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Creating Value Using Toyota Production Systems in a Leading Automotive Manufacturer

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Abstract

Despite research demonstrating the operational benefits of lowering the number of product offerings, manufacturing companies commonly service markets where customers require a wide range of products with various feature options at unpredictable intervals. While lean manufacturing principles have been recognized as enablers of operational excellence in high-volume manufacturing operations, doubts remain concerning the concepts' application in high-mix, low-volume, make-to-order contexts. This project investigates the applicability of Toyota Production Systems within this manufacturing environment. To be competitive, the company must produce high-quality, low-cost goods that fulfill customer standards with short lead times. Using a qualitative research design with a case study analogy and implementing waste elimination, mistake proofing and pull methods, a production cell increased the percentage of sales delivered on time to the customer by 15%.

Keywords
Toyota Production Systems, lean thinking, customer satisfaction

1. Introduction
The study was conducted at a company that provides competitive manufacturing solutions to major original equipment manufacturers (OEM)'s and 1st tier suppliers in the South African automotive industry and export markets. A variety of operations are conducted in the company's plant, and they include metal stamping and welding, polymer injection molding, metalworking, forging, tube bending, synthetic leather stitching, and various surface treatment processes (galvanizing, e-coating, powder coating, wet spray painting), as well as many highly automated assembly processes. The company is currently experiencing major production-related problems such high work in progress between the workstations of the e-coating line, inconsistent operation times, frequent machine breakdowns, inconsistent quality of coated products, and high overtime costs.

This study was conducted at the e-coating plant and the approach would be to focus on a monthly based study for analysis. A standardized production data collection sheet which was used to identify problems such as machine breakdowns, poor productivity on the production line. In order to ensure data validity, physical observations were also conducted. Statistical analyses were also conducted to analyse production related data, including cross tabulation of collected machine downtime data. A cause-and-effect diagram was used to investigate potential causes of machine downtimes.

2. Literature Review
This section of the paper focuses on the literature around the strategies that are commonly used for improving of manufacturing performance and these include the lean philosophy, six sigma, theory of constraints and just in time.

These concepts inform some of the recommendations proposed to improve productivity and reduce machine breakdowns.

2.1 The Concept of lean manufacturing

The discovery and removal of waste from processes to improve the overall value supplied to the customer are commonly understood principles in the lean methodology. Table 1 depicts the seven wastes as defined by Taiichi Ohno in the Toyota Production System, as well as Liker's definitions in The Toyota Way (Ohno 1988). High-Mix Low-Volume (HMLV) and Make-to-Order (MTO) manufacturing environments can create a variety of challenges for organizations adopting these principles and removing waste in the production process. HMLV environments must deal with product line cycle time variability as well as increased volatility in demand and delivery dates. An MTO firm, by definition, manufactures solely to client orders, but the actual batch size in the customer order can vary significantly. Value stream mapping is particularly complex in MTO businesses due to the enormous number of product lines that must be designed for flow (Amaranti et al. 2010). These variables might make locating and eliminating waste challenging.

Table 1. The 7 Wastes of the Toyota Production System

Waste	Definition
Over-production	Producing ahead of demand
Waiting	Idle for a machine, key inputs, or slack with no deadlines
Transportation	Moving materials or information inefficiently
Over-processing	Performing unnecessary steps in process
Inventory	Excess material, work in process or finished goods
Movement	Wasted motion employees perform during work
Defects	Production of defects and correction

Making value-creating steps flow while allowing the client to pull value is risky without expensive inventory. Another operational disadvantage is that the economies of scale associated with bulk ordering are not achieved. According to Biller et al. (2005), low-volume commodities usually have poor prediction accuracy, resulting in higher safety stock and higher procurement and shipping costs. All businesses must strike a balance between inventory and service level, but these businesses have a higher percentage of stock keeping units (SKUs) with high prediction error.
Despite the difficulties in implementing lean to the manufacturing process in this setting, there are instances of successful implementations in investigated use cases and useful beginning points to explore for implementation. Mudgal et al. (2017), discovered that doing a commonality study based on Bills of Materials (BOMs) and shared sub-processes was beneficial in grouping the various assemblies in an MTO manufacturing environment to comprehend the product families.

