LEARNING LEAN WITH LEGO

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40.012 Manufacturing and Service Operations

Group 4

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ID	Name
1006617	Michael Hoon Yong Hau
1006651	Wong Qi Yuan Kenneth
1007492	Nathan Ansel
1006615	Lim Kyu Ha

SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN

Engineering Systems and Design

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Abstract

The "Lean Lego" Workshop offers an engaging, hands-on introduction to mass production, lean manufacturing, and cellular manufacturing. Participants experienced how mass production leads to inefficiency, while lean manufacturing, using *kanban*, reduces waste. Cellular manufacturing further enhances efficiency by organizing production into self-contained units. This report documents our group's learning process and reflections throughout the Lean Lego Workshop. By explaining and evaluating the processes in the educational game "Lean Lego", key characteristics of the Lean philosophy were compared to traditional assembly line manufacturing processes, with insights detailing the pros and cons of both production systems. This report is also corroborated with existing literature regarding these production systems, and the "Lean Lego" game as an educational tool to engage students in learning the lean philosophy through a hands-on approach. We noted that this is more pedagogically effective compared to traditional teaching methods. Finally, this report gives further recommendations on how the workshop can be improved.

Keywords: Lean Process, Lean Lego, Educational Game, Production Systems

1 Introduction

Learning through hands-on activities is always fun. The Lean Lego Workshop provided us with an intriguing experience that helped us to understand and visualise the different systems of production in a manufacturing plant. Namely, there are the three systems of mass production, lean manufacturing and cellular manufacturing. Lean manufacturing has been widely adopted since the Japanese industry, led by Toyota, reached the top of the automotive industry. Companies today still see the lean manufacturing philosophy as a way to remain competitive in the market [1].

In order to understand these three systems of mass production, the workshop was split into three main parts, showcasing each production system in action. These three parts include the traditional mass production, the lean manufacturing that introduces the concept of the *kanban*, and the cellular manufacturing that is another alternative system. More details about how the Lean Lego workshop enriched our understanding of these systems will be provided in sections 2, 3, 4, and 6.

1.1 Literature Review

According to an article written by Maria Macietova [2] that aims to discern the difference between mass and lean production, the main idea behind mass production is simply to manufacture the **most number of products per lot**, whereas lean production focuses on producing as **per the latest market demand**, with an emphasis on **reducing waste** which is difficult to achieve under a mass production system.

More simply, mass production is **supply-oriented**, and it is a "push" system which "pushes" products into the market, while lean production **demand-oriented**, and it is a "pull" system which allows customers to pull the products based on market demand. Out of the seven types of waste identified in the article, there are three main ones of importance:

1. **Overproduction** - the production of goods that are in excess of customer requirements.
2. **Inventory** - the holding and purchasing of unnecessary raw materials, work-in-progress (WIP), and finished goods.
3. **Motion** - actions of people that do not add value to the product.

It is evident that the lean production system is superior to the mass production system, as it aims to reduce waste, and ultimately allows the producer to operate at a lower cost. Our experience at the workshop validates this claim, where we experienced firsthand how impactful a production system put in place can be in the organisation and efficiency of an assembly line.

Cellular production provides an alternative production system, where the different processes of an assembly line is instead combined into a single manufacturing cell. It is a subset of lean production systems, as its aim is also to reduce waste and increase efficiency in production. However, due to the complexity of determining the optimal allocation of resources such as deciding the right number of machines and workers in each cell, there are many mathematical models developed that aims to solve this by classifying the cellular production problem as either a binary or comprehensive problem. One such model was developed by Raminfar et al., which integrates production planning and cell formation in the optimal cell production system problem [3].

The basic concepts of these systems will be more clearly shown in the summary and review of our experiences during the Lean Lego workshop, in the next few sections.

