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Research on inventory model degradation

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Abstract: As a result of its practical importance in sectors dealing with time-sensitive products, things vulnerable to obsolescence, and perishable commodities, the study of degrading inventory has attracted a lot of interest in operations and supply chain management. This research delves into the history of declining inventory models, specifically looking at how they have included different elements that affect declining inventory, such as changes in demand rates, lead times, pricing tactics, and environmental concerns. The study takes a look at both old and new models, analysing deterministic and probabilistic techniques, and hybrid methods that use fuzzy and stochastic variables to convey real-world uncertainty better. Important topics covered include the financial effects of degradation, the best way to place orders, and how technology can help with both management and prediction of degradation. The purpose of this research is to fill knowledge gaps in the current literature by proposing novel theoretical frameworks and modelling approaches to deal with complicated inventory dynamics, particularly under unstable and unpredictable market conditions.

Keywords: Deteriorating inventory, perishable goods, demand fluctuation, stochastic models, optimal ordering

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INTRODUCTION

In businesses where items have limited shelf lives and are prone to degradation over time, inventory management has become a crucial component in optimising supply chain operations. This is particularly true in industries where products are consumed as quickly as possible. Products like as food, medicines, chemicals, and high-tech items that lose value or utility over time are examples of the types of inventory that fall into this category, which is usually referred to as degrading inventory (Jaggi & Aggarwal, 2020; Shah et al., 2022). In order to effectively manage deteriorating inventory, specialised models are required. These models must not only take into account typical inventory characteristics like demand rate and order quantity, but they must also take into account deterioration rate, holding cost, and waste management.

Beginning with deterministic models that assume a constant degradation rate over time, many models have been created to handle inventory deterioration (Goyal & Giri, 2001). These models have been developed to address inventory deterioration. However, such models often simplify the circumstances that exist in the actual world. In response, stochastic models came into being, which included probabilistic components to capture fluctuations in demand as well as uncertainty in the environment (Wee, 2021). In more recent techniques, fuzzy logic is combined with stochastic features. This combination enables decision-makers to capture both the intrinsic unpredictability of demand as well as the ambiguity of market situations (Kumar et al., 2023).

In a deteriorating inventory study, several key factors play critical roles in shaping inventory models and strategies. These factors are essential to understanding and optimizing inventory management for perishable or time-sensitive items. Here are some of the primary factors:

Deterioration Rate: The rate at which inventory loses value or usability over time, often influenced by the product's nature (e.g., food, pharmaceuticals) and environmental conditions (temperature, humidity).

Demand Rate: The rate at which inventory is consumed or purchased by customers, which can vary based on seasonality, market trends, or customer preferences. It may be deterministic (constant) or stochastic (variable).

Ordering Policies: Strategies for when and how much to reorder to minimize costs associated with holding, ordering, and shortage. Common policies include Economic Order Quantity (EOQ), Economic Production Quantity (EPQ), and just-in-time (JIT).

Holding Costs: Costs associated with storing inventory, including warehousing, insurance, and opportunity costs. For deteriorating items, holding costs can rise due to additional refrigeration, monitoring, or potential waste management.

Lead Time: The time between ordering and receiving the inventory. Lead time can be fixed or variable and significantly impacts inventory levels, especially for deteriorating items with limited shelf life.

Shortage and Backorder Costs: Costs incurred when demand exceeds supply, leading to stockouts or backorders. These costs often encompass lost sales, reduced customer satisfaction, and potential penalties for delayed deliveries.

Disposal or Salvage Costs: Costs associated with removing unusable or expired inventory, or the salvage value of inventory that can be sold at a discounted rate. Proper management of disposal helps reduce total inventory cost.

Price-Sensitive Demand: The impact of pricing on demand, especially when discounts are used to stimulate sales of inventory nearing its expiration or obsolescence date.

Uncertainty and Risk Factors: Factors such as market volatility, environmental conditions, or supplier reliability that affect both the demand and the deterioration rate, necessitating robust models that incorporate stochastic or fuzzy approaches.

The inventory problem of deteriorating items was first studied by Whitin (2002), he studied fashion items deterio- rating at the end of the storage period. Then Ghare and Schrader (2000)concluded in their study that the consump- tion of the deteriorating items was closely relative to a negative exponential function of time. They proposed the deteriorating items inventory model as stated below:

$$\frac{dI(t)}{dt} + \theta I(t) = -f(t)$$

In the function, stands for the deteriorating rate of the item, $I(t)$ refers to the inventory level at time t and then $f(t)$ is the demand rate at time t. This inventory model laid foundations for the follow-up study. [4] and [5] made comprehensive literature reviews on deteriorating inventory items in 1991 and 2001 respectively.

