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MOQ MODELS REVIEW IN PERSPECTIVE OF 7 WASTES

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Purpose: Paper aims to review available knowledge base about MOQ models and review their application to 7 wastes.
Design/methodology/approach: Research areas were identified through author-assigned keywords linked to individual scientific publications. The multi-stage research process incorporated two bibliometric methods: a systematic literature review and a traditional literature review. Scope of the paper gathers published optimization models of MOQ. Available database was reviewed with the purpose of Collected models are reviewed under the objective of 7 wastes.
Findings: The research identified five models focused on optimizing Minimum Order Quantity (MOQ). Each model addresses inventory-related waste, recognizing inventory costs as a significant factor in overall production expenses. Notably, one model also incorporates transportation and defect costs, providing a broader approach to waste reduction. The data shows a clear trend: as manufacturing costs rise, driven by factors such as inflation and supply chain disruptions, there is an increasing demand for advanced optimization models to mitigate these pressures. These models aim not only to reduce inventory costs but also to enhance production efficiency and quality, supporting manufacturers' ability to remain competitive in a challenging market environment.
Originality/value: Compared to other bibliometric analyses, this study distinguishes itself through the precise syntax of its constructed query. Furthermore, the paper investigates the application of models concerning waste categories recognized in lean management techniques. By identifying forms of waste that have been overlooked in prior research, this study offers valuable insights for researchers and practitioners in determining future research directions.
Keywords: MOQ, optimization, supply chain, lean manufacturing, lean management, 7 waste.
Category of the paper: Literature review.

1. Introduction

Supply chain (SC) is a network of organizations, resources, people, activities and technology involved in the creation and distribution of a product, from the sourcing of raw materials to the delivery to end consumers. It consists of components like suppliers, manufacturers, warehouses, distribution centers, retailers and customers. All of those stakeholders shape processes of procurement, production, logistics, inventory management and order fulfillment (Chopra, Meindl, 2016). Efficiency of the supply chain can be measured by various key performance indicators. Few of the most common ones are businesses waste results, dispatch rate, forecast accuracy and inventory turnover.

Optimizations in supply chain occur on multiple levels under various processes. The ideal and effective supply chain has the ability to balance costs, quality and speed in delivering the goods to the customers fulfilling their demand. Throughout multiple processes during the production, imbalances can lead to increase in costs. In order to improve the efficiency of the company manufacturers aim to identify and minimize such imbalances using various techniques.

Manufacturing, regardless of production volume, is inherently linked to waste. Taiichi Ohno, within the framework of the Toyota Production System, identified and categorized these inefficiencies as the '7 Wastes'. Based on those wastes each supply chain process can be analyzed and right bottle necks can be optimized. The idea is that reducing waste leads to higher quality, lower costs and improved delivery times. Optimization efforts are frequently supported by mathematical models tailored to address specific aspects of supply chain operations or provide a comprehensive, system-wide analysis. The purpose of this study is to evaluate the current body of knowledge on optimization models related to MOQ and to determine which categories of waste these models address.

2. Theoretical foundations of the concept of MOQ models and 7 wastes

Minimum Order Quantity (MOQ) optimization is a critical component of effective supply chain management. This optimization focuses on determining the optimal production or order volume that minimizes operational costs while maintaining an acceptable dispatch rate to customers. The MOQ represents the minimum quantity that a buyer must order from a supplier in a single transaction. Effective management of MOQ seeks to balance ordering costs, inventory levels, and potential business losses.

The significance of MOQ management is particularly pronounced for companies dealing in low-margin products, as high inventory levels can lead to substantial financial losses. By optimizing MOQ, businesses can reduce costs associated with inventory, minimize the risk of obsolescence, and enhance operational efficiency. A key challenge in MOQ optimization lies in accounting for demand variability and lead time uncertainty. These factors necessitate the use of advanced analytical methods, including stochastic modeling and computer simulations, to develop effective strategies (Shenoy, Zhao, 2019; Klamerek, Kutnik, 2023).

In the realm of global supply chains, the complexities associated with MOQ optimization increase significantly due to the diversity of suppliers, variations in delivery times, and fluctuations in transportation costs. In such contexts, well-designed optimization algorithms can lead to significant reductions in operational costs and improved cash flow. Furthermore, effective MOQ management can foster sustainable growth by addressing issues of overproduction and reducing the carbon footprint associated with transportation and inventory.

Research regarding supply chain optimization often integrates MOQ optimization with other operational decisions, such as inventory management, production planning, and transportation logistics. Consequently, MOQ optimization becomes an integral part of comprehensive operations management strategies aimed at enhancing a firm's competitiveness in the marketplace. The process of MOQ optimization is multifaceted, requiring a deep understanding of demand dynamics, cost structures, and operational constraints, positioning it as a vital element of contemporary supply chain management (Gupta et al., 2019; Li et al., 2020; Liu, Zhang, 2021).

