Balancing Chaos and Order: A Comprehensive Literature Review on the Trade-offs of Chaotic Storage in Warehouse Management

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Abstract

The purpose of this paper is to provide an in-depth analysis of the existing research regarding warehouse operation specifically storage policies. Warehouse operations are critical factors that affect the responsiveness of the supply chain. To meet customer demand on time, optimizing warehouse operations is critical to enhance the overall supply chain performance. Storage policy is critical in warehouse operations, directly impacting order fulfillment efficiency, lead times, and space utilization. The main objective of this study is to determine the effect of storage policies on the utilization of the warehouse, lead times, and overall operations of the warehouse. Hence, this paper examines the existing storage policies, types of simulation modeling that would aid in creating a simulation model that mimics warehouse operations for testing purposes.

Keywords
Storage Policy, Stock Keeping Unit, Turnover Ratio, Lean, RFID (Radio Frequency Identification).

1. Introduction
Warehouses are the heart of the supply chain, and many aspects are highly dependent on them. To better serve customers and ensure their satisfaction, products must be delivered on time and up to the expected quality. Thus, the warehouse operations must be optimized, including the warehouse layout, picking, and routing processes.

Warehouse layout is an essential aspect reflected in order fulfillment rate, reduced lead time, and utilized labor activity (Lewczuk and Żak, 2013).

Warehouse operations make up to 20% of the total costs of logistics, with order picking making 60% of the entire warehouse operation, where workers' time is spent on waste, known as a motion, for 50% of their time being spent between the aisles and the input/output point (Ene and Öztürk, 2012). Therefore, reduced lead times are required to serve customers better, which is highly dependent on the warehouse's layout and time spent traveling. The main challenge is to design the warehouse to its unique dynamic/nature. The general approach is to plan order-picking routes, divide the warehouse into zones, and then optimize shelf storage to maximize the capacity of the aisles (Ene and Öztürk, 2012).

In small warehouses, keeping track of product quantity and the reorder point is often done manually; however, as the warehouse capacity increases, keeping track manually becomes a challenge as the number of products and orders increase, making tracking prone to error and thus a challenge to keep track of reorder points (Bashir et al., 2020). The frequent change in demand and increased uncertainty with order rates lead to challenging warehouse layout conditions, making it uneasy to reduce travel time and ensure that orders are fulfilled. Besides, with the increase in products being special orders, shorter product life cycles, and an increase in e-commerce, the need for integrating technology is now higher than before. The use of sensors and barcodes to maximize storage location is required to enhance warehouse operations to reduce the time it takes to detect the location of products, resulting in a shorter lead time (Zuehlke, 2010). To elaborate, the use of technology in warehouse operations reduces the disadvantages of manually keeping track of products, which is time-consuming, has a high chance of error, and is considered a waste since a lot of the time is spent on checklists that can be automated to save time (Papcun et al., 2019)

2. Literature Review
2.1 Warehouse Management
Over the years, the warehousing system has significantly transformed from a small local storage area to a more sophisticated multimillion-dollar facility. Yet, the operations of warehouses remain approximately similar today. Warehouses are essential components that integrate all aspects of the supply chain network in order to fulfill the required flow of material and information throughout the system (Kumar et al., 2021).

Processes within a warehouse are essential components that affect the entire operations; the overall process remains the same between warehouses. However, the specific strategies and policies within the warehouse vary. Items flow through particular processes such as receiving, storage, and order picking. The receiving process begins when items arrive at the warehouse through trucks from suppliers for either storage or shipment purposes, depending on the warehouse. The storage process where things are being stored in a designated area. Depending on the warehouse and its layout and policy, this step highly varies based on various factors such as order quantity, product type, warehouse's end user, etc. Order picking is retrieving items from the storage area to the area to be prepared for dispatch. Many warehouses manually operate their steps, while others are automated using conveyor belts, forklifts, etc. (Rouwenhorst et al., 2000). Reducing response time is a critical factor in reducing lead time operations of the warehouse, which is then reflected in the responsiveness of the overall supply chain. The critical decisions that need to be identified are storage dimension, storage policy, and retrieval policy (Zaerpour et al., 2013).

Storage capacity is the allocated space needed to meet the level of inventory stored within a dedicated area. The efficiency of warehouses is highly dependent on the success of the order fulfillment rate, which is very reliant on storage types, reduced lead time, and efficient human motion within the warehouse. The design of the warehouse is highly dependent on various interrelated factors, including the receiving process, storage policy, order picking, and storage system. These decisions have to be structured, and the tradeoff of these factors has to be considered to maximize the warehouse's design to its optimal level (Rouwenhorst et al., 2000). The design of warehouses varies depending on the nature of the warehouse, equipment used to fulfill orders, human motion, use of technology, aisle arrangement, etc. This review examines four types of storage assignments: dedicated storage, chaotic/randomized storage, full turnover storage, and class-based storage (Muharni et al., 2019).

