furthermore, the 6R design will be the basis for realizing a circular economy. Utilization of waste into products will benefit the company both in economic aspects (saving raw material purchases) and environmental aspects (reducing wood waste). Recycling of wood waste is beneficial in delaying and avoiding carbon emissions stored in trees [23]. To validate the applicability of the framework, a case study was conducted in a furniture firm.

2. Methodology
2.1. Circular Economy
Macarthur introduces the concept of circular economy (CE), derived from the term restorative industrial economy, which enables the effective flow of material, energy, labour, and information. Restorative means the flow of material can be returned again from the end consumer to the initial economic activity
Thus, it is possible to take corrective actions and reuse materials. Kirchherr, Reike and Hekkert [5] examines transparency regarding the latest understanding of the concept of circular economics. For this purpose, 114 definitions of circular economics have been collected. His findings are that circular economics is most often described as a combination of reduce, reuse, and recycle, but often the article does not highlight the importance of systemic changes in circular economy.

Genovese et al. [24] examines Sustainable Supply Chain Management and its role in Circular Economy. Case studies are carried out in various process industries (chemical and food), by comparing the performance of traditional and circular production systems across a range of indicators. This paper confirms that the integration of circular economic principles in sustainable supply chain management provides clear advantages from an environmental perspective. Need to study other industries to compare the benefits of using linear and circular economic practices.

Kalmykova, Sadagopan and Rosado provides an overview of the literature on Circular Economy (CE) strategies and analyse implementation cases. The findings are that the 3R strategy stands out in the manufacturing process [25]. Accordingly, Lewandowski examines the principles of waste design for reuse [26]. Manufacturers need to think of methods to make this happen, for example by recycling. Economically, CE practices make it possible to minimize the potential for material extraction from nature. Environmentally, CE practices will reduce waste emissions to nature. This is one way to solve the problem of scarcity of resources and environmental impact. Huang et al conducted an analysis of construction waste management through the 3R principle [27]. Management policies and situations are investigated and analysed based on the principles of reduction, reuse and recycling. Barriers to reuse of waste due to lack of guidelines for effective waste collection and sorting, lack of knowledge and standards for reuse of construction waste. Moktadir et al [28] state that knowledge of the circular economy is very important for implementing sustainable manufacturing practices in the Bangladesh leather industry [28]. This lesson will help managers of leather companies to formulate strategies so that the utilization of available resources can be optimal, and be able to do waste reduction in the context of a circular economy.

2.2. Extended-Value Stream Mapping to identify the Potential Waste

Faulkner and Badurdeen [29] and Brown et al [30] developed a methodology for Sus-VSM to capture the economic, environmental, and societal sustainability of manufacturing firms. They also identified suitable metrics and visual symbols to develop Sus-VSM and conducted a study at satellite television dishes manufacturing firm. Folinas, Aidonis, & Karayannakidis [31] explores the application of the VSM tool so as to determine the waste that has an environmental impact in a specific agri-food supply chain; the production of the canned peach. The main objective of this study is to propose a four-step approach for measuring the environmental performance of supply chains in the food sector based on Lean thinking techniques so as to identify sources of waste in the selected supply chain.

Hartini, Ciptomulyono, Anityasari, Sriyanto, & Pudjotomo [32] develop sustainable-VSM for wood furniture companies. Sustainable-VSM involves indicators of lead time, defects, inventory, material consumption, energy consumption, and level of risk. The defect and material consumption indicators in sustainable-VSM are able to identify that there is potential waste in the production process both from the material preparation stage to the packaging stage. Potential waste has not been linked to a strategy to create a circular economy.

2.3. Principles of 6R

The 6R methodology consists of reduce, reuse, recycle, recovery, redesign, and remanufacturing [22]. Reduce refers to subtraction use of resources in pre-manufacturing, including reduction of energy consumption, material consumption, and other resources during manufacture, and reduction of emissions and waste during the use phase. Reuse refers to the overall reuse of a product, or its components, for the next life cycle, to reduce the use of virgin material to produce new products and components. Recycle refers to the process of material conversion which should be considered waste, become new material or product. The process of collecting products at the end of the use stage,
disassembling, sorting, and cleaning for utilization at the next life cycle of this product is called Recovery. Redesign activity involves the next action to redesign generation products, which will use components, materials, and resources recovered from previous life cycles, or previous product generations. Remanufacturing involves reprocessing products that have been used for recovery to their product’s original state or form as new through reuse as much as possible parts possible without loss of functionality. The integration of lean and 6R concepts is implemented in a company to analyze its ability to reduce waste and natural resources toward a circular economy. Research Method is shown in Figure 1.