Optimization processes are closely related to Lean Management as both aim to maximize efficiency and minimize waste. Lean Management's core objective is to identify and eliminate waste in all forms (e.g. time, materials, any non-value adding efforts). Optimization processes are often used within Lean Management to assess workflows, identify inefficiencies, and find ways to streamline operations, effectively reducing or eliminating these wastes. Lean Management tools encompass various methods and techniques utilized in the management and optimization of both production and service processes. The Lean concept originated in the 1950s at Toyota Motor Corporation in Japan, specifically within the framework of the Toyota Production System (TPS). Since then, it has gained global popularity. Lean Management emerged from post-war Japan, where Kiichiro Toyoda and Taiichi Ohno, inspired by American manufacturing methods such as the Ford Production System, developed their own approach to managing production processes. Initially implemented in Toyota's facilities, this system aimed to improve production efficiency by eliminating all forms of waste (Japanese: muda), defined as activities that do not add value to a product or service from the customer's perspective.

The principles of Lean Management have been widely adopted across various industries, driving significant improvements in operational efficiency and customer satisfaction. Researchers have explored the application of Lean Management in diverse contexts, illustrating their effectiveness in streamlining processes and fostering continuous improvement. One such application involves optimizing Minimum Order Quantity (MOQ) models, which align Lean principles with inventory management by reducing excess stock and waste, thus enhancing cost efficiency and supporting sustainable operations (Dekier, 2012).

In the framework of Lean Management, Taiichi Ohno conceptualized "waste" as any action that fails to add value to the process, product, or end customer. This led to the formalization of the "7 Wastes" methodology, which identifies and categorizes common sources of inefficiency in production systems. These wastes include (Ohno, 1988; Liker, 2004):

- Overproduction – production of more than required by the client which leads to increase in inventory, followed by additional inventory costs and risk of products going out of date.
- Inventory – excessive stocks of raw materials, semi-finished products or finished products are tied up capital that could be used more effectively in other areas of the business.
- Overprocessing – performing activities that do not add value to the product from the customer's perspective, such as additional testing or corrections that are not necessary.
- Motion – unnecessary movement of workers or tools in the production process, which increases the time it takes to complete tasks and reduces efficiency.
- Waiting – downtime caused by waiting for deliveries of materials, tools or information, which delays the production and delivery process.
- Defects – producing defective products that require correction or total rejection, which generates additional costs and delays.
- Transport – the unnecessary movement of products or materials between different locations in a production facility, which adds no value to the product but increases production costs and time.

3. Methods

The article uses the process of literature review enabling the identification of current state of researched area. Literature review is a systematic process of gathering, evaluating and synthesizing existing research on a particular topic or question. This type of review aims to provide a comprehensive summary of current knowledge, identify trends, and recognize gaps in the research. Unlike systematic reviews, which follow a rigorous, pre-defined methodology, regular literature reviews offer more flexibility in selecting and analyzing sources, allowing for broader coverage of the topic (Machi, McEvoy, 2021). In the initial stages, a literature review begins with formulating a research question to guide the review process. From there, sources are identified through systematic searching of academic databases, such as Scopus, Web of Science, and Google Scholar, and other relevant sources. The chosen source was Web of Science and the time frame covered the publications up until June of 2024. After selecting the literature, each study is critically analyzed for its methodology, findings, and relevance to the research question.

Based on the above, the aim of the article was to classify scientific research on the problem of MOQ optimization.

In the context of conducting a systematic literature review, two key research questions were developed:

I. What are the current MOQ models that focus on optimization published in the literature?
II. Which of the "7 wastes" have been addressed or mitigated by the available MOQ optimization models?

In the Figure 1 bibliometric analysis methodology for the study done for the paper is presented.

