Waste Minimization by Inventory Management in High-Volume High-Complexity Manufacturing Organizations

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Abstract. Organizations that manufacture high volumes of complex products (e.g., pharmaceutical, automotive, food) require specific strategies to ensure efficient processing of parts and a sustainable level of inventory by waste minimization. A review of literature sources revealed how inventory is classified and managed amongst organizations and industries and key challenges that current organizations face with existing inventory management systems. In this paper, these findings are compared against each other to determine best practices and potential shortfalls that should be addressed when trying to manage inventory holistically. A study is then conducted using qualitative data from 15 semi-structured interviews to answer key questions on inventory management based on the findings from the literature survey. Responses are inductively coded and analyzed to reveal the most important factors of inventory management and determine the most prominent themes. A graphical model to represent the findings is also presented. Inventory functional accountability, inventory classification, operational strategies, visual management of inventory data, and efficient processes were some of the key themes known to be critical for effective inventory management and thus illustrated in the graphical model.

Keywords: Inventory Management · Sustainability · High Volume · High Complexity

1 Inventory Management

Inventory management can be a complex and critical aspect of a business that needs to be proactively managed due to its financial, operational, and environmental impacts [1]. Inventory and production management decisions such as transport frequencies, energy management policies, and production strategies significantly influence emissions generated by transport and storage procedures. Therefore, the efficient management of inventory is crucial to the reduction of carbon emissions. Its importance is emphasized further because it influences all activities related to controlling inventory in the most optimal way to meet one or more business objectives [2]. For example, some of the most common problems faced by manufacturing organizations are underproduction, overproduction,

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out of stock situations, delays in the delivery of raw materials (RMs) and discrepancies in inventory [3, 4]. Moreover, facilities with high volumes of complex products are more prone to inventory issues; these production environments are challenging to control inventory due to the product's complexity and respective processes, which are further amplified by its volume. In this work, high complex products are defined according to the following conditions:

a) require an international supply chain or at least three national suppliers,
b) manufacturing requires at least ten weeks, including logistic transportation time,
c) the product requires at least five different manufacturing process families to be manufactured, such as grinding, coating, drilling, welding etc., and
d) the product comprises at least ten operations in its sequence from the requisition of RMs to dispatch to the customer.

Developing a typology or a classification of inventory helps effectively manage the inventory and align with the organization's priorities. A literature review found that researchers classify inventory by purpose [5], type [6], level of control [7], value [8], or multiple criteria [8, 9].

Perhaps the most common classification is RM, Work in Progress (WIP), and FG (Finished Goods). However, researchers highlight that inventory should not be studied as a monolithic entity because different types of inventory can affect each other [5, 10]. In addition, the imbalances in supply and demand produce a further inventory classification into buffer inventory, cycle inventory, decoupling inventory, anticipation inventory, and pipeline inventory [5]. Another approach to classification is via a hierarchical structure that splits between controlled and uncontrolled variables [7]. The authors claim that controlled variables consisted of item cost, holding cost, shortage cost and procurement cost, and uncontrolled variables consisted of demand, review period, lead time and reorder level. These classification criteria provide a different perspective to view inventory which can be valuable depending on the underlying goal of the organization, and a wide range of mechanisms can impact each one. Multiple classification systems have been studied and compared against the ABC system and found to be more effective; some of these alternatives are deemed more effective [9, 11–13]. However, little has been developed on inventory classification concerning environmental sustainability aspects. In addition, they mainly focused on lot size quantity with minimum possible costs and rarely considered environmental factors. This led to growing concern with regards to environmental challenges. Therefore, significant interest has been shown in developing more sustainable inventory management which is inclusive of environmental, social and economic factors [14, 15].

There are multiple ways that inventory can be classified, many of which have been tested through simulation to prove their merits. Still, none of these simulations represents a real-world application because they do not capture the influence of the human factors [9]. This paper develops a graphical model that highlights the factors to be considered to best manage inventory for high volume complex products in a manufacturing organization and its relation to resource efficiency and the minimization of waste.

2 Methodology

This research was carried out in the form of semi-structured interviews with 15 participants to obtain qualitative data. A qualitative approach was chosen to complement the numerous quantitative studies found and to overcome the criticism [9] that existing inventory management models fail to capture human factors and, therefore, are not representative of real-world performance. Also, it helped to develop further insights, fill in the missing gaps identified in the literature review but also to compliment it with supporting or contradicting information to gain a better understanding and evaluation on the topic.

