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Relayout of oxygen filling area with seven waste method and green manufacturing analysis

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ABSTRACT

PT MM aims to enhance efficiency in filling oxygen gas and reduce transportation routes by employing forklifts. They have reconfigured the company's oxygen gas supply area by eliminating damaged machines and relocating the functional ones to a new area. The proposed solution for the company involves redesigning the layout of the laser cutting machine area and optimizing it using the seven-waste method. The re-layout procedure comprises three steps: analyzing the initial layout, designing alternative layouts based on Lean Manufacturing principles, and evaluating and selecting the best layout. The alternative layout results in improved material handling efficiency and reduced transportation distances. The outcomes of this redesign included the removal of the MCP storage area, which was replaced by a minibulk and a pipe installation that connects the minibulk to each laser cutting machine. By eliminating the 20-meter square MCP tube storage area, forklift mileage in the laser cutting machine area was significantly reduced. Overall, these changes led to a 30% reduction in costs, calculated from the difference between monthly rental costs and usage costs. This initiative supports green manufacturing by decreasing Nox emissions through reduced forklift usage.

1. Introduction

The COVID-19 pandemic has brought about significant changes in many daily behaviors and habits. Apart from its impact on the healthcare sector, various adjustments have been necessary in other fields as well. The manufacturing industry is one such sector that has felt the repercussions of this pandemic. There have been shifts in material requirements, including raw materials, support materials, and others. Some materials have experienced increased demand, while others have faced stockpiling issues. One critical item that has seen a significant surge in demand is oxygen gas, primarily due to the needs of COVID-19 patients for oxygen during the healing process [1]. This situation has had a notable impact on the manufacturing industry, particularly on those relying on oxygen gas as a key support material for their production processes.

PT MM, a company specializing in sheet metal fabrication and the production of heavy equipment components, primarily employs laser cutting machines. These machines depend on oxygen gas as a vital support material. During the COVID-19 pandemic, PT MM encountered difficulties in sourcing oxygen gas, as suppliers prioritized its delivery to hospitals rather than industrial facilities.

Problem-solving for this issue needs to be addressed through improvement efforts related to the procurement and inventory of goods. Large orders were placed during periods when demand from hospitals was decreasing, enabling the company to maintain its supplies and prevent shortages of oxygen gas. Changes in inventory capacity have, of course, affected the storage locations for oxygen gas. Before the pandemic, the company utilized cradles or MCP (Manifolded Cylinder Pallet) for storing and delivering oxygen gas to the laser cutting machines at the company [2].

MCP (Manifolded Cylinder Pallet) is a collection of 16 gas cylinders with a capacity of 100–105 liters, all interconnected, filled or emptied together, and loaded and unloaded as a single unit. Manifold Cylinder Pallets are used in applications or industries where high volumes of gas need to be continuously supplied at regular flow rates and pressures, without interruptions [2]. In such applications or industries, the use of individual gas cylinders can be highly undesirable due to the time wasted in cylinder changeover, cylinder

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handling, gas wastage, and other factors. Moreover, because gas must be supplied according to process requirements, single cylinders often prove impractical due to their limited gas storage capacity.

While MCP is an improvement over single cylinders, there are still several drawbacks associated with MCP. It requires a considerable amount of storage and operational space, which becomes more apparent during situations like the Covid-19 pandemic when there is a shortage of oxygen gas. To address this, companies must become more adept at managing their oxygen gas supply. One way to mitigate the scarcity of oxygen gas is to place larger orders when suppliers have ample oxygen stocks. However, if MCP systems are still in use, it would require even more space to store the increased number of MCPs. To ensure a reliable supply of oxygen gas, we propose transitioning from MCP to Minibulk systems with a 100-liter capacity. Table 1 shows the data for the loading and unloading process.

The transition from MCP to Minibulk was implemented to address the issue of oxygen gas availability and to optimize the storage layout for oxygen gas. Figure 1 illustrates the layout of the laser cutting machine area when MCP was used as the oxygen gas supply. The MCP storage area accommodates five laser cutting machines: A, B, C, D, and E. Receiving the MCP involves the operator accepting the delivery from the supplier and then transferring the MCP to the gas storage area using a forklift. Subsequently, the MCP is distributed to each laser cutting machine by forklift operators. The use of forklifts for transporting MCP requires an evaluation in terms of exhaust emissions, worker safety, and the space required for the forklift route. According to research conducted by Andrzej Ziolkowski, forklifts produce emissions, including NOx. Emissions of NOx during cargo transport averaged 30.06 g/km for indoor operation and 33.76 g/km for outdoor operation. On-road emissions averaged 55.2 g/km in indoor yards and 47.5 g/km in outdoor yards [3].