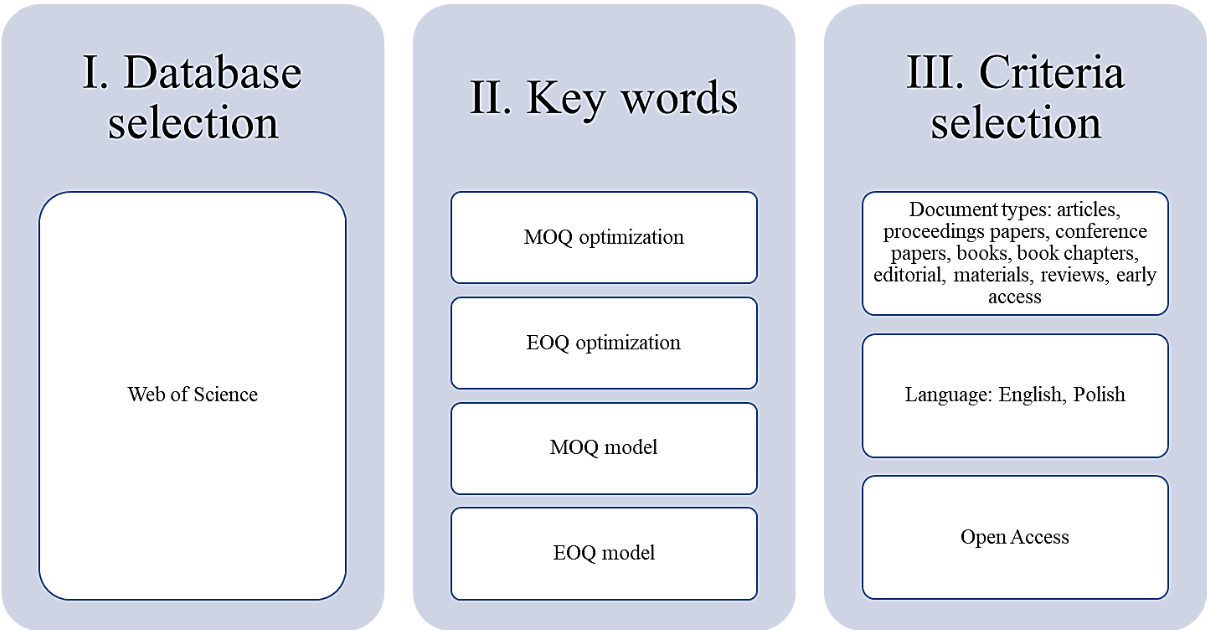

Figure 1. Bibliometric analysis methodology.

Source: author's own study.

As per fig. 1 for the first step bibliographic sources were selected. Web of Science (WoS) was taken under consideration as the leading citation indexing and research discovery platforms that offers valuable insights and performance statistics for academic publication. The WoS indexes over 34 000 journals across various disciplines and regions, but also includes books, conference proceedings and other types of academic documents.

The selection of key terms, such as Minimum Order Quantity (MOQ) and Economic Order Quantity (EOQ), is often based on their practical relevance in inventory management. Although MOQ and EOQ address different aspects of order quantities, they are sometimes mistakenly used interchangeably due to their apparent similarities in optimizing supply chain processes. MOQ refers to the minimum quantity of a product that must be ordered to satisfy production or supplier requirements, whereas EOQ is a formula used to determine the optimal order quantity that minimizes total inventory costs. The initial search for literature involved the use of phrases such as 'MOQ optimization' and 'MOQ model' within full-text documents, followed by a subsequent search incorporating 'EOQ' to expand the scope.

To refine the scope of the search, a set of eligibility criteria was applied. The search was restricted to publications that met the following conditions: a) openly accessible; b) available in English and Polish; c) comprising articles, conference papers, books, book chapters, reviews, editorials, and early access publications. Excluded from the search were withdrawn publications, conference reviews, short surveys, notes, errata, and letters.

4. Results and discussion

The screening process of Web of Science aimed to identify models optimizing MOQ, and not only mentioning it as a factor. The revision concluded with 2 linear and 3 nonlinear optimization MOQ models. The linear models are "Effective control policies for stochastic inventory systems with minimum order quantity and linear cost", "Two-level supply chain with order quantity constraints", and the nonlinear are model "SSMR", model "OWMR" and "MOQ and Batch ordering" model.

One of the linear models analised is Inventory management model. Inventory management name was implemented for the purpose of this paper, however the original name is *Effective control policies for stochastic inventory systems with minimum order quantity and linear cost.* This model was developed based on a periodic review of the stock of a single product. This model assumes that the retailer has the ability to place an order at any stock level with an order quantity equal to or higher than the minimum order quantity MOQ *M*. Inventory management model assumes in the first step that at the beginning of the adopted period of time, the retailer reviews the stock and places an order with its supplier. At the end of this period, the order is fulfilled and the retailer covers the demand of its customers. If the retailer's stock level is not sufficient to cover all customer demand, the demand generated after the stock is depleted is considered as a backlog.