Irani (2020) categorizes classic lean tools based on whether they have proven use cases to decrease waste and increase flow in HMLV contexts. Although Biller et al. (2005) do not specifically mention lean methodology, he does highlight two benefits that modular product architecture provides to a production system with a large number of product variations: it requires part standardization across products to reduce the SKU level.

There are also inventory models that have the ability to reduce inventory waste while still allowing customers to pull value. Most HMLV or MTO firms have stochastic demand at the component level, lead times for components are more than zero and the replenishment model is multi-period, indicating that orders can be fulfilled in the next period if there is a backlog. The continuous review policy appears to be more appropriate for this setting than the periodic review model because it ensures item availability at the lowest inventory-holding cost level for the items. In general, a continuous review policy improves inventory control since products are tracked instantly during transactions and reordered in optimal quantities only when they reach predetermined reorder points. One significant disadvantage of this strategy is that it can be more expensive to track inventories in real-time, although in this case, the organization already has a system that accomplishes this and procures in the best manner described by this model. As the literature implies, inventory holding costs for HMLV and MTO enterprises can be significant due to fluctuation and service requirements; this type of approach should reduce such costs. There have been studies that showed the usefulness of continuous review policies in organizations facing similar issues, such as an automotive factory with volatile demand and a hospital that provides pharmaceuticals and medical equipment. According to the literature, lean principles and methodologies need care in application, but when used appropriately, they can provide value for organizations functioning in an HMLV and MTO environment.

3. Methods

A qualitative approach was used with a case study analogy to gain insight into the daily performance of work using the Gemba walk during working hours. During the Gemba walk, notable observations were recorded, and discussions were held with operators and supervisors to gain an understanding of the current phenomena. These records were critically analysed to identify shortcomings in the process.

Interviews were conducted to gather the necessary information on how the organization reached its daily production targets. The departmental employees and supervisors were consulted from the beginning of the project, where the aims and objectives of the study were outlined. A sample of 15 operations personnel and five supervisors was consulted on a regular basis to extract the required information on the current performance of the department.

Time study is a work measurement technique used to establish the time necessary to perform a task. Time study was used in this research to find line efficiencies and to determine cycle time and takt time in order to identify bottlenecks in the modification processes. Current processes were analysed to find the root cause of the problems.

Observation through the Gemba walk was used to gather more information and help identify bottlenecks and areas of improvement, and to gain a better understanding of the processes while engaging with those who do the actual job.
A process flowchart is used in a variety of industries to analyze, create, document and manage a process or program (Benjamin et al. 2015). In this project, the process flowchart was used to evaluate the movement of the elements of each fitment.

Control charts are used to evaluate a process and to check if the process is stable or needs intervention. These charts are achieved using statistical process control, which is a quantitative approach, or analyzing data. An X-bar chart is used to evaluate the averages to identify problems relating to the stability of a process to avoid assembling defective products. A cause-and-effect diagram was used in this study to identify the root cause of the problems faced in the organization.

4. Results and Discussion

The data analysis process summarizes the information gathered. It entails the use of analytical and logical reasoning to data in order to identify patterns, correlations and trends. In order to provide value to customers, obtain a competitive edge and grow, the company attempted to enhance material and information flows to achieve operational excellence. This project examined numerous aspects of the organization's operations using Lean concepts, with the ultimate goal of increasing responsiveness to its customers. The key mechanisms for achieving this goal were as follows:

4.1 Lead times for components

Lead times in days ranged from 0 to 60 for these items at the plant for the 12 months ending in May 2022. Customers' expectations of lead times can vary due to variances in the quality of engineering or design that an order requires, the uniqueness of components contained in the product or the perceived differences in assembly hours. This truth has a couple of ramifications for how the production team operates. First, when the customer demand rate is not reasonably steady, it is exceedingly difficult for the organization to use lean approaches derived from takt time analysis. Furthermore, one can imagine a scenario in which orders with customer lead times of 7, 14 and 21 days all result in the same needed date by the customer, placing a burden on the ability to deliver. Given these circumstances, the organization can maintain client flexibility by reducing processing times per product.