![Figure 1. Research method.](image)

Step 1 aims to evaluate the performance of the production process with green-VSM by measuring time efficiency, quality, energy, material consumption, and waste treatment. Table 1 shown some previous studies involving these indicators.

The score of the indicator is determined by using the concept of efficiency, which is the comparison between the use of the sources with added value towards the total use. The score of economic indicator is the reflection towards the efficiency of time and quality. The score of the environment indicator is reflection towards the efficiency of the use of material, energy, and waste management. The common formula of efficiency that will be used ratio between the use of resource and total resource. Detail of formula shown in Table 1.

The next step is to identify waste and the potential to reduce, reuse, recycle, recovery, redesign, and remanufacture. The identification results are used as the basis for making the 6R diagram. Next will be the design of the company collaboration toward a circular economy. To evaluate the integration of value stream mapping and the 6R concept in identifying waste and reducing waste in the perspective of a circular economy, a case study was developed at a furniture company.
Table 1. Lean and green indicators in value stream mapping.

|                      | Related-metric          | Measurement Method                          | Reference |
|----------------------|-------------------------|---------------------------------------------|-----------|
| **Lead time Efficiency (LTE)** | Value-added time during process (VAT) | LTE = VAT/TT | [29], [33], |
| **n : process on sawing, construction, assembly, finishing** | Non-value-added time (NVAT) | VAT = \[\sum_{i=1}^{n}(VAT_i)\] | [34], [35] |
|                      | Total time during process (TT) | NVAT = \[\sum_{i=1}^{n}(NVAT_i)\] |           |
|                      |                         | TT = VAT + NVAT |           |
| **Quality Level Efficiency (QL)** | Quality level (QL) | QL = 1 – ND/TP | [36] |
|                      | Number of defect (ND) |                           |           |
|                      | Total product/component (TP) |                         |           |
| **Material Efficiency (ME)** | Material efficiency (ME) | ME = TMU/TM | [34,37], |
|                      | Total material used (TMU) | TMU = \[\sum_{i=1}^{n}(TMU_i)\] | [38], [7] |
|                      | Total material (TM) |                          |           |
|                      | Product/material defect (MD) | TMU = TM - MD |           |
| **Energy Efficiency (EME)** | Energy efficiency during process (EE) | EE = VAE/ET | [34,37], |
|                      | Value added energy (VAE) | VAE = \[\sum_{i=1}^{n}(VAE_i)\] | [38], [7] |
|                      | Non-value added energy (NVA) | NVAE = \[\sum_{i=1}^{n}(NVAE_i)\] |           |
|                      | Energy total during process (ET) | ET = VAM + NVAM |           |
| **Waste Efficiency (WE)** | Number of waste to landfill/river (ML) | WE = 1 – WL/TW | [7] |
|                      | Total waste during process (TW) |                              |           |

2.4. Green-Value Stream Mapping

Case study was done at PT X, wooden furniture company in Semarang City, Indonesia. The manufacturing process can be characterized as Flow Shop, and it presents a high volume and low variety of products. The sequence of the manufacturing process is shown in Figure 2.

![Figure 2. Furniture manufacturing process.](image)

Raw material preparation is turning wood logs into boards. The construction process is forming the boards according to the product design. Assembly is the process of combining the various components. Finishing is the last process to finalize the product, e.g. smoothening of the wood surface. Quality control is done before packaging to ensure that products are in accord with the specifications. Green-VSM is shown in Figure 3.

The top management state that the performance of indicators is safe if the efficiency value has a value of more than 90 and is declared critical if below 65. The efficiency score that is between 60 – 90. A Green-VSM has been able to identify non-value-added activities that occur during the production process so inhibit company performance. The company has very low efficiency in the time indicators of raw material cutting (45.7%), quality indicators in the assembly process (37.5%) and finishing (0%), material consumption indicators in material preparation (46%) and waste recycling indicators (20%) in all activities. Low time efficiency in cutting material is caused by high waiting time, changeover time, and transportation time. Waiting time occurs because the operator does other work and the production area is not neat. Changeover time is high because of the many variations of components in one machine and the setup time is done by trial and error. Transportation time is high because it doesn't use material handling equipment. Un Ergonomic work posture causes the operator to get tired easily so the work completion takes longer.

Low-quality efficiency in the assembly and finishing process caused by hot room temperatures causes shrinkage of wood moisture so that the wood is bent, cutting is not precise, or wood fibers are not straight. Quality control is not carried out in every process so that the quality of materials that are not good can pass to the production department. The efficiency of material consumption is low at the
material preparation stage because of inappropriate product size tolerance, type of logwood coming from community forests with low quality, and too much wood cutting depth resulting in large waste and incorrect product size. Meanwhile, waste treatment is still limited.