Inventory Management model (eq. 1) utilizes the assumptions of Markov's chain and (*s, t*) policy, where "*s*" stands for reorder point and "*t*" stands for time interval (Zhou et al., 2007).

$$p_{i,j} = \begin{cases} P_{(i-j)^+} & for\ j = t+1, t+2, \dots, s+M-1, \forall i = t+1, \dots, t+M \\ \sum_{k=i-s}^{+\infty} p_k + p_{(i-j)^+} & for\ j = s+M, \forall i = t+1, \dots, t+M \\ p_{i-j+M} + p_{(i-j)^+} & for\ j = s+M+1, s+M+2, \dots, t+M, \forall i = t+1, \dots, t+M \end{cases} \quad (1)$$

where:

$p_i = P(D=i)$;

$p_{(i-j)^+} = p_{i-j}$, if $i \geq j$, zero in any other cases;

M – minimum order quantity (MOQ);

k, i, j – based on equation assumptions (that is: $k=i-s$ in case of $p_k + p_{(i-j)^+}$, while values i and j are different for each assumption and depend on parameters t, s and M);

t – time interval;

s – reorder point.

By focusing on managing the inventory levels, controlling the reordering and considering probabilistic demand model aims to optimize the waste of excess inventory. Markov's chain approach with an (s, t) policy ensures that the inventory levels are within the optimal bounds, which means that there shouldn't be overstocking nor understocking. Reorder point and time interval incorporated by (s, t) policy helps the system to decide on reorder volume and time. Such system suggestion is crucial when MOQ is the inventory building component. Thanks to Markov's chain use the Inventory Management model is not constrained with demand fluctuations. Markov's chain allows for probabilistic modelling of demand improving the alignment of inventory with demand variability.

Model "Two-level supply chain with order quantity constraints" defines an objective function as the sum of total revenues and total costs over a specified time horizon. The model assumes that lead time between the manufacturer and the retailer is negligible and that product shortages may occur. Additionally, it is assumed that the retailer's order sizes must be placed in fixed quantities, and demand for each product is known but variable. Demand in each analyzed period is continuous, with no transportation constraints, meaning that a sufficient number of vehicles is available to fulfill all deliveries.

The mathematical representation of the "Two-level supply chain with order quantity constraints" model is presented in eq. 2.

$$\begin{aligned}\sum_t \sum_i \sum_j X_{ijt} * \left(1 - P_{ij}\right) * S_{g(ij)} + \sum_t \sum_i \sum_j X_{ijt} * P_{ij} * S_{d(ij)} - \sum_t \sum_i \sum_j X_{ijt} \\ * b_{ij} - \sum_t \sum_j O_j * Y_{jt} \\ - \sum_t \sum_i \sum_j X_{ijt} * v_i \\ - \sum_t \sum_i \sum_j Z_{ijt} * y_{ijt} * \beta_{ij} * (Q_{\min(i,j)} - X_{ijt}) \\ - \sum_j \sum_t E_{jt} * A_j - TC(H) - TC(L)\end{aligned} \tag{2}$$

where:
i – product variable;
j – supplier variable;
t – time period;
X_{ijt} – given order volume of product i at supplier j withing time period t;
P_{ij} – average percentege of products i defected in particular production batch at supplier j;
$S_{g(ij)}$ – unit price of non-defective product i producted by supplier j;
$S_{d(ij)}$ – unit price of defective product i producted by supplier j;
b_{ij} – market price of product i from supplier j;
$TC(H)$ – total holding period for all products;
$TC(L)$ – business losses;
Z_{ijt} – a binary variable defining the cost of reducing the order quantity (if the retailer places an order for product i from supplier j at time t with a batch size smaller than the minimum order quantity set by supplier j, then $Z_{ijt} = 1$; otherwise $Z_{ijt} = 0$);
O_j – the cost of ordering from a supplier j regardless of the type and quantity of products;
Y_{jt} – a binary variable specifying whether the order is fulfilled by supplier j (if the order is fulfilled by supplier j $Y_{jt} = 1$; otherwise $Y_{jt} = 0$);
v_i – inspection cost per unit of product i;
y_{ijt} – a binary variable specifying whether the order for product i is fulfilled by supplier j (if the order is fulfilled by supplier j $y_{ijt} = 1$; otherwise $y_{ijt} = 0$);
β_{ij} – the cost of reducing the order quantity per unit of product i determined by each supplier j;
$Q_{min(i,j)}$ – minimum order quantity for product i set by supplier j for each period;
E_{jt} – number of shipments sent from supplier j in period t;
A_j – fixed transportation cost for each vehicle shipped from supplier j.

The model considers several factors outlined in Equation 2, where the total cost of a production run is calculated as the combined cost of non-defective and defective products. From this sum, costs associated with ordering, quality checks, volume reduction, transportation, inventory holding, and potential business losses are subtracted (Gorji, 2014). The “Two-level supply chain with order quantity constraints” model components aligned with the 7 Wastes framework primarily highlight inefficiencies related to inventory, defects, and transportation.