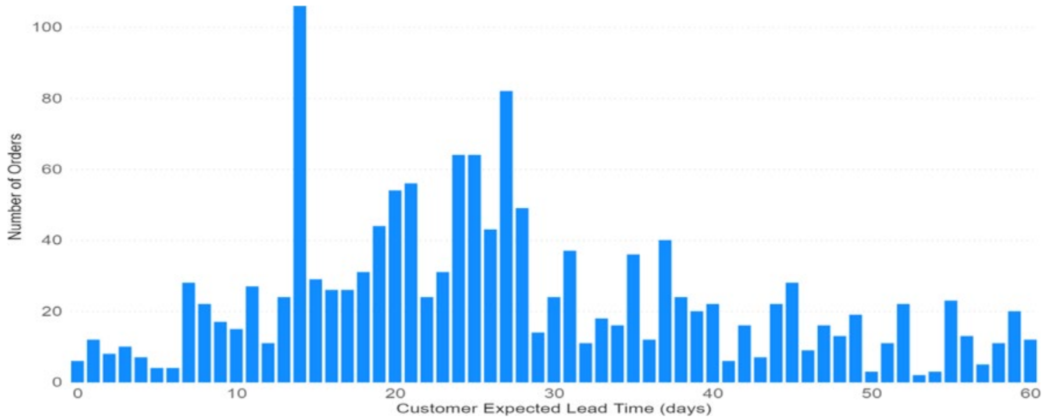

Figure 1. Number of orders by customer expected lead time in days, June 2021 – May 2022, limited to 60

4.2 Commonality based on BOMs

The first step in specifying the product lines is to perform a commonality analysis utilizing the BOM data from the client specifications and the business system. Table 2 displays the number of possible product codes and filter housings, as well as the assembled products and unique product codes ordered in the 12 months before 1 June 2022, to offer context for the product diversity and low volume.

Table 2. Characteristics of the product variation and volumes within the production cell. The volume and unique codes ordered are from June 2021 – May 2022

Item	Number
Possible product codes	Z212
Possible filter housings	15
Production volume	426
Unique product codes ordered	70

Thirteen of the 15 available filter housings in the customers' design were ordered in the same 12-month period. This mix, as proposed, allowed the classification of the various filter housings as runners, repeaters and strangers, with the actual occurrence of the filter housings among orders given. Upon evaluation of the production steps of the product families, it was discovered that almost 70% of the volume came from four of the top five filter housings that follow similar processes. This helps to appreciate both the mix and the opportunity to focus on efforts to improve.

Two separate pairs of filter housings belong to the same product family because their configurations are identical and safe for the filter housing; however, one filter housing is limited by component size requirements. Aside from the filter housing, the number of available combinations varies by product family, based on the configurations required for system integration. Figure 2 displays the possible configuration choices that allow end customers to choose from hundreds of product codes as an example of how the product family can vary.