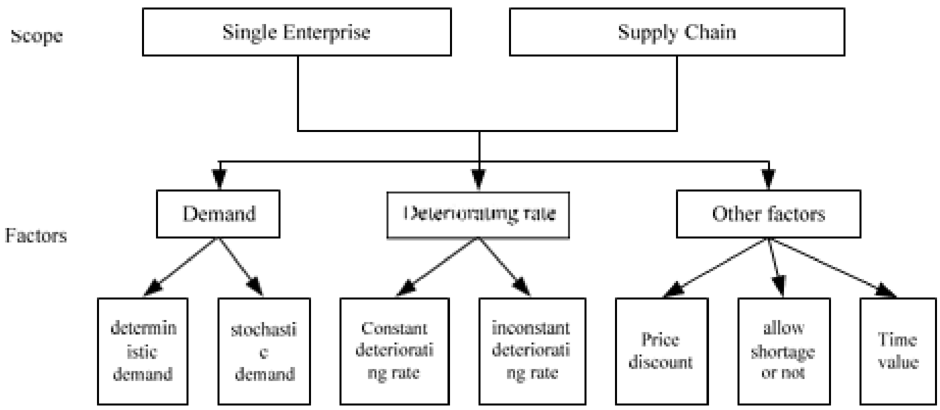

Figure 1: Deteriorating items inventory literature and its relation in the review

As shown in Figure 1, which illustrates the interdependence of components such as demand rate, ordering procedures, and deterioration rate, deteriorating inventory models take into account the whole lifespan of the product when they are put into reality. In order to minimise the overall cost, such models often concentrate on balancing the costs of storing inventory against the frequency of placing orders. Additionally, they take into account the costs of waste reduction and disposal as important factors (Nahmias, 2019).

A conceptual framework for controlling deteriorating inventory is shown in Figure 1. This framework highlights crucial factors such as demand rate, degradation rate, and ordering procedures. A visual picture of the feedback loop is provided by this structure. The feedback loop is characterised by degradation having an effect on inventory levels, which in turn impacts ordering choices, which in turn has a direct impact on cost optimisation.

Within the scope of this article, the most recent advancements in degrading inventory models are discussed, along with the identification of gaps in the existing literature and prospects for incorporating future technologies such as predictive analytics and the internet of things to improve real-time decision-making. The purpose of this study is to give insights suitable for the development of more robust models that are suitable for the complexity of contemporary supply chains. This will be accomplished by analysing the strengths and limits of existing techniques.

Research Problem

In the study of deteriorating inventory management, several research gaps remain unaddressed, limiting the development of models that can fully capture the complexities of real-world inventory systems:

Incorporation of Real-Time Data: Although recent advancements have enabled dynamic models, most deteriorating inventory studies still rely on historical or static data inputs. There is a significant gap in integrating real-time data (e.g., from IoT devices, sensors) to enable real-time decision-making, which is essential for highly perishable goods with rapid deterioration rates.

Multi-Echelon and Multi-Item Systems: While single-echelon or single-item models are well-studied, multi-echelon supply chains and multi-item deteriorating inventory models remain underexplored. Multi-echelon systems that consider multiple supply chain stages could more accurately represent interdependencies, but they are challenging due to increased model complexity and computational demands.

Hybrid Uncertainty Modeling: Existing models often use either stochastic or fuzzy approaches to address uncertainty. However, hybrid models that combine stochastic and fuzzy elements are rare, even though real-world uncertainties can involve both randomness (e.g., demand fluctuations) and ambiguity (e.g., customer preferences). This gap presents an opportunity to develop more comprehensive models.

Sustainability and Environmental Impact: With growing emphasis on sustainability, limited research addresses how deteriorating inventory models can include environmental impact measures, such as carbon emissions or waste management practices. Developing models that optimize for both cost and environmental considerations would meet modern supply chain sustainability goals.

Dynamic Pricing and Demand Forecasting: There is a lack of advanced models that integrate dynamic pricing strategies with demand forecasting under deterioration constraints. Studies often assume a fixed demand rate, but demand in practice may vary based on price adjustments, promotional strategies, and external economic factors, particularly in competitive markets.

Impact of Technological Innovations: Emerging technologies, such as artificial intelligence and machine learning, are underutilized in deteriorating inventory models. There is a gap in research focused on leveraging these technologies to predict deterioration rates, forecast demand, and automate ordering policies, potentially enhancing efficiency and reducing waste.

Interdisciplinary Approaches: Most deteriorating inventory research has been conducted within the field of operations management, with limited cross-disciplinary collaboration. Engaging perspectives from economics, environmental science, and behavioral psychology could enrich inventory models, particularly in addressing the human elements of demand and disposal behaviors.