One of the nonlinear models found in the literature is model SSMR. The model provides a mathematical approach to determining the optimal order quantity, lead time, safety stock levels for buyers, and the number of shipments within a production cycle between the manufacturer and buyers. This optimization aims to minimize the total expected cost per unit of time in the producer-buyer relationship, while meeting the requirements of the Service Level Commitment (SLC). The total expected production cost includes ordering and inventory holding costs, costs related to potential failures during order fulfillment borne by all buyers, as well as setup and inventory holding costs on the manufacturer’s side.

SSMR model ensures cost efficiency and reliability in the supply chain by optimizing key logistical and financial elements, ultimately supporting a sustainable, service-oriented production framework.

The total expected cost per unit of time for the SSMR model is the sum of the total expected costs incurred by both the retailers and the supplier. The SSMR model is represented by equations 3 and 4.

$$JTEC(Q,k_1,k_2,\dots,k_N,L_1,L_2,\dots,L_N,m)=\sum_{i=1}^{N}TEC_{bi}(Q,k_i,L_i)+TEC_v(Q,m) \tag{3}$$

and

$$\begin{aligned}JTEC(Q,k_1,k_2,\dots,k_N,L_1,L_2,\dots,L_N,m)\\ =\frac{D}{Q}\left[\frac{A_v}{m}+\sum_{i=1}^{N}(A_{bi}+C_i(L_i))\right]\\ +\sum_{i=1}^{N}\left[h_{bi}C_{bi}(\frac{Q}{2D}D_i+k_i\sigma_i\sqrt{L_i})\right]+\frac{Q}{2}h_vC_v[m\left(1-\frac{D}{P}\right)-1+\frac{2D}{P}]\end{aligned} \tag{4}$$

where:

JTEC –Joint Total Expected Cost;

Q – batch size per shipment, necessary to meet the demand of all buyers;

k_i – safety factor, a multiplier used to set the level of additional inventory required to minimize the risk of stockouts due to demand variability and supply chain uncertainty;

L_i – lead time for delivery;

m – number of batches supplied from the producer to each buyer within the production cycle;

N – number of retail sellers;

TEC_{bi} – total expected cost per unit time for the i-th buyer;

TEC_v – total expected cost per unit time for the producer;

D_i – average demand per unit time;

A_v – production setup cost for each configuration;

A_{bi} – order cost for each order;

h_{bi} – inventory holding cost per unit time for retail seller;

C_{bi} – purchase cost per unit for the retail seller;

P – production rate;

h_v – inventory holding cost per unit time for the producer;

C_v – purchase cost per unit for the producer.

Equation 3 expresses the expected total cost as the sum of costs for all buyers and producers, based on variables like batch size Q, safety factors k_i, lead times L_i, and the number of batches m. The expected cost for each individual buyer i is influenced by the batch size Q, safety factor k_i, and lead time L_i. Meanwhile, the producer's expected cost depends on the batch size Q and the number of deliveries m.

Equation 3 further expands into equation 4, which dissects the joint total expected cost (JTEC) into its individual components. Equation 4 summarizes the costs associated with ordering and holding inventory for each buyer i, scaled by demand D and batch size Q, including storage, safety stock, production, and delivery costs. This layered approach allows the model to identify cost optimization opportunities across the supply chain, balancing production, ordering, and inventory strategies to minimize overall costs (Jha, Shanker, 2013).

To determine the total expected cost, situations involving stockouts for retail sellers were not considered. Stockout costs are challenging to estimate due to the influence of intangible factors, such as loss of reputation and delays in subsequent supply chain stages. Through various variables, the SSMR model aims to balance storage, ordering, and production costs while minimizing the total expected cost across the entire supply chain.

Another nonlinear model that deals with optimizing the minimum order quantity is the OWMR model. The OWMR model is designed around a two-level inventory system with one warehouse and multiple retailers (OWMR). The model assumes that retailers receive orders from customers at independent times. If the demand cannot be met immediately, retailers place an order and replenish the inventory from the warehouse (level 1), which in turn replenishes it from an external supplier (level 2). In the case of the OWMR model, a warehouse is not just a room for storing inventory. The warehouse is an intermediary between the supplier and the retailers, receiving orders from retailers and then processing them into orders for the supplier. It is also assumed that there is a delay between orders and deliveries at each stage.