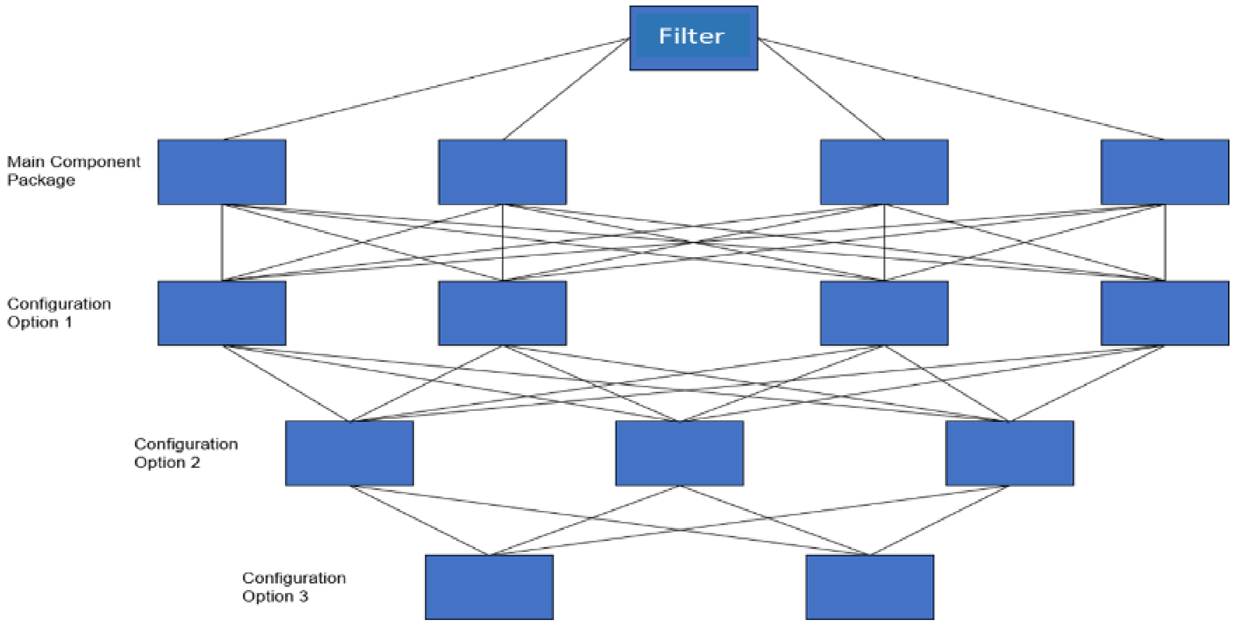

Figure 2. Configuration options for one product family that has 96 end product codes

Upon reflection, it was reassuring to see that of the 13 product families, three accounted for 68% of the volume and ten accounted for 88% of the volume. This depiction of actual production data assisted team members to understand the relative value of the various families in addition to their most recent experience. It also showed that, while variety occurred in the Z212 end product assemblies, genuine variation was less common since certain families were far more popular than others.

4.3 Visualizing Order Flow

As an MTO company, the organization provides a product in the form of an assembled filter. This section maps the process flow diagrams connected with the order and product status changes from order receipt to shipment.

4.4 Process Flow Diagrams

The organization combines many of its processes through its business system and has adapted the business system to improve visibility of production progress in addition to the usual order processing. The results show that the flow of the business system standard "order status" processing at a high level. The diagram shows that the majority of the information required to understand the operational procedures is contained in the "Pending Fulfilment" stage, where production takes place (Singh et al. 2020).

The order is sent to the manufacturing team via the business system, the product is assembled and dispatched, and the sales staff update the business system to reflect the shipment and invoice issuing. The manufacturing process is depicted with the customized "work status" stages.

The business system did not prevent the user from changing the employment status from one status to another; therefore, the paths were the most typical paths based on conversations with employees and observations. In addition, some of these stages could be skipped. Some production cells, for example, employed "New Order" and "Need to Assemble" to sort visibility on forthcoming orders, while others began with "Need to Print Pick Ticket" and progressed immediately from "Parts Pulled" to "In Assembly." Overall, updating an order's job status created a shared understanding among employees across the organization. It is also worth noting that five of the nine stages that reflect a deviation from the optimum path are related to parts shortages. Because the organization designated this list of stages, one can deduce that parts availability was a likely source of frustration for the manufacturing crew.

4.5 Production Process Mining

Figure 3 was generated as a preliminary pass to comprehend the quantity of orders that are "In Assembly Waiting for Parts" and "In Assembly" at each window. Figure 3 shows how, at various points, particularly in 2022, orders in production began to encounter increased interruption due to missing parts.