A dedicated storage policy allows efficient data handling as items are in dedicated locations, where each product's unique code is assigned to its location; that allows efficient product handling by minimizing time to get to the product, especially experienced within the warehouse labor. In the dedicated storage warehouse, each product has a designated assigned location for storage (Muharni et al., 2019). The main advantage is that having dedicated storage allows products with a high order ratio to be placed closer to the warehouse's input/output point, allowing an efficient order fulfillment rate (Lee * and Elsayed, 2005). Accordingly, less time is spent on traveling due to the fixed locations of inventory. However, due to limited space, the maximum number of products allowed within the warehouse should be equivalent to the number of stock-keeping units (SKU) available in the storage (Rizzi and Zamboni, 1999). Accordingly, the assumption that the inventory turnover rate is constant is unreliable, as demand changes frequently, and thus as the turnover rate of products changes, the allocation has to be altered (Zaerpour et al., 2013). Dedicated storage is cost-effective if order-picking cost is considered only (Muppanimuppant and Adil, 2008).

In a randomized storage warehouse, the closest empty storage slot is assigned to any product (Muharni et al., 2019), which has a randomized chance of being allocated in any location within the warehouse, where once the item has arrived at the input point, empty slots are scanned for the products to be placed (Hausman et al., 1976). Hence, this allows better utilization of the warehouse. Furthermore, the capacity of the warehouse is not necessarily correlated with the amount of inventory available. However, due to products being randomly assigned to slots, this results in high levels of waste identified as motion, as time is spent searching for products (Petersen, 1999). Unlike dedicated storage, this option is cost-effective if only space cost is considered (Rizzi and Zamboni, 1999).

Full turnover storage is a storage policy highly dependent on demand, such that products with high turnover rates are placed closest to the input/output point, and products with lower demand rates are placed further down the warehouse. However, this storage policy is inconsistent as it is based on demand, which fluctuates frequently, especially with shorter product life cycles. The prediction that the product turnover rate remains approximately constant is unrealistic, and with fluctuations in demand, products will often be reallocated as the storage policy would likely be inconstant (Zaerpour et al., 2013). Shifts in the market and the resulting need to reassign warehouse storage space frequently often require the movement of stock, which can lead to significant disturbances in warehouse activities (Fontana and Cavalcante, 2014).

A class-based storage warehouse combines dedicated and random storage, also known as ABC Zoning. Using class-based storage allows products with high demands to be placed in the zone closest to the input/output point, thus being stored randomly within this location as a utilization technique to maximize flexibility within the area and reduce total lead time. Class-based storage implies the use of the Pareto principle, which indicates that 80% of the revenue is generated by only 20% of the products. Hence, products are assigned to each class based on the revenue generated (Derickx, 2012). A common criterion is created to determine the zone of each group, and then each product is randomly assigned a location within the zone. Thus, using dedicated storage zones are assigned and then randomly assigned to each slot within the zone according to a random storage policy [6]. This storage policy incorporates the benefits of both dedicated and random storage, along with a minimized travel time (Zaerpour et al., 2013).

There are mainly two options for the picking route: single order picking or batch picking. Single-order picking involves assigning one customer order to each picker, who picks all around the warehouse specifically for that order. In contrast, batch picking consists of assigning orders to a picker based on the capacity in which all orders in the batch must be completed in a single trip, which usually takes thirty minutes to two hours. Batch picking is beneficial because it significantly reduces the total picking time (Derickx, 2012). In order fulfillment operations, two key factors are performed regarding inventory management: stocking list and picking list. A stocking list is the placement of incoming products in the desired location within the warehouse. While the picking list is the location selection from which orders are being retrieved (Zhang et al., 2020).

Several literature works have shown that heuristics are the most commonly used approach in applications in warehouse optimization. Heuristic methods provide near-optimal solutions with fewer confusions and inefficiencies, leading to fewer mistakes by the pickers. However, they have the downside of providing only a near-optimal solution and may be overly simplistic. The optimal algorithm can confuse the pickers and may not offer a consistent pick path. Theoretically, an optimal algorithm through simulation would result in more accurate results rather than the heuristics method. However, from a practical perspective, heuristic methods are more commonly utilized due to their simplicity (Derickx, 2012).