2.5. Identification of Wood Waste in Furniture Company
The types of wood waste that occur in furniture companies that are case studies shown in Table 2. There are the sawdust, slabs, bark, wooden board, and pieces of wood.

Table 2. The types of wood waste in furniture companies.

| No. | Description | Type of waste |
|-----|-------------|---------------|
| 1   | Sawdust is wood waste obtained from sawing wood using both manual and machine sizes of about 0.25 mm - 2.00 mm. Sawdust which is left to rot, stacked, or burned will have a negative impact on the environment. Its lightweight in a dry state is easily blown away by the wind and can damage breathing. |
| 2   | Slabs are wood waste that is produced from the logwood breakdown process. A piece of wood has a width of 15-20 cm, thickness 1-3 cm, and a length of 3-4 cm. |
| 3   | The bark is wood waste that comes from the outer layer. The bark is very soft so it cannot be material for wood furniture. The bark is usually removed during the sawing process. The layer of wood adjacent to the bark is also discarded because of its soft texture and high water content so it is easy to shrink, brittle, and break easily. |
| 4   | The wooden board is damaged wooden boards that occur due to poor sawing processes, the quality of logs with many holes and cracks, or the quality of saw blades. The company should check the raw materials to be processed and check the cutting tools before use. |
| 5   | Pieces of wood produced from the process of reducing and cutting materials to get products that match the planned product. |
Figure 3. Green-value stream mapping of Furniture company.
3. Analysis and Discussion

3.1. Reducing wood furniture waste with the 6R strategy

The resulting Green-VSM is able to identify non-value added activities that occur in the furniture production process. Low-quality performance results in components/defect products. Low material consumption performance produces a lot of waste. If the company does not have good waste management, this waste will have a negative impact on the environment. To reduce the impact of wood waste on the environment, 6R strategies need to be developed. Some of the strategies implemented are explained in Table 3.

Basically, the 6R strategy can be applied to furniture suppliers, producers, and consumers. The 6R strategy in this furniture company can be grouped based on the 6R principles. The reduction activity is carried out with reducing the use of resources in the pre-manufacturing stage, by implementing a selective cutting system. Only cut down the right trees, the right amount, and reforest. Make saving using energy, materials and other resources during manufacturing, for example using glue and paint as needed, turning off the engine when not in use, turning off the water tap when not in use, reducing the use of fuel for kilns, reducing errors in cutting wood and others. Reducing emissions and waste by consumers by recovering products and not burning post-use products. Reuse is done by reusing waste to reduce the use of raw materials, for example using sawdust that is not utilized into board particles that can be processed into other products. Recycle converts waste into raw material for other products. Some furniture company waste recycling processes include utilizing the remnants of wood pieces into other products such as children's toys, assembly tables, and others.

Utilizing sawdust for briquettes, bricks, organic fertilizer, growing media, paving blocks. Recovery includes the process of collecting products at the end of the use, dismantling, sorting, and cleaning stages for utilization in the next life cycle of the product. Products that have expired in the hands of consumers can be recovered by making improvements either by furniture service services or by working with furniture manufacturers to make recovery. Redesign activities can be done by adding product variants by utilizing existing wood waste. For example using waste boards and pieces of wood into tables. Remanufacture involves reprocessing a product that has been used for recovery to the original state or form as new through reusing as many parts as possible without losing functionality. For example, companies do repair furniture products that are damaged by consumers rather than thrown away.

3.2. Reusing wood waste as raw material: a coffee table product

Waste in the company should be used as a variety of products so as not to have an impact on the environment. The product design tries to vary the table with raw materials from the company's waste. The product design was developed using the TRIZEE method. The TRIZEE design method was introduced by Issac Lim Sing Sheng and Teoh Kok-Soo [39]. The concept analysis takes a minimalist, multifunctional, and unity concept. The minimalist concept is used to get products that are easily made and require a faster process. The minimalist concept eliminates complicated details while still prioritizing space efficiency, quality, and function over quantity. The multifunctional concept is done by adding storage such as drawers, cabinets, and shelves. Furniture with a multifunctional concept is one aspect that must be present in product design. The concept of unity is used to bring together small blocks into a blockboard. These block boards are shaped like ordinary square boards that can be processed into furniture products like primary wood raw materials. The design and prototype of the product is shown in Figure 4.
Table 3. Input-output of furniture company and 6R strategy.