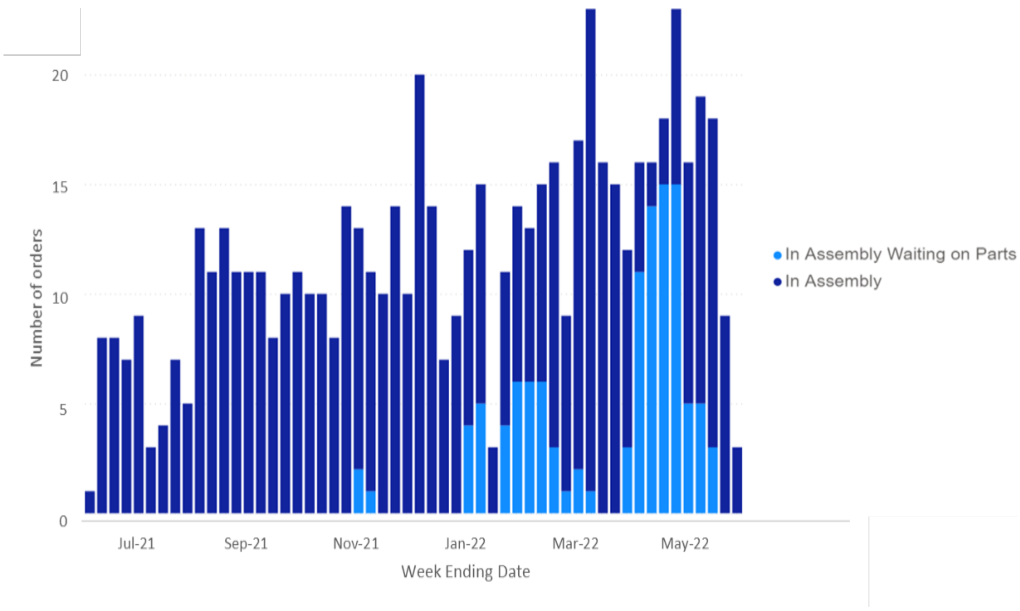

Figure 3. Comparison of quantity of orders in assembly with quantity of orders in assembly waiting on parts, June 2021 – May 2022

Because there were so many distinct end product assemblies that were offered at varying prices, it was critical to assess whether the impacted orders were reflective of the total mix, as opposed to solely affecting orders of lower or higher price. To do this, a ratio indicator that compares the number or value of impacted orders to the total number or value of orders at this point was implemented. Equation 1 represents this measure.

$$Waiting\ Ratio = \frac{Order\ in\ assembly\ waiting}{Orders\ in\ assembly\ waiting + Orders\ in\ assembly} \qquad (1)$$

Figure 4 depicts this ratio in terms of both order quantity and order sales amount. Parts shortages clearly affected sales order amounts, or revenue to be gained, with the same frequency as sales order quantity.

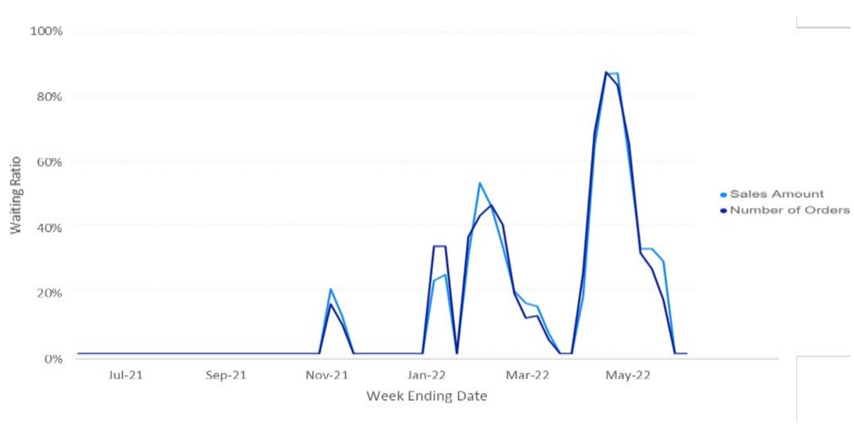

Figure 4. Waiting ratios of quantity of orders and sales amount of orders, June 2021 - May 2022

These numbers indicate that it is difficult to have the proper parts accessible for assembly when needed. Parts shortages have on impact on delivery performance.

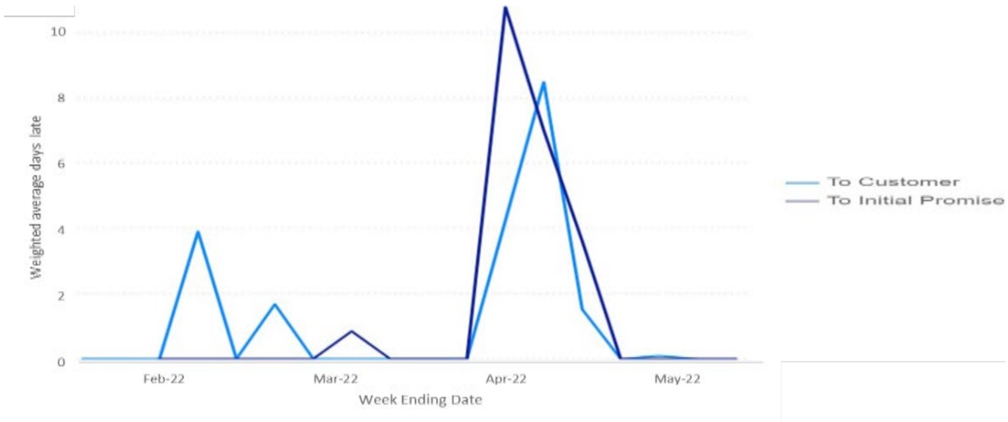

Figure 5. Weighted average days late to want and to initial promise, February - May 2022

4.6 Visualizing Material Flow

The spaghetti diagram is a handy tool for visualizing how materials move through a manufacturing facility as they are changed from raw ingredients to final goods. In this situation, it will provide a general overview of the material placements within the facility as well as the first steps towards identifying transportation or movement wastes. The spaghetti diagram in Figure 6 uses red lines to indicate the movement of the parts in final assembly.