To determine the storage policy, the picking policy must also be examined since these two attributes are codependent. The literature suggests considering the two aspects is critical when determining the optimal solution. Where the storage policy highly affects the picking policy recommended. Thus, simulation is an essential tool to analyze different alternatives combined since selecting the appropriate storage and picking a policy is complex and requires trade-offs between multiple objectives at various stages of the process (Derickx, 2012). However, simulation models are complex and require training to develop models that are valid and mitigate real-life scenarios. Developing the model is time-consuming as it might require coding languages. Lastly, due to many random external effects in real case scenarios, reflecting that on a simulation model can be challenging to interpret (Banks, 1999).

The literature requires a systematic approach to warehouse design. However, the challenge remains that there needs to be a general model or systematic approach to lead researchers in this field. There are variations within different warehouses due to the different circumstances of each warehouse and its costs. Once the costs are estimated, this would enable the development of a systematic approach to designing warehouses, which would address the gap existing in the literature as identified by researchers in this field (Derickx, 2012).

2.2 Automation in warehouses

Another aspect that reflects an excellent warehouse layout is automation. Keeping track of an item's location within a small storage area can be done manually through sheets, ticking off items available within the store, and reordering as soon as are missing. Performing this task manually is inexpensive and time-consuming as the location is kept to a minimum distance within the storage area. Thus, when implementing a randomized storage location within a larger storage area or a warehouse with many aisles, storage locations, and various products, keeping up with it manually is not convenient, inaccurate, and very time-consuming. Hence, with barcodes, keeping track of products and empty slots maximizes warehouse utilization and increases product handling efficiency. Thus, using barcodes to transmit information to a system is a cost-effective tracking tool that can reduce time, where both item's locations and number in stock are tracked, which allows information on replenishment times (Bashir et al., 2020).

Barcodes could also be utilized as effective codes that can be recognized by a machine/computer, where codes consist of a group of lines, spaces, and numbers that can be scanned through the laser beam known as the barcode reader. This can be later reflected in the central processing unit to determine information about the barcode. In the case of a retail hypermarket case study by Hamdi et al., barcodes have reduced labor costs by 25% (Bashir et al., 2020). In a randomized or class-based storage warehouse, implementing barcodes could be the main tool used to track and trace items and determine the empty slots, product location, replenishment cycles, etc.

Many subprocesses have been automated throughout the product development until the supply chain network, starting from raw materials production to delivering the products to the end customer. Today, automation is needed in any aspect that fulfills human requirements, whether that means a simple task such as using automation to read the news or to predict the weather. Automation is commonly used in warehouses to increase efficiency, reduce error, and better handle products within the warehouse. Implementing automation within the warehouse allows better tracking of products and the exact location of empty slots, reducing the total lead time of the logistics process. Accordingly, implementing automation minimizes the data input error in the system (Muppanimuppant and Adil, 2008). However, integrating automation requires alerting the nature of the warehouse by switching to technology-based systems. This is considered costly in the short term from a financial perspective, along with the time it takes to adapt and implement the changes. Such as training labor, understanding the warehouse's nature to integrate automation, etc. (van Geest et al., 2021). Integrating the use of automation along with barcodes will reduce the time it takes to fulfill orders, as scanning the barcodes allows easier tracing of the product's location and exact slots, increasing the efficiency of the logistics process, thus meeting demand and delivering orders on time indicating customers satisfaction which reflects on the success of the warehouse operations (Rizzi and Zamboni, 1999).

Radio Frequency Identification (RFID) is a cutting-edge technology in which items can be identified and tracked automatically by placing a single tag. This is accomplished by using a transceiver, its antenna, and the transponders, which are the tags that carry the data (R.T. White et al., 2007). RFID has many potential benefits; amongst them is the ability to trace and track items within the supply chain and locate them within the warehouse in a timely, efficient manner. Many corporations are incorporating RFID into their warehouses to enhance supply chain efficiency while reducing waste and errors [21].

Both barcodes and RFID originate from the same concept, auto identification, a broad category of technologies used to identify objects and people. Unlike barcodes, RFID can identify multiple tags simultaneously. RFID allows items to be tracked automatically, which is considered a significant benefit, unlike barcodes, which require manual scanning and tracking. However, RFID uses signal frequency which can be interrupted, and the tags are affected when containing metals and liquids. While barcodes are not affected by such conditions (R.T. White et al., 2007).

In most supply chain, barcodes dominate the market as it is widely applied in many markets and is considered a mature technology. While RFID's implementation is highly dependent on the return on investment and thus from a financial perspective, many companies still employ barcodes for that reason (R.T. White et al., 2007).

With the growing interest in utilizing RFID technology throughout the supply chain and its various industries. Its applications vary from asset tracking, such as cargo tracking, to supply chain management and operations. RFID has numerous advantages and disadvantages. Its advantages include better inventory management within warehouses, reduced logistics costs, and overall efficiency in business operations. The increase in scanning efficiency results in reduced labor intensity. Better tracking in the warehouse and better resource utilization. Yet, with the increased costs of RFID, its cost isn't noticeable to the customers where; some see it as unworthy since it doesn't benefit end users. Other disadvantages include privacy concerns, implementation costs, and human resistance to technology adoption (Osyk et al., 2012).