| Stage      | Process       | Input          | Product Output                      | Non-Product Output                                                                 |
|------------|---------------|----------------|-------------------------------------|----------------------------------------------------------------------------------|
| Pre-       | Manufacturing | Tree           | Log                                 | a. Pieces of wood log edges                                                       |
| Manufacturing | Logging      |                |                                     | a. Reuse (firewood)                                                              |
|            |               |                |                                     | b. Recycle (toys and tables)                                                      |
|            |               |                |                                     | c. Reuse (firewood)                                                              |
|            |               |                |                                     | d. Recycle (antique table)                                                       |
|            |               |                |                                     | e. Reuse (Animal feed)                                                           |
|            |               |                |                                     | f. Recycle (particle board, crafts, briquettes, organic fertilizer, mushroom growing |
|            |               |                |                                     | media, bricks and paving blocks)                                                  |
| Sawmills   | Drying in the | Beam and       | Log                                 | a. Sawdust                                                                        |
|            | kiln          | Board according to specifications |                                     | a. Recycle (particle board, crafts, briquettes, organic fertilizer, mushroom growing |
|            |               |                |                                     | b. Recycling (energy for kiln)                                                    |
|            |               | Beams and boards of appropriate size and moisture content | Emission                          | a. Recycle (particle board, crafts, briquettes, organic fertilizer, mushroom growing |
|            |               |                |                                     | b. Reuse (firewood, toys, table)                                                  |
| Construction |               | Beams and boards of appropriate size and moisture content | Component                         | a. Sawdust                                                                        |
|            |               |                |                                     | b. Piece of wood                                                                  |
| Assembly   |               | a. Component   | Product                             | a. Remaining glue                                                                 |
|            |               | b. Glue        |                                     | a. Reducing glue (become children's toys and table assemblies)                    |
|            |               |                |                                     | b. Recycle (become children's toys and table assemblies)                        |
| Finishing  |               | Product        | Finished Product                    | a. Sanding dust                                                                    |
|            |               |                |                                     | a. Reduce with air circulation                                                   |
|            |               |                |                                     | b. Dust machine                                                                    |
|            |               |                |                                     | c. Reducing paint waste                                                            |
|            |               |                |                                     | d. Reduce (reduce excessive spraying)                                             |
| Production | Packaging     | a. Finished product | Product is ready to delivery       | a. Remaining glue                                                                 |
|            |               | b. Glue        |                                     | a. Reduce (reuse for packaging)                                                   |
|            |               | c. Cardboard   |                                     | b. Reduce (reduce the use of excess staples)                                      |
|            |               | d. Staples     |                                     | c. Reuse (reuse for packaging)                                                    |
|            |               | e. Rope        |                                     |                                                                                   |
| Post-Use   | End of life   | broken furniture | furniture has been recovered        | a. Glue                                                                            |
|            |               |                |                                     | a. Reducing glue waste                                                             |
|            |               |                |                                     | b. Reducing paint waste                                                            |
|            |               |                |                                     | c. Reduce (reduce excessive spraying)                                             |
|            |               |                |                                     | d. Recycle (toys)                                                                 |

The efficiency of material consumption on sawmills is around 46%, with wood waste averaging 19.44 m³/month. Wood processing efficiency of around 49%. the company can make blocks with a size of 1200 x 600 x 30 as many as 89 pieces. It the tables made from the wood waste volume of about
1,116,304 mm³, so the production capacity of about 56 tables. And the waste that has been successfully reused is around 64 m³.

Figure 4. The design and prototype of the product.

4. Conclusion
VSM is able to identify the waste that occurs during the production process. By adding indicators from green manufacturing, Green-VSM is able to identify the efficiency of material consumption and the amount of waste that has been treated. Furniture companies that use logs as raw material have a potential waste of more than 50%. The quality of wood, cutting technology, and operator workmanship affect the amount of waste produced. However, wood waste can be reduced by implementing the 6R strategy. This research proves that wood waste can be reused as raw material for table products. This strategy is environmentally beneficial because it reduces wood waste and is economically beneficial because it saves the purchase of logwood. This confirms the statement
Jawahir et al [2] and Bradley [22] that the application of 6R in the perspective of a circular economy can reduce the use of resources. Although this research has detailed the types of wood waste produced by wood furniture companies and their potential uses, it is still limited in its implementation. This research is limited to using a strategy to reuse and redesign wood waste into coffee table products. Further research can be done by implementing other strategies, such as remanufacturing and recovery at the post-used stage. Research in other sectors will be interesting to study in order to realize the circular economy and efforts to reduce the use of natural resources.

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