The cell arrangement within the huge panel assembly area is intended to support U-shaped product flow. Several product families require the installation of components weighing more than 500 kg in the filter housing; therefore, racks of the required sizes are available to allow the rotation and bracing of filter housings, and a top-running crane is used to safely transport heavy goods within the crane area (Singh et al. 2020).

Estimates of the distance spent on material movement are done by taking into account the fact that these movements require round trips for team members to move to and from the location with material, estimating the number of trips required during production of each product from runner or repeater families, and measuring the distance involved in the movement. Table 3 indicates the results from applying this strategy to the material movements.

It is also crucial to evaluate how the material is stored in the facility and how it is transferred, in addition to where it is stored. Based on the feedback from team members and personal experience, it was discovered that the filter housings, their accompanying pieces and panels, and two of the bigger internal components caused problems for the warehouse team and production cell (Dhiravidamani et al. 2018).

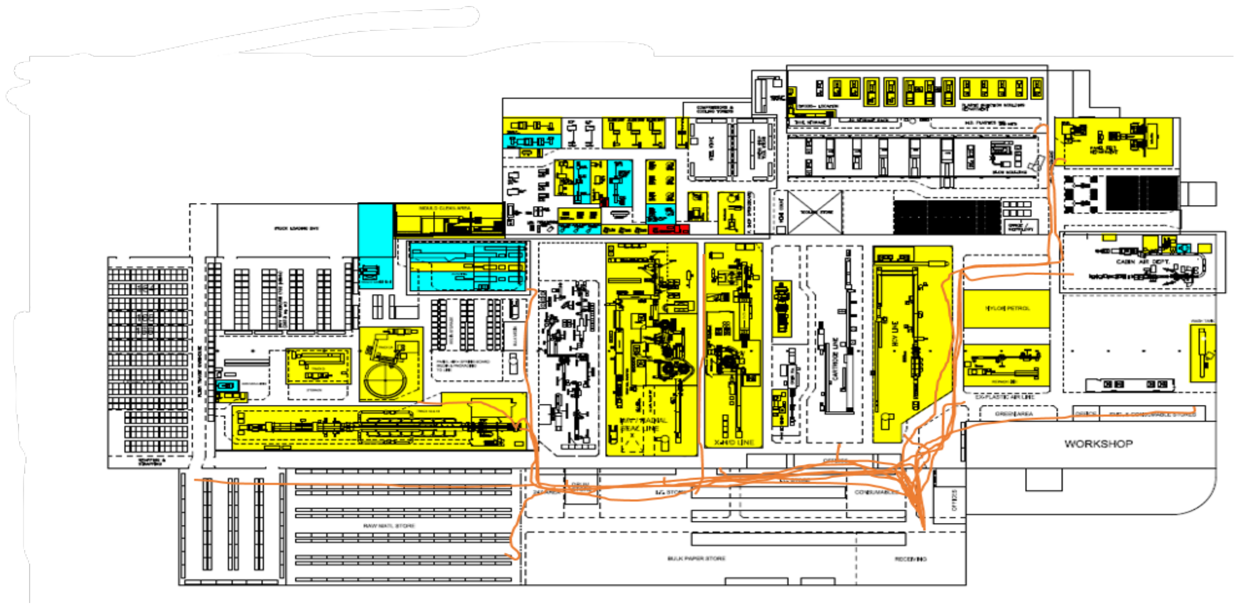

Figure 6. Spaghetti diagram of material movements within the factory

Table 3. Current state of material transportation and employee movement distances for various components common to products from runner and repeater families

Material	Per Product	Distance [m]	Total [m]
Cans	1	150	300
Seals	2	185	740
Washers	1	185	370
Element assembly	1	175	350
Centre tube	1	50	100
End caps	2	220	880
Media	1	40	800
Labels	1	80	160

4.7 Picking, Sub Assembly Production, Testing, and Shipping

The next step in the fulfilment process is to pick the order and gather the necessary components for assembly. Employees from the warehousing department carried out this action after obtaining a picking ticket from the manufacturing cell's team leader. All of the required smaller components were loaded onto a cart, labelled with the matching order information and a status form, and staged in allocated open space in the warehouse room until carried to the assembly area by a member of the production cell. Larger components housed in the storage bay or outside were fetched immediately by production cell members when needed for the order.