2.3 Simulation Classification

Classification of simulation modeling methods are mainly three: system dynamics, discrete events, and agent-based. Each of these types has its uses, benefits, and software depending on the functions of the model (Sumari et al., 2013). The method employed for modeling a problem should be driven by the nature of the problem itself and the objective of the model (Maidstone, 2012).

System dynamics is a form of simulation modeling that revolves around the network's flows; it comprises stocks and flows. Stock is the accumulation, while the flow is movements in and out of the stock (Maidstone, 2012). System dynamics emphasize feedback loops, mainly positive and negative, depending on the relationship among variables. System dynamics is used at a tactical level to gain insight into system behavior. However, modeling the system through system dynamics becomes challenging as it becomes more complex. System dynamics can be modeled through various software; the most common is Vensim and Stella. In comparison, Vensim is considered more complex than Stella because Stella has a user-friendly help guide that is more beneficial for beginners (Sumari et al., 2013).

Discrete event is often correlated with the use of queues and servers (Maidstone, 2012). It has been primarily utilized in the field of operations research since the 1960s. Used at the operational level as it evaluates system performance through the process flow sequence of events with the use of stochastic methods. A discrete event uses a top-down approach to the model. It is a very effective tool to be utilized when making decisions and predicting outcomes. It is considered a direct approach to modeling once the problem to be solved is identified. Yet, it has the shortcoming of not being an effective tool for modeling human behavior and interactions within a system. Discrete event simulation can be modeled through two leading software, ProModel, and Arena, due to its simplicity (Sumari et al., 2013).

Introduced in the 1990s, Agent-based simulation (ABS) uses agents that follow specific guidelines/rules and interact with other entities in the model (Maidstone, 2012). Using state charts, entities are to be distinguished, and transitions occur when agents interact. An agent-based simulation is often used to demonstrate problem-solving due to its ability to have agents interacting, and a new phenomenon or agent can emerge due to the interaction. Unlike discrete event simulation, Agent-Based simulation uses a bottom-up approach when modeling; once the characteristic of the agents is identified, the model can be established. However, agent-based simulation requires computation skills to mimic complex real-life systems. The agent-based simulation uses the Anylogic software, which mimics agent-based interactions. Anylogic uses Java code to model and is flexible for using discrete event simulation, system dynamics, or agent-based (Sumari et al., 2013).

2.4 Implementation of Lean and RFID in warehousing

Lean manufacturing also correlated with just-in-time production and the Toyota Production System based on the philosophy of continuous improvement. It aims to eliminate waste and reduce overall costs associated with the production or the process. Value stream mapping (VSM) is a standard tool correlated with continuous improvement such that it identifies waste and then aims to eliminate it, improving productivity and providing efficient processes. It demonstrates how material and information flow within a process, allowing the bottleneck to be identified (Chen et

al., 2013). Lean techniques can be utilized to increase the utilization of the warehouse, its operations, and resources; with the motion being recognized as a form of waste, it is often abundantly identified in warehouses from the receiving process up until the shipping process (Gopakumar et al., 2008).

Value Stream mapping consists of two diagrams, current and future state. The current state is the initial or current state at any facility, which is used to identify waste, redundant steps, and waiting times. It allows visualization of the process in order to capture the essentials from the trivial processes/steps. After waste is identified and eliminated through the various techniques and tools used to eliminate waste and enhance operations, the future state map is created to recognize the improvement to the system/process visually (Chen et al., 2013).

In a study by Chen et al. in a distribution center, lean has been integrated with the use of RFID to improve the system's productivity. The storage policy of the warehouse has been adjusted to dedicated rather than random, with products having the highest turnover rate being placed closest to the input/output point of the warehouse. Improvements were made to the receiving, storage, packing, and shipping processes. The receiving process had an 81% improvement in the value-added time, while the storage, packing, and shipping showed 95%,60%, and 99% improvement, respectively. With the integration of lean and RFID, the overall operations of the warehouse can save up to 87% (Chen et al., 2013).

3. Conclusion

After a deep investigation into warehouse management and storage policies, the following research concluded that the policy relies on choice. Therefore, the storage policy deployed must align with its specific objectives, requirements, and costs. To best utilize warehouse operations, the automation of processes enhances the performance, resulting in the overall improvement of the supply chain performance. Creating a simulation model that represents a warehouse and its various processes is valuable for testing different storage policies and assessing their impact on operations, lead times, and utilization of employees. The processes imitated and the outcome expected will determine the best-fit simulation type and receive effective results.

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