Observing this situation, the author suggests a series of enhancements within the laser cutting machine area. This includes transitioning from MCP to Minibulk for the supply of oxygen gas and incorporating pipelines to deliver oxygen to each laser cutting machine. This adjustment is anticipated to eliminate the need for forklifts in the laser cutting machine area, thereby reducing exhaust emissions, which aligns with the principles of green manufacturing [4], [5].

Table 1.
Initial condition for loading and unloading gas

No	Description	Condition
1	Loading time from supplier trucks	3 min
2	Delivery time to storage area	1 min
3	Manpower required	2 persons
4	Area of storage	20 m^2
5	Time of gas replacement	4 min
6	Forklift usage frequency	10x/day

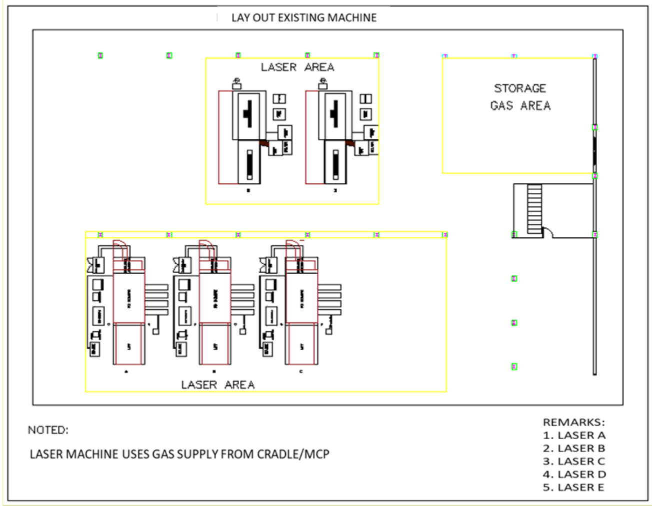

Figure 1. Layout with MCP storage

The aim of this research, aside from endorsing the green manufacturing initiative, is to create a more efficient layout design. This design provides additional space, enhances material handling efficiency, and reduces material handling costs by transitioning from MCP to Minibulk for oxygen gas supply [6]. The following image depicts a Minibulk unit, which will be situated outside the building, and illustrates the distribution of oxygen gas through the installation of pipelines connecting Minibulk to each laser cutting machine.

2. Material and method

This research commences with an examination of the background problems concerning the utilization of oxygen gas and tube storage facilities. Subsequently, a review of the relevant literature was conducted to identify methods that aligned with the encountered issues. In addition, on-site assessments were performed to gain firsthand insights into the situation. The literature review revealed that this issue could be addressed by implementing the seven waste method and conducting a green manufacturing analysis or adopting green industry practices. The process of reconfiguring the layout commenced with the vacating of the MCP tube storage area and was followed by the installation of pipelines to connect Minibulk to the laser cutting machines. The results were then subjected to a cost analysis to evaluate the efficiency of this layout reconfiguration and the transition from MCP tubes to Minibulk.

This research primarily addresses the redesign of the laser cutting machine area, adjustments to the current production systems and sequences, and the evaluation of the efficiency of the new layouts. A well-planned layout and streamlined processes are anticipated to lead to reduced production costs [7], [8].

2.1. Laser cutting machine

In the manufacturing industry, laser cutting is a frequently employed tool for cutting intricate parts of a product [9]. It operates by directing a high-power laser at the material to be cut, with computer programming controlling the process [10]. PT MM relies on laser cutting as its primary machine in production, as indicated by the number of available machines.

2.2. Gas and its use in laser cutting machine

Additional gases used in laser machines include nitrogen gas, compressed air, and oxygen. Different gases are utilized for cutting various materials based on factors such as the material thickness, pressure, and gas flow rate. Varied gas flows and pressures directly impact the effectiveness of laser cutting. The selection of gases for the laser cutting process plays a crucial role. [11].

Nitrogen, being an inert gas, serves to prevent oxidation and combustion at the cut tip, particularly when dealing with relatively thick plates. Its usage is ideal for products demanding high-quality surface finishes at the exposed cut ends, such as in certain decoration industries, aerospace applications, and the manufacturing of specialized parts.

Compressed air is well-suited for cutting aluminum, steel sheets, nonmetals, and galvanized materials. Under certain conditions, it can reduce oxidation and cost, particularly in cuts involving plates that are not excessively thick, where the final surface requirements are not stringent.

Oxygen primarily functions in combustion, accelerating cutting speeds. It is well-suited for thick plate cutting, high-speed operations, and ultra-thin plate cutting, particularly in applications involving carbon steel plates.