2 Part 1: Mass Production

In the first part of the workshop, the class was divided into two teams (i.e. assembly lines), that produces houses made up of 16 specific Lego bricks. There was a requirement to build the house, using Lego pieces of the same colour. Each team was further split into four groups, which represent different stages of the assembly line. The four groups are:

1. **(Group A)** Stocking the warehouse: This group mainly takes pieces out from a box and passes it on to the next group.
2. **(Group B)** Colour Sorting: This group sorts the Lego pieces by colour before moving it to the next group.
3. **(Group C)** Shape Sorting: This group further sorts the Lego pieces into groups of 16 pieces of specific shapes that are required to build the house, before passing it over to the last group
4. **(Group D)** Builders: This group builds the house and stores it in the finished inventory.

The goal of the two teams is to make the most profit, where we only take into account the revenue earned by selling the houses and the inventory holding costs incurred. For each house sold, the team earns $25 in revenue and each piece of Lego stored as inventory along any part of the assembly line incurs a holding cost of $1. There were 5 rounds of 60 seconds each, where the teams would carry out their respective tasks and at the end of each round, the revenue and inventory costs were calculated. Although this model is an oversimplification of an actual assembly line, it is sufficient for us to understand the concept of the 'push' system.

During these 5 rounds, due to their tasks being a lot easier, earlier groups tended to push many bricks over to the next groups without considering the situation of the later groups. Table 1 below displays the inventory levels of each group in our team across all days.

Day/Group	Group A	Group B	Group C	Group D
Day 1	150	177	100	32
Day 2	105	128	200	44
Day 3	61	175	300	28
Day 4	0	150	450	56
Day 5	0	183	600	40

Table 1: Inventory levels of Mass Production

It can be seen that Group A's inventory level decreased, to the point where they exhausted all of their inventory. On the other extreme, Group C struggled with their task in sorting the Lego pieces by shape and ended up with excessive inventory. Groups B's and D's inventory levels maintained a steady level, albeit with random fluctuations. While we are uncertain of the exact inventory levels of the other team, we observed that they also faced a similar situation of inventory stockpiling somewhere in the middle of the assembly line. Managing and balancing inventory levels for all groups were observed to be hard to do in this system, as the groups 'pushed' their output as soon as they finished their task. The unequal time taken for each task thus led to a huge imbalance in the inventory levels after 5 rounds. Without looking ahead of their own task, Group A pushed all the pieces it could, leading to Group C's excess inventory, which actually slowed down the process of sorting the pieces as there were too many pieces on the table.

Day	Sales	Cost	Profit
Day 1	25	459	-434
Day 2	25	477	-452
Day 3	25	564	-539
Day 4	25	656	-631
Day 5	25	823	-798
Total	125	2979	-2854

Table 2: Sales, Cost and Profits of Mass Production

Table 2 shows the sales, cost and profit made by our team during these 5 rounds. It is observed that our team is struggling financially and possibly on the brink of filing for bankruptcy, with a loss of 2854 dollars. As the rounds progresses, the inventory costs increased at an increasing rate, while production of houses remained constant at 1 per round. This system has proven to be unsustainable, with the team incurring more and more losses per round.

Through this, we learnt that the 'push' system, if left unregulated, could lead to adverse consequences due to a lack of communication and a mismanagement of inventory handling.

3 Part 2: Lean Production

In the second part of the workshop, the groups in the team remained the same, but we were instructed to only progress through the assembly line whenever the group after us requested for the Lego pieces. This is similar to the concept of the *kanban*, that is commonplace in many industries today that follows a lean production system. Furthermore, the duration of each round was reduced from 60 to 30 seconds, reducing the production time per day by half. Throughout the 5 rounds, our team was less chaotic and more well organised, where the order was delivered only upon request of subsequent groups. It was interesting to note that there was a lot of idle time doing nothing, as many team members end up not having to do anything as they anticipated for demand.

While instructed to supply only on demand, the team as a whole did not execute this perfectly, as some team members were overzealous and supplied more than what the group after them asked for. However, we did use the kanban concept for the most part, avoiding the mindless pushing of Lego pieces when no one is asking for it.