Equation 5 provides the formal mathematical formulation of the OWMR model (Huaxiao et al., 2019).

$$L(S_0, S_1, \dots, S_N) = \sum_{y=S_0}^{S_0+M-1} \sum_{q \geq M} Prob(Y = y, Q = q) \sum_{k=0}^{q-1} C(y-k, S_1, \dots, S_N) \tag{5}$$

where:

$L(S_0,S_1,\dots,S_N)$ – the average cost;

M – minimum order quantity, MOQ;

S_0 – agreed stock level parameter for the warehouse;

S_i – agreed stock level parameter for the retailer;

Y_n- inventory level after placing an order within n time;

$C(y\text{-}k,S_1,\dots,S_N)$ – storing cost in single time period for single retailer when inventory is $(y\text{-}k, S_1,\dots,S_N)$;

q – order volume;

y – inventory level.

The equation 5 represents the average cost as a sum over various inventory levels and orders. It is equal to a double sum; the first sum iterates over all possible inventory levels y in the central warehouse, starting from a value S_0 (the initial inventory level for the warehouse) up to S_0+M-1, where M is the minimum order quantity (MOQ); the second sum iterates over the order quantity q, which must be at least equal to MOQ M. The probabilistic part of the equation represents the probability that the inventory level Y is y and that the order quantity Q is q. This probability takes into account random changes in demand and order quantity that may result from market dynamics. The expression $y-k$ represents the inventory level after taking into account changes in inventory (for example, reductions due to sales or deliveries). In practice, the purpose of equation 5 is to balance the costs of ordering, storage, and potential losses, while taking into account variable demand and lead times.

The model minimizes the total cost of inventory management by optimizing the order size and managing inventory levels in a probabilistic manner that is responsive to changing demand. By taking into account probabilities and minimum order sizes, the model allows for achieving a balance between storage costs and ordering costs, which is crucial for effective supply chain management.

The nonlinear model, which for the purposes of this work is called the MOQ and Batch Ordering model, i.e. ordering in batches (originally called Effective inventory control policies with a minimum order quantity and batch ordering), considers a system of periodic inventory review for a single product with irregular demand. The retailer replenishes inventory from the supplier, and its order must meet stated conditions. One is that it should be a specified minimum quantity M (i.e. MOQ) and the other is that is should be a multiple of the established batch of orders Q (i.e. Batch Ordering).

The model assumes that M is an integral multiple of Q and that M is greater than Q. The retailer places an order after analysing the status of its inventory. After placing the order, the supplier fulfills the demand, and in the event of failure to fulfill the order, it is recorded for later production. In the last step, the cost of holding inventory is calculated, taking into account the costs of storing excess inventory and penalties for failure to fulfill the order (Zhu et al., 2015).

Mathematical formulation of the MOQ and Batch Ordering model is provided by equation 6.

$$C_n(y_n) = h\mathbb{E}[(y_n - D_n)^+] + p\mathbb{E}[(D_n - y_n)^+] \quad (6)$$

where y_n and D_n are integers, and:

$C_n(y_n)$ – total costs;

$\mathbb{E}$ – expected value;

h – storage cost;

y_n – stock after placing an order in a specified time period n;

x_n – stock before placing an order in a specified time period n;

D_n – demand in a specified time period n;

p – penalty cost per unit in a specified time period.

The cost function (eq. 6) enables optimization and waste reduction by balancing holding cost and shortage (or penalty) costs. Holding cost component captures the expected cost of holding surplus inventory at the end of period *n*, where y_n is the inventory after placing an order and D_n is the demand in period *n*. minimizing this cost prevents excessive stock accumulation, which is critical for reducing waste. Storage cost component accounts for the penalty cost when demand exceeds inventory, representing the expected cost of stockouts. By including this penalty, the model discourages understocking, ensuring a balance between inventory availability and minimizing overstock. In general MOQ and Batch ordering model provides a mathematical approach to optimizing inventory while simultaneously minimizing waste by balancing the key costs associated with both overstock and shortage situations.

The collection of MOQ optimization models addresses several of Taiichi Ohno's "7 wastes". Each model is designed to calculate the total production run costs for suppliers and/or retailers, focusing on different drivers of waste. In the Figure 2 shows specific wastes included in the MOQ models.

	Over production	Inventory	Over processing	Motion	Waiting	Defects	Transport
Effective control policies for stochastic inventory systems with minimum order quantity and linear cost		x					
Two-level supply chain with order quantity constraints		x				x	x
Model SSMR		x					
Model OWMR		x					
MOQ and Batch Ordering model		x					

Figure 2. Types of wastes included in selected MOQ models.

Source: author's own study.

Figure 2 provides an overview of the '7 wastes' and highlights the models analysed, using an "X" to indicate which wastes each model addresses. From this overview, it is clear that inventory waste was a primary focus, appearing in all five models reviewed. Additionally, the two-level supply chain model with order quantity constraints also considers defects and transportation waste alongside inventory.