2.1 Data Collection

All interviewees belong to multiple organizations but work for the same industry of civil aerospace, gas engine, and turbine blade manufacturers. The selected interviewees were a mixture of managers and staff within organizations that manufactured high volume, highly complex products answering a series of six questions. The decision to involve interviewees from different organizations was motivated by the aim to create a diverse participant list in their roles and facilities. Interviews all took place in person and were audio-recorded and transcribed.

2.2 Data Analysis

Once the interviews were recorded, they were all reviewed and amended to ensure the transcriptions were correct to the audio recordings. Transcribed interviews were coded using NVivo, which is a qualitative data analysis computer software package. It allows further analysis by organizing, analyzing and discovering insights from unstructured or qualitative data such as interviews, open-ended survey responses, etc. [17]. Several matrices were used to correlate the codes with questions and codes with the different interview participants, these included weightings based on the frequency of appearance of codes. The weightings is essentially how many times a code appeared across all the interviews resulting in its popularity, the more often a code appeared the more prominent it is.

The literature review provided a basis of what is required for inventory management. However, using deductive coding could have potentially narrowed down the findings too much to the point important subtle information would be omitted. The coding technique used was inductive for each question. It ensured that all themes were captured accurately to support and contradict existing findings in the literature review. Once all coding was completed, a consolidation has been operated based on equivalent meaning, reducing their number from 189 to 91. All 91 codes were used in varying degrees based on the interview responses. These remaining codes were then put under different themes to group them, resulting in 10 themes. Figure 1 provides an example of how the codes and themes are structured. Some of the coding examples are: Increase inventory to protect customer from arrears, Operations are accountable for inventory, Planning & Control are accountable for inventory, everyone is accountable for inventory, etc.

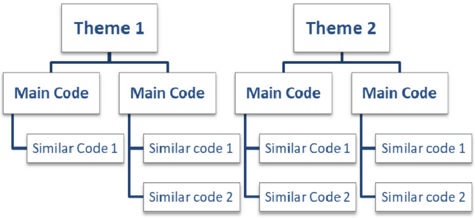

Fig. 1. Coding structure

3 Discussion

Discussing the most popular codes identified is space-consuming, therefore, for this research paper, the discussion will focus on the themes level rather than the code level. Each of these themes had multiple codes under them, and each of the codes was used in varying amounts across all the transcribed interviews. The themes were also inductive to best group the codes produced. The following Table 1 summarizes the most popular themes developed from the interviews and an explanation of the codes each theme contained. Mapping the themes to the main areas of sustainability (i.e., economic, environmental and social), there is evidence that inventory management in high-volume and high-complexity manufacturing systems does not simply affect economic aspects (as traditionally perceived), but it is relevant also to environmental and social instances. Relatively recent legislative efforts do align financial goals with broader sustainability goals including (at least some) externalities in the balance sheets of enterprises. There is an expectation that this trend will grow further in the coming years, in particular in the regards of environmental impact and resource efficiency. These considerations show how important the optimization of inventory management can cascade in a less obvious way in contributing to sustainability goals.

To cover all the high-level key points extracted from the study, a graphical model (see Fig. 2) was developed. Organizations with high volume complex products could use the model in order to have a good grounding in inventory management. The model represents a manufacturing process flow with WIP at various processes. The process is in the form of a pipeline that is angled to represent the production flow as a constant variable in relation to gravity. The pipeline using gravity also represents a First In, First Out (FIFO) system. However, when there is more inventory in a process than desired, the first in first out system fails to work as expected because the system becomes overloaded and different policy rules (e.g., prioritization and partial orders delivery) are enforced. It reflects the importance of having the correct inventory level at each process. The three key accountable functions: Operations, Planning & Control and Engineering, are highlighted around the model. A conveyor belt below called "Side Processes" represents parts leaving the main pipeline. The conveyor belt is moving parts upwards and thus against gravity to represent the challenge that side processes can have more resistance to processing parts; this is an area that Engineering need to focus on to improve. Some parts may also leave the side process because of not being suitable for the customer; this is a potential case with complex products.