Day/Group	**Group A**	**Group B**	**Group C**	**Group D**
Day 1	150	100	64	64
Day 2	150	84	48	64
Day 3	134	84	64	64
Day 4	134	68	64	64
Day 5	118	54	80	64

Table 3: Inventory levels of Lean Production

Table 3 shows the inventory levels of our team throughout the 5 rounds in the lean production system. As seen, the inventory levels of every group is more stable, and inventory costs thus do not increase as each round progresses.

Day	**Sales**	**Cost**	**Profit**
Day 1	25	378	-353
Day 2	25	364	-339
Day 3	25	346	-321
Day 4	25	330	-305
Day 5	25	316	-291
Total	125	1734	-1609

Table 4: Sales, Cost and Profits of Lean Production

As seen in the above table, although the profits are still in the negatives, the inventory costs incurred are decreasing after each round, which is a huge difference as compared to the mass production system. After implementing the lean production system, our team was able to self-correct our inventory levels, albeit at a very gradual pace. Furthermore, we were able to produce the same output of 1 house per round despite being given lesser time. This increase of efficiency could be attributed to the better organisation of pieces, where lesser pieces on the table made it easier to sort and build the houses.

If we could redo this round, we could have identified that there were excess inventory right from the start, and ensure that Group A took lesser Lego pieces from the warehouse at the start to reduce the inventory costs. Nevertheless, this system being self-correcting means that if we were given enough rounds, we would have been able to make a positive profit eventually.

4 Part 3: Cellular Production

In the third part of the workshop, group members from all 4 teams were divided equally and reformed into more groups, where each group had 4 to 5 members, coming from each of the groups from the last two production systems. This was mainly to emulate the way that different processes and workers' skill set combine to form cell groups that have the capability to produce the finished product starting from the input resources, independently from other cell groups.

After getting into our groups, we were given some time to discuss our strategy on how to produce the most houses. A total of 3 minutes were given to every cell group, to see which group can produce the most number of single-coloured Lego houses. Our group chose to have one person dedicated to sorting the pieces by colour, while the other 3 built the Lego houses. Since there was no need to have someone get the pieces from the warehouse, and we felt that sorting the pieces by shape was unnecessary and inefficient, we converted the members that came from Groups A and C to be builders as well.

During the 3 minutes, we noticed a significant increase in our productivity levels. By merely utilising 4 workers, we managed to produce 6 houses—more than what the push and pull systems previously produced using 20 workers. This surge in productivity was thanks to the significant reduction of worker idle times. Whereas the push and pull systems had 3 brick sorters for every builder, in our cellular system, there was only 1 brick sorter for 3 builders and no worker was idle at any point of the production. In the push system, brick sorters experienced little idle time but hoarded a lot of inventory. In the pull system, brick sorters minimised inventory by anticipating for demand but were otherwise mostly idle. However, in the cellular system, both worker idle time and inventory were minimised thanks to our worker reorganisation strategy. The 3 builders ensured that the only brick sorter in our group was constantly at work, experiencing little idle time and always contributing meaningfully to the production.

Furthermore, by implementing a cellular system, we integrated all necessary tasks within a single cell, thereby reducing the time lost in transferring items between stages. This streamlined approach not only allowed us to produce more Lego houses within the given time, but also reduces the amount of unnecessary worker movement. Indeed, a hurdle faced by brick sorters in the push and pull system was moving the bricks from one phase of the assembly line to another. Communication was also largely enhanced as workers worked at a closer distance with each other.

Could we have done better?

Our cell required a large number of builders, most of whom were unfamiliar with building Lego houses prior to the start of production. One way we could have done better was to facilitate better training for our junior builders. Michael, our senior builder, could have provided a crash course for Nathan and Kyu Ha so that both of them would be better prepared to overcome the learning curve. Instead, both Nathan and Kyu Ha had to self-learn building Lego Houses, a process which took them about a minute to fully complete.

Indeed, this precisely illustrates one of the challenges faced when implementing a cellular manufacturing system. While each cell forms a highly independent, compact production unit, it is neither the simplest nor cheapest production system to set up. Designing an efficient cellular layout requires thorough analysis and planning. Thus, ensuring that each cell is optimally arranged for maximum efficiency can be complex and time-consuming. Transitioning from the pull system to the cellular system also required a layout shift, a process which would have been a hurdle if not for the assistance of the well-experienced ESD staff.