Considering the findings of focus to optimize costs driven by inventory, defects and transportation, it is worthwhile to examine the potential explanations and underlying mechanisms. To illustrate global trends driving the need for cost optimization tools, graphs from Eurostat and Trading Economics are used to show rising industrial production prices. Implementing MOQ optimization models is thus a logical step for manufacturers seeking to manage and control these costs. By optimizing order quantities, manufacturers can reduce excess inventory expenses, a major component of production costs. Notably, MOQ models also target defects, addressing quality issues alongside cost-efficiency and reducing waste from defective products, ultimately contributing to a more streamlined and cost-effective manufacturing process.

Manufacturing cost management is increasingly complex and essential globally, so it’s no surprise that researchers are intensifying efforts to optimize these expenses. Key cost drivers include rising environmental and transportation costs, ongoing supply chain disruptions, and a growing emphasis on sustainable practices in inventory management (Pattnaik et al., 2021; Dalhousie University, 2023). Cost management for manufacturing has become increasingly intricate due to a variety of factors that directly impact operational efficiency and profitability. Rising industrial production and gasoline prices, for example, elevate both production and transportation costs, which can lead to excess inventory holding and distribution inefficiencies if not managed carefully. Additionally, increased emphasis on sustainability compels companies to reduce defects and optimize resources, further highlighting the relevance of MOQ optimization models. By addressing these specific areas of waste (such as minimizing excess inventory, reducing transportation costs, and preventing defects) MOQ models enable manufacturers to adapt to cost pressures while maintaining lean, sustainable operations (Nayak et al., 2021).

To further support above tendencies, Figure 3 presents relevant data from Eurostat regarding the industrial producer prices increasing trend.

Figure 3 presents an overview of changes to producer prices since 2015. The Y-axis represents the Industrial Producer Price Index (PPI), which is a relative measure where 2015 is set as the base year (2015 = 100). This index shows the price level changes in industrial products over time, with values above 100 indicating if prices have risen compared to the 2015 baseline and values below 100 showing a decrease. Axis X displays time, specifically the years from 2015 to 2023. Analysed period of time shows clear increasing trend in prices regardless of market kind. Types of markets shown on the graph are EU Total Market, EA-20 Total Market, EU Domestic Market, EA-20 Domestic Market, EU Non-domestic Market, EA-20 Non-domestic Market (Eurostat, 2024). This increasing trend in industrial producer prices underscores the need for companies to enhance profitability by optimizing their operational processes. One effective approach is the implementation of Minimum Order Quantity (MOQ) optimization models, which help organizations manage inventory more efficiently, reduce waste, and offset rising production costs.