Four of the seven product families that were runners or repeaters necessitated the creation of sub-assemblies in different portions of the facility. If a sub-assembly was necessary for an order, the business system created a work order, and the production cell team leader filed a picking ticket to the warehouse section to gather those components. Team members who built the sub-assembly drew the staged cart and assembled the sub-assembly in their work locations. The sub-assembly work for this production cell mostly consisted of cables and smaller filters that were later placed into the bigger filter. Team members from the production cell would pull these sub-assemblies for installation as needed when finishing the final assembly (Rifqi 2021).

The final product assemblies were tested for safety and quality by the production cell team leader. When an assembling team member finished the product they were working on, they would transport it to the testing part of the cell so they could start working on the next order. The Quality Management System classified problems into four basic categories: Wiring failures occur when components are not properly connected; connections fail when terminal connections are not secure; component failures occur when incorrect components are used within the product; and label failures occur when labels fail to reflect correct panel ratings or information about the product or components within the product. The team leader offered input on any problems discovered to the team member who assembled the product so that it might be corrected in future for that product and similar items. The quality system used a variety of measures, including panel first pass yield and defect kinds. Figure 7 depicts the production cell assembly error type per month (Jasti et al. 2014).

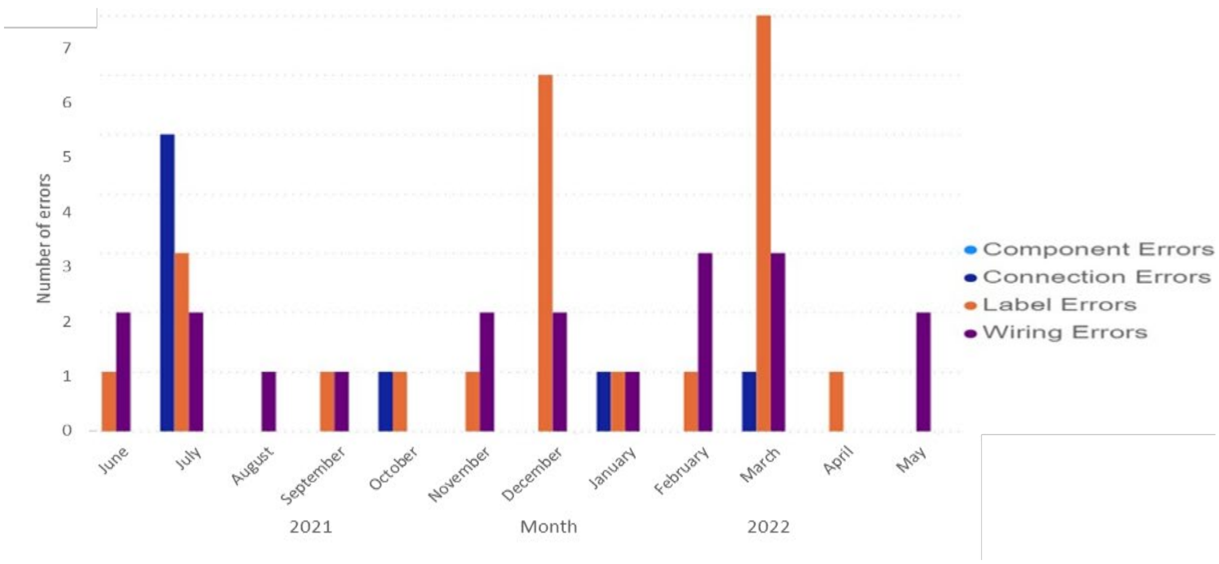

Figure 7. Breakdown of production cell assembly error type per month, June 2021 - May 2022

5. Conclusion

This research revealed the complexity of the processes involved in the filter industry. Lessons about which strategies are effective as well as the limitations of the methods that the organization can use were revealed in this investigation.