Table 1. The identified themes and the explanation of codes they contained categorized according to the three "pillars" of sustainability

Theme	Explanation of codes each theme contained	Economic	Environmental	Social
Accountability	Codes that discuss or specify individuals or functions who should be accountable for inventory management	x		
Awareness, Behaviours and Culture	Codes that mentioned any one or more of those elements in relation to inventory management			x
Data	Codes that related to inventory management data, any data related practices and issues	x	x	x
Efficient Processes	Codes that allude to processes need to be lean, easy to follow, and resource efficient	x	x	
Management & Leadership	Codes that mentioned how senior figures in an organization could influence the way inventory is managed or how they manage other concerns of an organization	x	x	x
Planning & Control	Codes that covered the way inventory can be managed through planning techniques, forecasting and strategies for domestic and the external supply chain	x	x	
Process Compliance	Codes that mentioned compliance issues and importance		x	x
Technology	Codes that highlighted technology in relation to inventory management	x	x	
Visual Management	Codes that alluded to any visual management	x	x	

Planning & Control dictate the launch of inventory dictated by the customer demand and operations. It is because operations report what is in the various processes; this information with customer demand should be used to carefully control the launch of parts to ensure just the right quantity of parts are in the process. There is an optimum level of inventory for each process, this optimum level needs to be visually highlighted to all functions so the correct decisions can be made on inventory prioritization and the correct inventory classification can be applied. The more accurate the planning is in regard to RMs, and FGs needed to satisfy the customer requirements consistently, the less inventory management is required due to fewer errors between actual and forecasted demand. Moreover, controlling the flow of materials by the use of supermarkets and calculated amounts of WIP, will result in less wasteful processes and fewer energy consumed [18].

Operations are directly and solely in charge of "opening the gates" for each operation to allow parts to flow through. Some of these parts may be in batches as they are easier to control. It is illustrated by how the batches of parts are grouped together versus the mix of all sorts of different parts that are difficult to quantify. A weighing scale shows how the inventory management metrics of cost, quantity and slow-moving WIP for each process and area must be balanced with other organizational metrics. Otherwise, effective inventory management can be jeopardized. Flowing through the operations consumes energy and requires resources. Therefore, a lean operation with less waste produced and resources consumed would allow for a more resource efficient system with fewer inventory and less energy required for storage and transportation [16, 19].

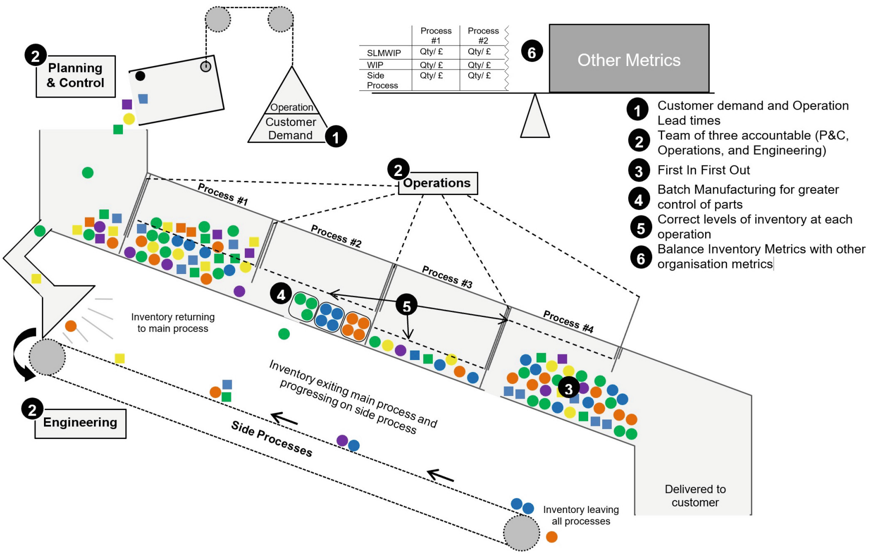

Fig. 2. Graphical model of inventory management for high volume complex products

4 Conclusion

Inventory management for high volume complex products requires the cooperation of many areas of an organization with clear decision making, metrics and visualization. When appropriately broken down and sub-categorized, Slow-moving WIP, value and quantity were the main classifications that yielded the most benefit. However, an effective way to manage inventory is to manage the culture and behaviors, manage metrics and their visualization, simplify processes and ensure adequate storage areas on the shop floor. The issues and resolutions were quite vast and broad but consisted of visual management, raising inventory management awareness, improving processes, utilizing technology where possible and processing parts in batches. In particular, improving the processes via lean principles will lead to waste minimization and resource efficiency. Although it was not mentioned to apply different weightings or priorities for different criteria as inventory was not given a score in the organizations involved in this study, business-specific inventory classifications with different weightings for each criterion is suggested. Moreover, the reliance on technology and human factors result in effective inventory management.

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