OBJECTIVE OF THE STUDY

- Evaluate and analyze existing inventory management models for deteriorating items to identify their strengths and limitations, particularly in the context of real-world supply chain applications.
- Suggest interdisciplinary approaches that incorporate insights from economics, environmental science, and behavioral psychology to enrich the understanding of deteriorating inventory management in supply chains.
- Practical recommendations for businesses and policymakers aimed at improving inventory management practices for deteriorating items, with an emphasis on enhancing supply chain resilience.

LITERATURE REVIEW

The need of modelling and optimising inventory systems for items that lose value over time has been a driving force behind the tremendous evolution that has taken place in the area of deteriorating inventory management. current techniques have changed towards accommodating the intricacies of real-world supply networks, where uncertainties are significant. Historically, inventory models were deterministic, assuming constant demand and degradation rates. However, current approaches have shifted towards accommodating these complexities.

1. Incorporation of Data Collected in Real Time

Utilising data that is either static or historical is one of the main issues that are associated with the deterioration of inventory management. Early models, as pointed out by Nahmias (2019), were mostly based on assumptions of unchanging demand and degradation, which restricted their flexibility to changes that occurred in real time. Real-time data has become increasingly available as a result of improvements in the Internet of Things (IoT) and sensor technologies. This has made it possible for inventory models to integrate live information on parameters such as temperature, humidity, and stock levels (Goyal & Giri, 2001). Nevertheless, in spite of these developments, the majority of the models that are now in use are still theoretical, and they are unable to incorporate Internet of Things-driven real-time data into practical inventory systems (Wee, 2021). When it comes to very perishable items, where external factors may considerably increase the pace of degradation, the integration of this data is especially important.

2. Systems that Are Both Multi-Echelon and Multi-Item

Because of the complexity of supply chains in the real world, there is a growing need for inventory models that include several tiers and multiple items. A more all-encompassing viewpoint on inventory management may be obtained via the use of multi-echelon systems, which take into account different phases of the supply chain. The usefulness of single-echelon models in complex supply chains is limited since degradation at one level does not immediately effect subsequent levels (Kumar et al., 2023). This is because of the way that these models are constructed. In contrast to the significant amount of research that has been conducted on single-item models, multi-item inventory models have not been well investigated. This is mostly because of the computational difficulties that are connected with the management of interdependencies across several product categories (Shah et al., 2022). As a consequence of this, the lack of comprehension of multi-echelon and multi-item degrading inventory models restricts the practical use of these models in industries such as the food and pharmaceutical industries, where items have varying rates of degradation and lifespans.

3. The modelling of hybrid uncertainty

When it comes to dealing with demand and degradation variability, deteriorating inventory models have traditionally concentrated on either deterministic or probabilistic techniques throughout their history. The use of stochastic models, for example, is advantageous since they are able to capture random variations in demand; yet, these models often fail to take into account ambiguous aspects such as consumer preferences and environmental uncertainty (Jaggi & Aggarwal, 2020). However, hybrid models that integrate both stochastic and fuzzy aspects continue to be restricted (Nahmias, 2019). Recent research have added fuzzy logic as a means of addressing uncertainty. It is possible that these hybrid models might be more effective in addressing the realities of inventory management, which include the coexistence of ambiguity and unpredictability. Furthermore, hybrid uncertainty models have shown the ability to improve inventory optimisation, particularly in markets that are extremely variable and unpredictable (Wee, 2021).

4. Impact on the Environment and Long-Term Sustainability

Despite the fact that sustainability has become an increasingly important aspect of supply chain management in recent years, there are still very few inventory models that take into account the effect on the environment. According to Kumar et al. (2023), traditional models are mainly concerned with minimising costs, and they often fail to notice the environmental costs that are linked with the disposal of garbage and the release of carbon. The incorporation of sustainable practices into inventory models offers a considerable research need, particularly in light of the growing expectations from both regulatory bodies and consumers for environmentally responsible business operations. Models that optimise for both financial and environmental outcomes might give a twofold advantage, aligning with global sustainability objectives and lowering the environmental imprint of deteriorating inventory (Shah et al., 2022). This would be a win-win situation.

5. Demand forecasting and dynamic pricing.

The use of degrading inventory models is also restricted in the domain of dynamic pricing. Traditional models often make the assumption that demand is constant; but, in reality, demand is frequently price-sensitive and is impacted by promotional activities. As an example, food sellers often provide discounts on products that are getting close to their expiry dates in order to drive demand. Goyal and Giri (2001) found that many inventory models do not sufficiently reflect this strategy. According to research conducted by Wee (2021), integrating dynamic pricing with demand forecasting while taking into account degradation limits has the potential to considerably cut down on waste while simultaneously increasing income. There is a study vacuum in understanding the relationship between pricing strategies and inventory degradation, which is shown by the fact that few models integrate this dynamic approach, despite the fact that it has the potential to be used.