2.3. MCP and Minibulk in oxygen

Generally, the MCP (Manifolded Cylinder Pallet) and MINIBULK are crucial components of the system. The MCP, serving as a housing for both oxygen and nitrogen, comprises 15/16 tubes per unit, maintaining a pressure of 150 Bar with 99.6% purity. This MCP is equipped with a regulator serving as an indicator and hoses connected to the laser machine [12].

On the other hand, the MINIBULK is a high-pressure gas cylinder with a 1000-liter capacity. This cylinder significantly reduces the challenges associated with handling gas requirements and mitigates concerns stemming from lost or damaged cylinders.

2.4. Lean Manufacturing

Lean manufacturing is a process management philosophy rooted in the Toyota Production System (TPS). Renowned for its emphasis on eliminating seven types of waste, it aims to enhance overall consumer satisfaction [13], [14]. According to Monden, as mentioned in Taylor D. and Brunt D.'s book (2001), companies have three types of activities within the realm of internal manufacturing [15].

To enact significant changes within the operating system, it's crucial to eliminate waste from these operations, which can involve creating new layouts [16]. Here, the seven types of waste are outlined [13], [15].

Overproduction. Overporduction is characterized by excessive output, is a critical concern as it disrupts the balance between supply and demand. To maintain an optimal flow, emphasis is placed on providing excellent service in terms of quality and productivity. Overproduction or rapid production pace can result in detrimental consequences such as inventory buildup, extended lead times, inefficient information or material flow, and surplus inventory.

Waiting time. Waiting time represents unproductive and wasted time within a process, leading to conditions that are far from ideal and ultimately slowing down the production process. It stems from human inactivity or prolonged periods of inactivity regarding information or material, significantly impeding the smooth flow of both material and information, resulting in extended waiting periods.

Transportation. Transportation involves the movement of materials from one place to another, essential for their delivery. It's crucial to ensure that transportation does not involve unnecessary or excessive movement and aligns with its intended purpose. Delays in the transportation process can lead to losses, necessitating prompt repairs. While transportation cannot be eliminated, it can be minimized through two approaches: reducing distances between locations within and outside the company's supply chain and maximizing the efficient utilization of transportation facilities and infrastructure between these locations.

Improper process. Implementing *improper processes* or using the wrong set of procedures and equipment can significantly impact the entire production process. Such instances often arise when machines are damaged.

Useless inventory. Useless inventory not only increases lead times but also leads to higher storage costs.

Excessive movement. The lack of ergonomic workplace and equipment forces operators to work under conditions involving excessive movement. Such conditions lead operators to perform unnecessary movements while carrying out their duties, ultimately impacting their safety and adversely affecting both productivity and the quality of the output within the system.

Defect. Defects represent frequent errors in workmanship, issues related to product or service quality, and inefficiencies in product and service delivery. These occurrences signify that the resulting product quality does not meet expectations, necessitating rework and potentially leading to extended lead times.

2.5. Green Manufacturing

Green manufacturing denotes environmentally friendly manufacturing practices [17]. Ensuring the sustainability of manufacturing activities entails consistent focus on environmentally responsible performance and assessing the impact of the production process[18], [19]. Moreover, manufacturing company management is obligated to actively engage in and support green manufacturing initiatives, making it a pivotal element on the company's agenda [20].

3. Results and discussions

The research results are divided into three parts: firstly, the outcomes of the laser cutting machine area relayout; secondly, the analysis of the relayout using the seven types of waste; and finally, a comparative analysis of the costs associated with MCP and Minibulk usage.

3.1. Relayout and lean analysis

In the latest layout, adjustments were made by repositioning two machines to an adjacent building block and relocating the unused machine, thereby aligning the laser machine in a parallel setup. Additionally, the Minibulk is now placed outside the building, allowing the elimination of the $20m^2$ gas storage area within. This positioning also ensures the safety of the panel by maintaining a distance not less than 20 meters from the Minibulk tube and a maximum pipe distance of 30 meters. These considerations were meticulously considered to ensure safety in the delivery process to each laser cutting machine. The new layout is depicted in Fig. 2. Table 2 illustrates the impact of the layout changes, process modifications, and elimination of the Seven Wastes in lean manufacturing.