Another aspect of improvement for our group would be to follow instructions with more caution and discipline. Throughout the way, both Michael and Nathan deviated from the original Lego house design, building Lego houses of unique shapes and colors. While this contributed to an increase in our production levels, it meant that our cell deviated from the instructions given by the higher authorities.

5 Discussion/Benefit Analysis

All three systems discussed above have their own advantages and disadvantages. Whereas a system might work well in a specific scenario, it may work poorly in other situations.

Some major advantages to the push system include (1) economies of scale, (2) high production output, and (3) predictable production schedules. The push system is also very simple to implement relative to the other systems. However, the push system involves high inventory costs; is unable to adjust production quickly in response to changes in demand, leading to potential overproduction or stock outs; and can lead to quality issues as the system focuses on quantity over quality.

The pull system was better than the push system in terms of minimising inventory. The system produces goods only as they are needed, minimising inventory levels and associated costs. It is also capable of quickly responding to changes in customer demand, making it ideal for dynamic market conditions. The system is also very good at focusing on quality control and continuous improvement, effectively reducing defects and waste. However, the pull system is not the simplest system to implement. It requires a well-coordinated and responsive supply chain, which can be difficult to achieve: communication between different sections of the assembly line is absolutely crucial. The system is also highly dependent on accurate demand forecasting; errors can lead to production delays or shortages.

Finally, we have the cellular system, which offers highly independent, compact production units. Here, cells can be quickly reconfigured to produce different products, allowing for rapid changes in production. The system also minimises lead time through the elimination of unnecessary worker and material movement. Most importantly, the system enhances quality and employee morale as workers have more control over the production process, which often leads to better quality and higher job satisfaction. However, this system is perhaps the most difficult to set up compared to the push and pull systems. Setting up cells require investment in equipment and manpower training. Thorough analysis and design must also be done to ensure that the cell layouts are not wrongly made, and workloads must be carefully balanced to avoid bottlenecks, which can be difficult to manage.

That being said, it is crucial to select the right production system while considering the situation and nature of the end product. A make-to-stock situation typically involves products with stable demand and low customisation (e.g., chemicals, canned foods, textile, etc.), whereas a make-to-order situation typically involves products with more demand uncertainty and higher customisation (e.g., DELL custom laptops, NVIDIA graphics cards, Rolls-Royce custom car). As such, in a make-to-stock situation, a push system may be more suitable. As the products are stable, they should be produced in push systems to maximise economies of scale.

On the other hand, in make-to-order scenarios, both the pull system and cellular manufacturing offer distinct advantages and disadvantages that can significantly impact production efficiency, quality, and flexibility. The pull system operates on the principle of producing goods only as they are needed, which significantly reduces waste associated with overproduction, excess inventory, and unnecessary processing. Techniques such as Just-In-Time (JIT) production and Kanban ensure that each step in the production process is triggered by actual customer demand, thereby minimising waste. Meanwhile, cellular manufacturing organises production into small, self-contained units that can handle the complete production of a product or component. This structure provides significant flexibility and adaptability, allowing for rapid reconfiguration to accommodate different products or changes in production volume. Such flexibility is crucial in make-to-order environments where customer specifications can vary widely. Each cell typically manages the entire production process for its assigned component, fostering a sense of ownership and accountability among workers. This responsibility often leads to higher quality, as workers are motivated to ensure that their output meets required standards.

When comparing the pull system and cellular manufacturing in make-to-order situations, both offer high levels of flexibility and responsiveness. The choice between them depends on the specific requirements of the production environment, such as the level of customisation, order volume, and product complexity. The pull system is particularly effective in environments with highly variable demand, ensuring that production closely aligns with customer orders. In contrast, cellular manufacturing excels in situations requiring quick reconfiguration and high-quality standards, making it ideal for producing complex or customised products.