5.1. Theme 1 - standardization

The first theme that can be effective across the multiple dimensions of product manufacture was standardizing the products and processes as much as is feasible. This enabled the discussion and execution of standard work, reduced time spent due to seeking and enhanced team members' perceptions of operational processes and interactions.
The modular design offered by suppliers was one of the most effective techniques of enabling flexibility and pooling volatility in demand. This decreased the need to handle each order based on its unique requirements rather than a set of known requirements, allowing for advances in capacity and quality. According to the research literature, the supply chain was easier to manage when the parts were shared across multiple product versions.

5.2 Theme 2 – improved service

Improved service levels were experienced by internal and external customers while reducing inventory levels for numerous items with higher holding costs by learning how to extract data linked to lead times and demand and implementing the continuous review inventory replenishment policy. The results show that such a model may be effective in this environment despite the complexity of SKUs and demand.

5.3. Theme 3 – improved information flow

Efforts to improve information flow centered on enhancing access to the information required each team member to make choices and create redundancy in the communication that already occurred between team members. The greater understanding of how their actions affected the value stream boosted team members' skills to make individual judgments that were more helpful to the entire system. These advancements were also aimed at leveraging the business system as the one source of truth, so that each team member could relate to the issue from the same contextual perspective (Palange et al. 2021).

5.4. Theme 4 – automation

Team members appreciated the relatively basic automation created for the quality it ensured, the annoyance it alleviated and the capacity it added to the operations. The key to this automation was that it was not limited to specific use cases but could be applied to any product variation experienced by the team members. As a result, rather than being regarded as a step with significant setup costs and limited impact, it could become ordinary and standard.
Using data from the business system in process mining assisted in visualizing the steps of the manufacturing process and alleviating the shortage of data surrounding the manufacturing processes. This was a workaround, but it might be used in conjunction with a system to track actual production times to better evaluate operational performance.

5.5. Theme 5 - groupings

The whole menu of product variations was understood and characterized by product codes and groupings, which was a vital condition for the deployment of many of the initiatives that enhanced efficiency. This enabled one to structure the analysis around product families, collect and categorize usage data, take advantage of modular design opportunities and automate numerous phases in the process. None of these efficiencies could be reached without product codes or a complete grasp of the number of different configurations, what they have in common or how they differ and what the product family groupings are.

5.6. Theme 6 – data integrity

The inability to track actual production times using business system data and the data integrity underlying the analysis limit the use of the process data analytics. Understanding the lead time or demand characteristics at the SKU location level would have been impossible if the business system had not been a trustworthy source of data for how components flowed in and out of the plant. Further examination of operational performance would be possible if there is continuance to refine which metrics are tracked and how data are recorded.

5.7. Theme 7 - investing in fixture or production automation

Clarifying the influence of machine automation investment on various steps of this manufacturing process is one area for future investigation. Because of the variance and confined places in which most of the assembly happens, the existing method is highly human, and there are several constraints to using fixture automation in this setting. This application potential will expand as robotic technology progresses and machine manufacturers continue to create and produce adaptable solutions. There are only a few case studies involving the effective deployment of machine tools in this type of HMLV and MTO setting with these production restrictions, and this research might benefit from them.

5.8. Theme 8 - information architecture

This study provides basic insights into how data processing can be used to create information architecture for individual team member decision making. There is more opportunity to investigate the implications of ideal information architecture for enterprises manufacturing in this environment and utilizing approaches such as Industry 4.0. The applicability of establishing an information architecture throughout the production processes, like other decisions requiring investment in this technology, depends on how effectively the development will handle the mix and volume.

5.9. Theme 9 - replenishment model refinement

The supply chain modelling research revealed the early promise of the continuous review policy in an HMLV and MTO environment, but there is still room to learn about the following stages of supply chain evolution. Aside from simply applying the models presented in a more systematic manner throughout the organization, there is a strong possibility that one could continue to improve performance at a lower cost by conducting a multi-echelon inventory optimization analysis within the facility and treating on hand and available inventory as separate demand stages with different characterizations. Additional research into the appropriate length of historical demand to consider in the model best suited for this environment may be conducted (Gaspar et al. 2020).

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Biographies

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