6. The Role of Technological Advancements in Society

On account of the proliferation of artificial intelligence (AI) and machine learning, there are an increasing number of chances to improve inventory models that are degrading. For the purpose of forecasting demand and optimising reorder points based on complicated statistics, technologies such as predictive analytics may be used (Nahmias, 2019). Artificial intelligence systems are also capable of predicting degradation rates with a higher degree of precision, which enables inventory management to be more exact. The use of these technologies in degrading inventory management remains restricted, notably in the integration of AI-driven insights into traditional models (Jaggi & Aggarwal, 2020). This is despite the fact that these technologies represent a significant potential. For the purpose of developing models that can dynamically adjust to shifts in demand and degradation, research that focusses on the junction of artificial intelligence, machine learning, and inventory management might be of great assistance.

7. Approaches Conducted Across Disciplines

The vast majority of research on deteriorating inventory has typically been conducted within the realm of operations management, sometimes without incorporating viewpoints from other fields of study when applicable. The fields of economics, environmental science, and behavioural psychology, for instance, have the potential to provide useful insights into the elements that drive demand, disposal behaviours, and consumer preferences (Kumar et al., 2023). Working together across different fields might make it possible to develop more comprehensive models, particularly those that take into account the behaviour of consumers and the societal aspects that influence the demand for perishable items. It is possible that future models may be able to give a more complete perspective of inventory management in degrading items if they handle these multidisciplinary issues.

Deteriorating Items Inventory Study in a Single Enterprise

Due to the direct influence on operational efficiency and cost-effectiveness, the study of deteriorating inventory management within a single company has garnered a significant amount of attention. This is particularly true for commodities with limited shelf life, such as food, medicines, and high-tech products. For the purpose of minimising losses caused by spoiling, obsolescence, and waste, organisations may optimise their stock levels with the use of deteriorating inventory models. Early research mostly concentrated on fundamental models for a single-item, single-period framework; however, more recent studies have widened the scope to integrate dynamic aspects like as demand fluctuation, lead times, and pricing strategies that are relevant to single-enterprise contexts (Nahmias, 2019).

Inventory Models for Items That Are Not in Good Condition

This was the main motivation for the development of the fundamental models for deteriorating inventory, such as the Economic Order Quantity (EOQ) and the Economic Production Quantity (EPQ) (Goyal & Giri, 2001). These models were first intended to meet constant demand rates and fixed deterioration rates. The fundamental insights that these traditional models provide about order amounts that minimise overall inventory costs are presented here. Their simplicity, on the other hand, restricts their use in settings where demand and degradation rates are subject to change. Wee (2021), for example, extends the capabilities of conventional EOQ models by including time-dependent degradation rates. This allows the model to more accurately represent the storage issues that are encountered by businesses that deal with perishable items. This flexibility is particularly helpful for single-person businesses, who are in a position where accurate forecasting and exact control over stock levels are of the utmost importance.

When dealing with a single organisation, it is sometimes necessary to modify inventory models so that they are suitable for the particular operational restrictions and product characteristics of the firm. Jaggi and Aggarwal (2020) conducted research that resulted in the introduction of models that take partial backordering into consideration. These models enable businesses to reduce the risk of stockouts by fulfilling requests after the stock has been refilled. When it comes to high-demand commodities that are degrading, this strategy is especially advantageous since it strikes a compromise between maximising consumer happiness and minimising inventory expenses. In addition, partial backordering models within a single firm provide more practical solutions. This is because many companies may not completely backorder owing to the fact that they prioritise providing excellent customer service.

Adaptive models that are driven by demand and seasonality

Single-person businesses often have to contend with variable demand that is driven by seasonal patterns, the tastes of customers, and promotional and marketing activity. In these kinds of situations, traditional deterministic models, which presume that the pace of demand remains constant, are insufficient. According to research conducted by Shah et al. (2022), the incorporation of demand elasticity and seasonality into inventory models has the potential to result in more efficient decision-making, particularly for perishable items that experience substantial demand fluctuation. when an example, the use of dynamic pricing methods within these models enables a single business to modify prices when products are getting close to their expiry date. This not only increases sales but also reduces the possibility of losses resulting from unsold or degraded stock products.

Demand forecasting may also be used by sole proprietorships in order to anticipate seasonal peaks and manage inventories in accordance with those predictions. Recently, hybrid models have been developed that include both deterministic and probabilistic components in order to capture both predictable and unpredictable changes in demand (Nahmias, 2019). These models are a reflection of this approach. For instance, fuzzy logic has been included into demand forecasting in order to handle ambiguity in customer behaviour. This has provided single businesses with an edge in situations when accurate demand data is either unavailable or inconsistent.