6 Educational Outcomes Analysis

From a pedagogical standpoint, the Lean Lego Workshop provides several advantages over traditional theoretical lessons. Leal et al. [1] provides interesting perspectives on the efficacy of the Lean Lego game, which he classifies as a "Serious Game" (SG), incorporated into learning environments to teach the Lean philosophy. The current job market has been looking for qualified professionals with competencies that extend beyond theoretical knowledge. Soft skills and competencies such as teamwork, communication, and leadership are pivotal in a successful career, but are hardly developed in traditional teaching environments, including SUTD. SGs are one approach to improving existing methods, incorporating elements of interaction, inductive, reflective and exploratory learning [1].

In contrast to traditional theoretical classes, the Lean Lego workshop provided an avenue for us to collaborate with other participants and work in teams, which is essential in lean implementations. The active learning and engagement aspects of the game allowed for participants to be more involved in learning concepts, and made the learning process significantly more enjoyable, in contrast to traditional lectures on Toyota Production and Lean Processes.

An important aspect of this workshop is the application of theory in practice, where we were introduced to the concept of lean philosophy prior to the Lean Lego game. This was a key contributor to participant engagement and motivation: bridging concepts learnt previously in lecture, with an educational game which helps with active recall and retention of lean concepts. Our findings were corroborated by Leal et al., where students (regardless of whether they had learnt Lean concepts previously) were able to successfully transmit theory to practice, and showed positive results in learning and motivation [1]. They concluded that the use of an SG such as the Lean Lego game does improve the process of teaching and learning, which we wholeheartedly agree with.

A small area for improvement for this workshop could include a short summary and recall of each of the 3 production methods before commencement of the game, to facilitate better retention of the concepts. Additional concepts such as Value Stream Mapping (VSM) could be incorporated into the game as well, for students to better visualise the entire process.

7 Conclusions & Further Work

The Lean Lego Workshop offers a practical, engaging way to understand different production systems, namely mass production, lean production, and cellular production. Each system has distinct characteristics and implications for inventory management, production efficiency, and response to market demand.

Mass production, characterised by a 'push' system, is effective for high output and economies of scale but struggles with high inventory costs and inflexibility. Lean production, using the 'pull' system, aligns production closely with market demand, reducing waste and improving efficiency, though it requires careful coordination and accurate demand forecasting. Cellular production, a subset of lean production, optimises efficiency by minimising worker idle time and enhancing communication but demands significant planning and investment to implement effectively.

Through hands-on activities, the workshop demonstrated these principles in a dynamic and memorable way. We experienced firsthand the challenges and advantages of each system, reinforcing theoretical knowledge with practical application. This experiential learning approach fostered teamwork, problem-solving, and adaptability, which are crucial skills in modern manufacturing environments.

The workshop also highlighted the importance of selecting the right production system based on specific scenarios and product requirements. It emphasised the value of mass, lean and cellular production in reducing waste and improving responsiveness, which are vital factors in remaining competitive in today's market. Integrating these interactive approaches in educational settings can significantly enhance learning outcomes and better prepare individuals for real-world manufacturing challenges.

Lastly, future iterations of the workshop could adopt variations in product complexity and customer demand scenarios to simulate more realistic environments, allowing for dynamic strategy adaptation. Using digital tools such as a tablet for real-time updates on production metrics could further enhance the learning process.

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References

[1] Fabiano Leal, Paula Carneiro Martins, Alexandre Fonseca Torres, José Antonio de Queiroz, and José Arnaldo Barra Montevechi. Learning lean with lego: developing and evaluating the efficacy of a serious game. *Production Journal*, 27, 2017.

[2] Mária Mičietová. Lean production, lean vs. mass production, tpm as a tool of lean production. *Perner's Contacts*, 6(4):210–216, Dec. 2011.

[3] Reza Raminfar, Norzima Zulkifli, Mohammadreza Vasili, and Tang Hong. An integrated model for production planning and cell formation in cellular manufacturing systems. *Journal of Applied Mathematics*, 2013, 01 2013.