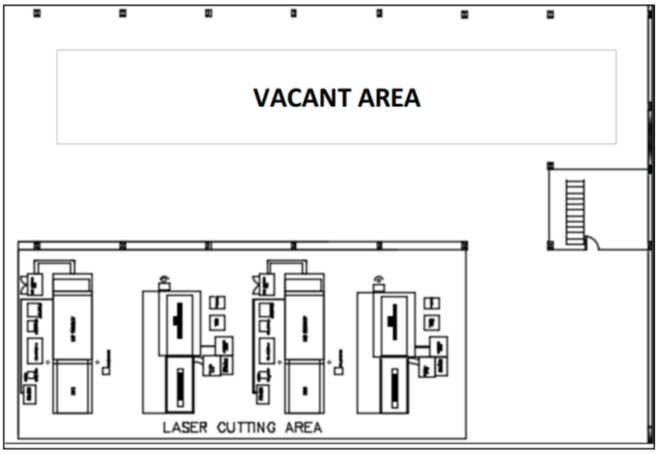

Figure 2. New laser machine area layout

Table 2.
Conditions by using Minibulk

No	Description	Condition
1	Oxygen gas charging time to *Minibulk*	15 min
2	Oxygen delivery time to storage area	-
3	Manpower required	-
4	Area of oxygen storage area	$45m^2$
5	Replacement time from storage to engine	- -
6	Duration of forklift used	-

Table 3.
Nox emmisions for transporting cargo

No	Activity	Mileage/day	Emissions/day
1	Inside buildings	2 km/day	60.06 g/day
2	Outside building	1 km/day	33.76 g/day

Referring to Table 2, this study focused on eliminating four out of the seven wastes, which include:

- Inventory: No need for storage as the gas is filled outside the building area.
- Transportation: Elimination of the use of forklifts as the tube positions are now fixed.
- Motion: Removal of the process involving mounting and tightening the regulator bolt to the MCP.
- Waiting: Unlike the previous setup where the engine had to be turned off to replace the Oxygen gas when using MCP, the engine remains charging ON.

3.2. Cost analysis

To assess and communicate the cost comparison between replacing MCP with Minibulk, it's crucial to involve management support for this change. The initial consideration involves the contract terms for Minibulk usage, inclusive of pipe installation connecting Minibulk to each laser cutting machine. The price analysis considers consistent monthly usage; for instance, with a gas consumption of 2400 m^3 per month, using either cradles or MCP amounting to 24 MCPs, each with a volume of 100 m^3.

When utilizing Minibulk with the same 2400 m^3 volume, a cost-saving of 30% is achieved. Detailed information is provided in Table 3. Table 3 illustrates a notable variance between MCP and Minibulk usage in a month, amounting to IDR 6,840,000,-. However, factoring in the Minibulk rental fee of IDR 1,500,000,-, the net difference becomes IDR 5,840,000,-, approximately 30%.

3.3. Green Manufacturing analysis

According to research conducted by Andrzej Ziolkowski, forklifts produce Nox as one of their exhaust emissions. During load transportation, the average NOx emissions measure 30.06 g/km inside warehouses and 33.76 g/km outdoors. Meanwhile, on-road emissions average 55.2 g/km in indoor yards and 47.5 g/km in outdoor yards [3].

As part of the company's efforts to reduce Nox emissions, minimizing the use of forklifts for MCP transportation has been implemented [5], [21]. Table 3 shows the emmisions of NOx for transporting the cargo inside and outside buildings. Table 3 demonstrates a reduction in daily Nox emissions, decreasing from 60.06g/day to 33.76g/day as a result of transitioning from MCP tubes to Minibulk, thereby reducing the reliance on forklifts.

4. Conclusions

MCP and Minibulk serve as oxygen gas filling systems compatible with laser cutting machines, each carrying its own set of advantages and disadvantages. Users can tailor their choice based on agreements between the gas supplier and the company. Through field knowledge and direct observations, it becomes evident that Minibulk proves more advantageous than MCP in terms of functionality and efficiency. Its utilization yields approximately 30% higher profitability for the company compared to MCP.

Furthermore, the reorganization implemented, utilizing the seven-waste method and eliminating the MCP storage area, has freed up space within the laser cutting machine area. The absence of forklifts in this area contributes to reduced exhaust emissions within the factory premises. Undoubtedly, this initiative has positively impacted the environment and enhanced the health and safety of the company's employees. Considering the Minibulk's connection to the production area with its interconnected pipes prone to potential leakage, daily checks on components like naple drat or hose connections via hose clamps are prioritized to promptly identify any leaks.

Further research could focus on establishing a maintenance system for Minibulk to ensure its durability without incurring high costs.

Declaration statement

Ayu Nurul Haryudiniarti: **Conceptualization, Methodology, Supervision, Writing – original draft.** Samsudin: **Resources, Validation, Formal Analysis, Writing - Review & Editing**. Sinta Restuasih: **Data curation, Validation, Writing - Review & Editing**.

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Disclosure statement

The authors report there are no competing interests to declare.

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Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article or its supplementary materials.

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