Lead Times and Policies Regarding Reorders

When it comes to controlling deteriorating inventory, lead time, which refers to the amount of time it takes for an order to arrive after it has been placed, is also an essential component. The lead times of an organisation may have a significant influence on the ordering procedures and inventory expenses of that organisation, especially for products that have a limited lifetime. Variability in lead time may result in either overstocking or stockouts, which can either lead to greater degradation or discontent among customers. In order to solve this issue, current models that were created by Kumar et al. (2023) suggest the incorporation of stochastic lead times inside frameworks that are based on a single company. Single-entity businesses have the ability to establish buffer stocks or flexible reorder points in order to improve their ability to manage things that are degrading and to lessen the likelihood of spoiling.

As a result of its alignment with the objective of minimising holding costs by receiving stock only when it is required, reorder policies such as the just-in-time (JIT) method are also popular with single businesses that manage perishable items. According to research, just-in-time (JIT) has the potential to eliminate waste in inventory systems that are degrading, despite the fact that it needs precise coordination with suppliers (Wee, 2021). By efficiently implementing these principles inside a single organisation, it is possible to implement a lean inventory strategy, which is particularly ideal for products that have a high turnover rate.

Issues Relating to Environmental Sustainability and Waste Reduction

Companies are working to limit their waste and their effect on the environment, and as a result, sustainability has become an increasingly important problem for single-entity businesses that are managing deteriorating inventory. According to Shah et al. (2022), businesses that are engaged in the manufacturing and distribution of food have major challenges in terms of both the expenses associated with disposal and the environmental repercussions of using expired inventory. Research that was conducted not too long ago highlights the significance of waste reduction methods within inventory models. These tactics include the incorporation of donation or recycling alternatives for things that are unable to be sold. In addition, there are models that propose that shortening lead times may further minimise the environmental effect by ensuring that items are consumed before they reach their expiry date (Goyal & Giri, 2001).

It has also been shown that single businesses may reap benefits from incorporating carbon footprint monitoring and analysis into their inventory management systems. According to Nahmias (2019), businesses are able to evaluate the environmental costs that are associated with overstocking and have the potential to establish strategies to optimise inventory in a manner that is in alignment with environmental objectives when they integrate sustainability indicators.

Models that are driven by technology and actual monitoring in real time

The incorporation of technology into single-enterprise inventory management systems has made it possible to provide more effective management of things that are degrading via the use of real-time monitoring and data analysis. According to Kumar et al. (2023), technologies such as Internet of Things (IoT) devices, sensors, and artificial intelligence algorithms have opened up new opportunities for single businesses to monitor product conditions, forecast products' degradation, and make choices in real time. As an example, temperature and humidity sensors are able to transmit data to inventory management systems, which enables managers to continually check conditions and avoid early deterioration. In addition, algorithms that are powered by artificial intelligence assist optimise ordering points and forecast future demand, which further reduces waste and enhances efficiency (Jaggi & Aggarwal, 2020).

It has been shown in research conducted by Wee (2021) that machine learning models have the ability to improve the accuracy of demand forecasting by recognising patterns within huge datasets. This is an extremely useful capability for single businesses that manage a variety of perishable commodities. Businesses have the ability to design proactive methods to limit degradation risks via the use of predictive analytics, which ultimately results in a reduction in both waste and expenses. Despite the fact that technology integration presents a big opportunity, there are still obstacles to overcome in terms of cost, scalability, and technical competence. This is particularly true for smaller single-entry businesses that have less resources at their disposal.

Inventory of Deteriorating Items in the Supply Chain

Supply chain management is concerned with the issues of managing things that lose value over time owing to variables such as perishability, obsolescence, and spoiling. The study of degrading items inventory covers these challenges. It is essential to have effective inventory management for things that are degrading in order to minimise losses, maximise optimisation of costs, and efficiently satisfy the demand of customers. The purpose of this analysis is to investigate the creation of models and techniques that address degradation within the supply chain. Particular attention is paid to the complexity of multi-echelon systems, demand fluctuation, concerns over sustainability, and the role that technology plays in improving inventory accuracy.

1. The theoretical underpinnings and the classical models:

The Economic Order Quantity (EOQ) AND Economic Production Quantity (EPQ) models have typically been the foundation upon which deteriorating inventory models have been built. These models have been designed to strike a balance between holding and ordering costs under circumstances of constant demand and degradation rates. Traditional models, such as those that Goyal and Giri (2001) addressed, were crucial in laying the framework for single-echelon inventory management, which is characterised by the gradual deterioration of things over time. The fact that these early models assumed a constant demand rate, which limited their applicability to supply chains in the real world that experience varying demand, meant that they were able to give insight into reorder points and an ideal order quantity.