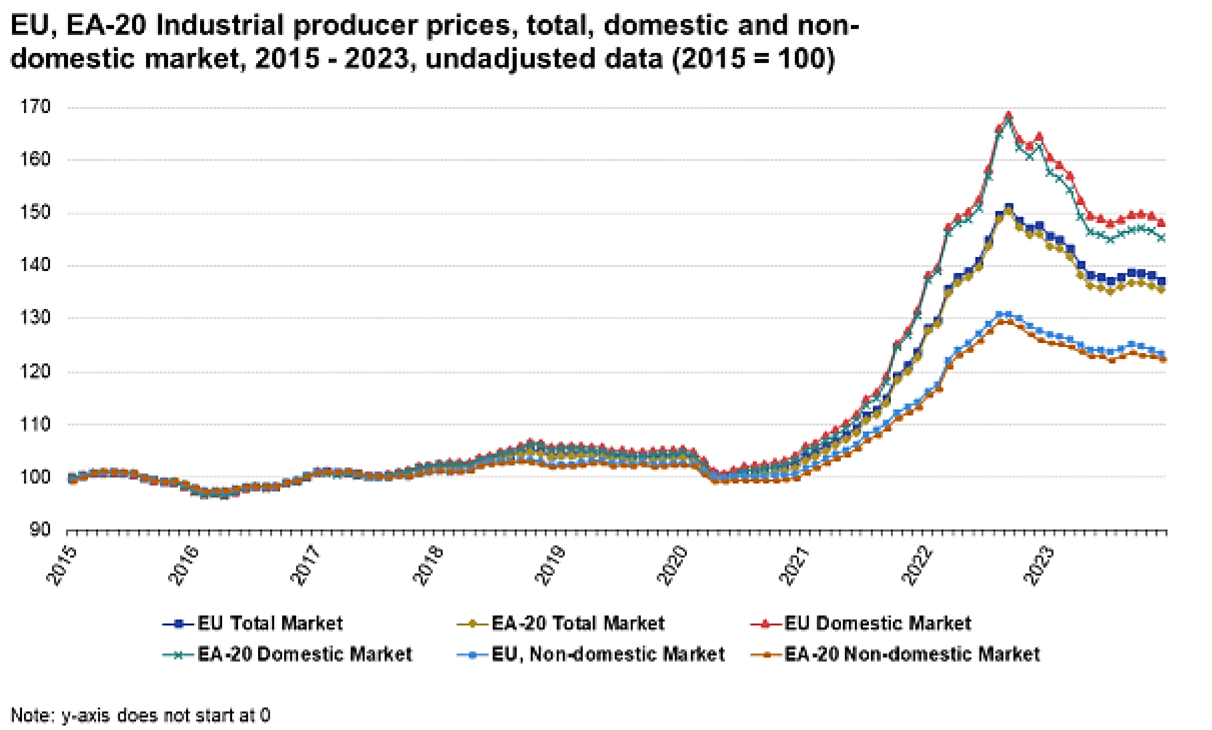

Figure 3. EU, EA-20 Industrial producer prices, total, domestic and non-domestic market, 2015-2023.
Source: Industrial producer price index overview, Eurostat.

Recent findings indicate that the cost of warehousing and inventory has been growing due to heightened demand for storage, logistics challenges, and a push toward sustainable practices. These costs are driven partly by increased energy prices, particularly the rising costs of gasoline and diesel, which significantly impact transportation expenses. This is compounded by new regulatory requirements aimed at sustainability, making inventory management and storage more expensive overall. Studies in sustainable inventory management emphasize integrating environmental considerations into inventory practices to reduce carbon footprints and improve efficiency. Implementing Minimum Order Quantity (MOQ) optimization models supports these goals by streamlining inventory levels, reducing excess stock, and lowering associated costs (Becerra et al., 2022; Schoenberger, 2024).

The observed cost increases related to warehousing, inventory, and transportation align with the broader trend of rising gasoline prices, as shown in Figure 4. The data from Trading Economics highlights these trends, supporting the rationale for adopting optimization strategies like MOQ models to counteract rising operational costs.

Figure 4. Gasoline price changes in years 2015-2024.

Source: Trading Economics, Gasoline.

Figure 4 presents the graph of historical data of gasoline prices throughout the years 2015 till 2024. Axis Y presents the USD/Gal unit (US dollar per gallon). Within this period of time the gasoline price went up from 1.35 USD/Gal in January of 2015 to 1.96 USD/Gal in October 2024 (Trading Economics, 2024). Aside from increasing trend the gas prices are easily impacted by the geopolitical reasons. Price drop in early 2020 can be related to the COVID-19 pandemia (World Health Organization, 2020) and the spike in early 2022 to Russian invasion of Ukraine (United Nations, 2022). To such price trend of gasoline manufacturers must respond by implementing optimization solutions related with transport and logistics.

5. Summary

Minimum order quantity (MOQ) has a direct impact to waste in the concept of lean management as visible within all quoted models. The review identified five models in scientific publications addressing the issue of MOQ optimization ("Effective control policies for stochastic inventory systems with minimum order quantity and linear cost", "Two-level supply chain with order quantity constraints", "SSMR", "OWMR" and "MOQ and Batch ordering"). All of these models considered the inventory. Only "Two-level supply chain with order quantity constraints" model considered defects and transport along the inventory.

A critical evaluation of these models reveals their strengths and limitations. While they offer valuable insights into reducing inventory costs and enhancing operational efficiency, their narrow focus often neglects other significant wastes identified in lean management, such as overproduction, waiting, and excess processing. This limitation underscores a critical gap in the current body of knowledge, presenting an opportunity for the development of more holistic optimization frameworks.

The study underscores the practical importance of selected models in managing rising production costs and improving efficiency. However, adapting them to modern challenges such as sustainability and global disruptions is crucial. Future research should expand their scope to include the full spectrum of the "7 Wastes", enabling more comprehensive waste reduction strategies. This paper's literature review finds that a focus on inventory management is especially prudent in this context. As discussed, manufacturing processes show a tendency toward rising costs. To achieve business efficiency while maintaining quality, production costs must be continually optimized. The analysed MOQ models primarily address inventory costs but also consider factors like transport and defects occurring during the production. With ongoing environmental, geopolitical, and economic changes, the supply chain will need to continuously enhance its efficiency. These dynamics will shape the future of enterprises and the evolution of new models to meet emerging demands.

Existing MOQ optimization models lay a valuable foundation but require enhancements to meet evolving supply chain demands. Expanding their applicability could advance both academic research and practical implementation, supporting more efficient and sustainable operations.

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