According to Nahmias (2019), extensions of these models have resulted in the introduction of time-dependent degradation rates. These models also include characteristics such as inventory depletion and dynamic pricing in order to accommodate fluctuations in demand. These modifications address the constraints of static models by taking into account fluctuations in demand that are caused by the passage of time. This is particularly important for products that have varied shelf life. In spite of these advancements, the most significant restriction is that they sometimes only take into account a single echelon or a single step in the supply chain. As a result, they are not enough for complicated multi-echelon networks.

2. Supply Chain Models Representing Multiple Tiers

The complications of maintaining deteriorating commodities throughout multi-echelon supply chains are the subject of a substantial amount of study that has been conducted before. In multi-echelon models, the interdependencies that exist across several stages, such as retailers, distributors, and manufacturers, are taken into consideration. The authors Kumar et al. (2023) highlight the fact that multi-echelon systems provide a more true portrayal of supply chains that exist in the actual world, where the rates of inventory movement and degradation vary greatly from stage to stage. These models often entail coordination between stakeholders in the supply chain in order to minimise the costs of cumulative degradation and to guarantee that things flow effectively from one stage to the next.

When it comes to multi-echelon degrading inventory models, one of the most significant challenges is striking a balance between the expenses of each step while still maintaining service levels. Multi-echelon inventory systems, which feature partial backordering and centralised management, were presented by Jaggi and Aggarwal (2020) as a solution to this problem. These systems enable businesses to manage stock levels collaboratively rather than separately. Collaborative initiatives like this have the potential to reduce losses that occur across the supply chain as a result of overstocking and understocking. Nevertheless, the rising complexity of multi-echelon systems presents computational hurdles. These issues need the development of sophisticated algorithms and frameworks for data exchange in order to provide real-time changes and cost-sharing agreements among participating parties.

3. Uncertainty about demand and the forecasting of inventory:

Because changes in demand may lead to overstocking or stockouts, both of which are especially expensive for perishable or deteriorating commodities, demand uncertainty is a significant issue in deteriorating inventory management. This is because such fluctuations can lead to overstocking or stockouts. The majority of supply chains are characterised by demand that is both unpredictable and variable, and traditional deterministic models, which assume a constant demand rate, are unable to take into account both aspects. Stochastic techniques, which regard demand as a random variable and determine ordering points based on demand distributions, have been added into current models in order to overcome this issue (Nahmias, 2019).

In order to take into consideration both randomness and ambiguity in demand forecasting, hybrid techniques that mix stochastic and fuzzy models have been created. Providing a more realistic method for demand fluctuation in degrading inventory models, fuzzy logic is used to represent ambiguous elements such as consumer preferences and seasonal patterns, as recommended by Shah et al. (2022). Fuzzy logic is used to model ambiguous factors. These hybrid models are especially helpful in supply chains that deal with considerable demand fluctuation. In these supply chains, precise forecasting is crucial in order to prevent excessive spoiling or demand that is not satisfied.

4. Strategies for Dynamic Pricing and Discount Mechanisms:

Price strategies are a crucial component in the management of the supply chain for deteriorating inventory, as they help to regulate demand and reduce the amount of spoiling that occurs. The use of dynamic pricing, which involves adjusting prices in accordance with inventory levels and the shelf life of a product, has been shown to be an effective method for increasing demand and decreasing waste for perishable items. Wee (2021) conducted research that demonstrates the efficacy of discounting products that are getting close to their expiry date in order to shift demand and avoid stockouts. particularly in the food and pharmaceutical sectors, where items have short shelf life, retailers regularly employ this strategy to maintain inventory flow. This is particularly noticeable in the food industry.

In addition to straightforward price reductions, several models integrate pricing elasticity, which involves altering prices in response to changes in market circumstances, consumer preferences, and the activities of competitors. Businesses are able to maximise their income and prevent losses caused by unsold inventory by including methods like these into their models of deteriorating inventory models. Nevertheless, there are still difficulties in achieving a balance between the optimisation of revenue and the limits of operations across the supply chain. This is especially true when taking into account the financial repercussions of making quick modifications to price and the possibility of over-discounting (Jaggi & Aggarwal, 2020).

5. Some Considerations Regarding Environmental and Sustainable Practices:

Sustainability has emerged as an increasingly significant component of supply chain management, particularly in the context of the management of things that are degrading. Because of the environmental effect that supply chains have, it is very necessary to implement sustainable procedures. This is because the disposal of expired items and the carbon footprint associated with unsold inventories both contribute to the environmental impact. According to Kumar et al. (2023), typical models of degrading inventory almost never take into account sustainability issues, instead concentrating on minimising costs. The incorporation of environmental variables, such as carbon emissions and costs associated with waste disposal, into more recent models enables businesses to make choices about their inventory that are in line with their sustainability objectives.

Donation or recycling programs, minimising disposal costs, and measuring carbon footprints are all examples of sustainable practices that may be used throughout the process of managing deteriorating inventory. A further benefit of incorporating sustainability into inventory models is that it helps ensure regulatory compliance and coincides with the expectations of consumers for environmentally responsible business activities. However, the inclusion of these variables heightens the complexity of the model, necessitating the use of multi-objective optimisation in order to successfully strike a balance between financial and environmental objectives (Shah et al., 2022).

6. Recent technological developments and the ability to monitor inventory in real time:

The use of technology in supply chains for degrading inventory has resulted in substantial breakthroughs in real-time tracking, predictive analytics, and decision-making that is driven by data. According to Nahmias (2019), real-time monitoring of product conditions and deterioration rates is being made possible by technologies such as the Internet of Things (IoT), artificial intelligence (AI), and machine learning. These technologies are altering the management of deteriorating inventory. Internet of Things sensors, for instance, are able to monitor temperature, humidity, and other environmental elements that are essential to the preservation of perishable goods. This enables supply chain managers to make modifications to the storage and distribution procedures based on accurate information.

By analysing vast datasets and recognising patterns in consumer behaviour, sales trends, and seasonal swings, artificial intelligence and machine learning algorithms may also improve the accuracy of demand forecasting. It is possible for supply chain managers to change reorder points, decrease safety stock levels, and enhance demand accuracy with the use of predictive analytics, which ultimately results in a reduction in waste and an increase in efficiency (Wee, 2021). In spite of these advantages, the adoption of technology in supply chain management is often hindered by the high costs of installation and the need for professionals with the necessary skills to analyse and handle data.

7. Approaches that are Collaborative Instead of Centralised:

When it comes to efficiently managing deteriorating inventory, it has been recognised that collaboration between participants in the supply chain, such as producers, distributors, and retailers, is crucial. Decentralised systems, in which each link in the chain is responsible for its own inventory management, often lead to inventory levels that are less than ideal and inefficiencies across the chain. Conversely, centralized control models, where a single entity oversees the entire supply chain, facilitate better coordination and enable cost-sharing among partners, particularly for high-turnover deteriorating items (Jaggi & Aggarwal, 2020).

Collaborative efforts within the supply chain have the potential to cut down on losses by facilitating coordinated reorder points, combining demand data, and correcting for degradation rates along the supply chain. For example, joint forecasting allows partners to anticipate demand more accurately, while coordinated ordering reduces the risk of stock imbalances (Kumar et al., 2023). Collaborative deteriorating inventory models remain an area for further research, as trust, data-sharing, and alignment of incentives are essential but challenging to achieve among supply chain partners.

DISCUSSION

The management of declining inventory in the supply chain is a complex task that has greatly developed owing to shifting market needs, technical progress, and sustainability objectives. This discourse consolidates ideas from the literature on declining inventory models, focussing on critical aspects such as multi-echelon complexity, demand forecasting, dynamic pricing, sustainability practices, and technology interventions. This study examines these areas to underscore persistent issues, the need for adaptable solutions, and prospective research prospects that correspond with contemporary supply chain requirements.

1. Intricacies of Multi-Echelon Deteriorating Inventory Models

Multi-echelon models tackle the interdependencies across various supply chain stages; nonetheless, their complexity poses a considerable problem. These models highlight the significance of synchronising inventory across several tiers, including producers, distributors, and retailers, facilitating enhanced cost-sharing and inventory minimisation. Jaggi and Aggarwal (2020) assert that controlling declining inventory in a multi-echelon supply chain requires significant computing resources and extensive data integration to enhance decision-making at every level.

Notwithstanding the apparent advantages, the deployment of these models across many firms within a supply chain encounters real constraints. Coordination and cooperation often face challenges like mismatched incentives, data security issues, and the technical preparedness of supply chain participants. Research should further investigate decentralised but coordinated models that enable supply chain participants to autonomously manage inventories while using a collective forecasting mechanism. This approach enables organisations to maintain authority over their inventory choices while using the shared insights of a collaborative framework.

2. Challenges and Opportunities in Demand Forecasting

Demand unpredictability significantly affects inventory management, since erroneous estimates may result in considerable financial losses from either excess inventory or insufficient supply. Hybrid techniques that integrate stochastic and fuzzy logic models provide a sophisticated means of addressing demand uncertainty; nevertheless, their implementation may be limited by the availability of data and the computing resources of each organisation (Nahmias, 2019). A primary challenge is the balance between model complexity and practicality, since more intricate models may enhance forecasting precision but might be impractical or too resource-demanding for smaller enterprises.

A possible direction for future study is the creation of adaptive forecasting methodologies that dynamically react to fluctuations in demand, using real-time data streams. Despite the potential of IoT and machine learning technologies, its complete integration with declining inventory models remains unachieved. Going ahead, the issue will be to reconcile the expenses and practicality of deploying such technologies with their capacity to enhance demand forecast precision. Additionally, organisations must rectify the skills gap by either educating staff or creating intuitive technologies that facilitate decision-making without necessitating extensive technical knowledge.

3. Dynamic Pricing and Discount Strategies for Degrading Products

Dynamic pricing systems have shown efficacy in regulating demand variability and reducing losses for perishable commodities. Nonetheless, the implementation of these solutions in real-time within declining inventory models presents significant hurdles. Wee (2021) illustrates that price tweaks may effectively increase demand prior to expiry; yet, this strategy may result in unforeseen demand surges, supply shortages, and logistical challenges. Effectively implementing dynamic pricing requires a comprehensive knowledge of price elasticity for each item, which might differ markedly across consumer groups and external economic situations.

Furthermore, dynamic pricing must be meticulously included into multi-echelon supply chains to avert discrepancies in price strategies among partners. A retailer's discount on a declining product should correspond with the wholesaler's incentives to guarantee that the whole supply chain reaps the advantages of the approach. Literature indicates that dynamic pricing strategies throughout the supply chain, underpinned by shared data, may enhance revenue while maintaining operational integrity. Subsequently, studies may concentrate on measuring the effects of coordinated pricing strategies across various supply chain stages, including future demand variations and degradation rates.

4. Integrating Sustainability into Depleting Inventory Models

Sustainability factors in supply chain management, especially with perishable inventory, have emerged as a significant issue as corporations encounter increasing demand to diminish environmental effect and comply with legal requirements. Traditional models mostly emphasised cost minimisation, however contemporary models have included metrics like waste reduction, carbon emissions, and disposal expenses (Kumar et al., 2023). The incorporation of environmental objectives into declining inventory models adds complexity, since balancing cost-efficiency with environmental aims may be difficult.

An essential finding from the literature is the significance of multi-objective optimisation models that reconcile sustainability with operational expenses. Companies managing perishable or ecologically sensitive goods should prioritise short lead times, sustainable packaging, and disposal solutions that reduce environmental impact. Additional study is required to examine the cost-effectiveness of these methods across many sectors, particularly for smaller enterprises with constrained resources. Through the examination of these trade-offs, forthcoming models may more effectively direct organisations towards sustainability while maintaining financial viability.

5. Technological Innovations and Real-Time Monitoring

The influence of technology on the decline of inventory management has increased markedly, as IoT, machine learning, and AI provide real-time monitoring, predictive analytics, and data-informed decision-making. Research highlights the benefits of IoT sensors and machine learning for tracking item conditions and forecasting degradation; nevertheless, extensive implementation is hindered by financial and knowledge constraints (Nahmias, 2019; Kumar et al., 2023). Although bigger corporations with significant resources may incorporate these technologies, small and medium-sized organisations may face challenges with initial expenses and necessary technical proficiency.

Considering the capacity of real-time monitoring to revolutionise declining inventory management, study need to explore economical technology solutions designed for smaller businesses. This may include creating scalable, cloud-based inventory management systems that use data analytics for cost-effective real-time modifications. Furthermore, machine learning methods may be streamlined and customised for tiny enterprises to render technology-driven inventory management attainable throughout all tiers. These advancements would provide a framework for smaller firms to use new technology without the exorbitant expenditures usually linked to IoT and AI systems.

CONCLUSION

The literature on perishable goods in supply chains has advanced considerably in tackling issues associated with multi-echelon systems, demand forecasting, dynamic pricing, sustainability, and technological integration. Nonetheless, deficiencies persist in real-time data integration, the scalability of sophisticated models, and the actual execution of collaborative strategies across many phases of the supply chain. Future research need to emphasise adaptable models that include real-time data and technology advancements, ensuring cost-effectiveness and accessibility for various organisations. Furthermore, collaborative frameworks, particularly in multi-echelon systems, provide significant opportunities to improve decision-making; yet, they need investigation into the practical, legal, and operational dimensions of data-sharing agreements among supply chain participants.

The examination of degrading inventory in supply chains is essential for the efficient management of perishable and time-sensitive items, as it tackles the difficulties associated with demand unpredictability, multi-echelon frameworks, and the need for sustainable practices. Notwithstanding progress in modelling and technology, substantial deficiencies persist in real-time data integration, adaptive forecasting, and the implementation of dynamic pricing schemes. The integration of sustainability goals with inventory management procedures poses problems and possibilities for firms aiming to reduce waste and environmental impact. Subsequent study need to concentrate on formulating adaptable, data-centric models that improve cooperation among supply chain stakeholders, while using new technology to establish more agile and efficient inventory management systems. By tackling these difficulties, the field can enhance organisations' ability to manoeuvre through the changing dynamics of inventory management, hence minimising losses and bolstering overall supply chain resilience.

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