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REVIEW ARTICLE

Deterministic and Stochastic İnventory Models in Production Systems: a Review of the Literature

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Abstract
Inventory modeling allows understanding and knowing the behavior of production systems, based on the construction, solution and analysis of a representation of the real world, which allows an adequate management of the operations of any type of company or chain network. the objective of this research is focused on a literature review of deterministic and stochastic inventory models in production systems. A methodology based on three (3) stages is proposed: (i) design of the search, which includes guiding questions, sources of information and search strategies; (ii) selection process, which considers the selected studies and the inclusion and exclusion criteria; and (iii) synthesis, where the established questions are analyzed and answered. The findings show that there is scientific interest in different types of inventory models in an independent and hybrid way, more specifically in deterministic service systems with Economic Production Quantity (EPQ), Queue Model (QM) and Optimization–Linear Programming (OP) models and in stochastic supply chain management with Optimization OPT and SImulation (SIM) models. A more detailed study showed an inclination towards article-type products, with low frequency of literature review type, which makes the development of the present work attractive and interesting. The research suggests future avenues based on common characteristics, problems addressed and frequent variables, solution techniques and additional perspectives or recommendations from recent and relevant authors in the literature are framed to support decision making.

Keywords Inventory models · Production systems · Deterministic · Stochastic

Introduction

Production systems are characterized by the fact that they constantly generate an exchange of products between the different agents with whom they interact. According to (Ponsot 2008), inventories constitute a resource in terms of stored goods that organisations use to satisfy a demand. According to (Landeta and Manuel 2012) it fulfils certain vital functions such as (i) avoiding shortages that may occur due to changes in demand, (ii) benefiting from lower volume costs during procurement or manufacturing, and (iii) having a sufficient level of quantity to meet the needs and demands of customers in precise periods.

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Due to the effects of globalisation, companies are nowadays obliged to be more and more flexible and dynamic, so that they can meet the fluctuations of the environment. This is why they must efficiently manage their processes and especially the management or appropriate inventory levels in order to cope with this situation. Since there are possibilities of shortages or excesses that ultimately lead to high costs, customer dissatisfaction and low service levels. According to (Blanco 2003) the main objective of an adequate management is to minimize the costs of supplying and maintaining inventory stocks.

Inventory theory has its beginnings at the beginning of the twentieth century, given the concern in replenishment and stock control. From this, a deterministic model called economic order quantity (EOQ) appears (Harris 1913). It was analyzed and disseminated to the scientific community in 1934 (Wilson 1934). Later, in the middle of the century, after the Second World War, (Churchman et al. 1957) suggested an extension of the model, considering quantity discounts. Consequently (Hadley and Whitin 1963), proposed inventory problems with budget and space capacity constraints.

Nowadays, these models are of great benefit, given that they allow establishing inventory policies linked to the useful life of the products, the loss of quality due to deterioration, availability over a period of time and determination of excess or shortage levels. Good inventory management requires models, techniques and methods that allow an adequate use of resources, cost control in its operations and support decision making (Cervera 2012). According to (Chase and Aquilano 1995) define these models as "the set of policies and controls that monitors inventory levels and determines what levels should be maintained, when inventory should be replenished and what size orders should be." Two types of classical families are evident in the literature from demand behavior, (i) mathematical deterministic model (regular demand) and (ii) stochastic model (probabilistic demand). Both comprise relatively complex mathematical operations, but in turn provide different mechanisms of relevant information for decision making and competitive advantage.

Inventory models have been developed in the literature when different materials are used to obtain a single product (uniproduct) and other types of systems where different inputs are used to create several outputs (multiproduct), the latter being the most widely explored due to the high prevalence and complexity. According to (Ackoff et al. 1971), when stocks are multi-product, it brings with it complications associated with inventory and storage management. Another managerial concern is the decline in product quality or spoilage (Blackburn and Millen 1982; Ferguson et al. 2007), which is linked to the nature of perishable and non-perishable products. The former being of greater concern given the value or usefulness of products over time, given the above researchers have made distinction according to fixed or deterministic shelf life Raafat (Raafat 1991); (Maity and Maiti 2009) and random or stochastic type (Goyal and Giri 2003). Therefore, it is a challenge in inventory management to maintain availability and avoid excesses or shortages, where the main objective is the minimisation of total costs (cost of ordering, cost of holding inventory and cost of lost sales) (Yalçiner 2021) and the increase of the level of service that is related to the fulfilment of demand by the different warehouses, which can be achieved through the design and implementation of inventory level policies (Viswanathan 1997; Mathur et al. 1996).

Given the above, this paper presents a literature review on inventory management in production systems specifically in deterministic and stochastic modelling. Based on a proposed three (3) stage method (i) search design, which considers the guiding questions, information sources and search strategies, (ii) selection process, which considers the selection studies and inclusion and exclusion criteria, and (iii) synthesis, where the established questions are analyzed and answered. It is divided into three sections, first the method is developed, followed by the results, then the discussion and finally the conclusions.

Method

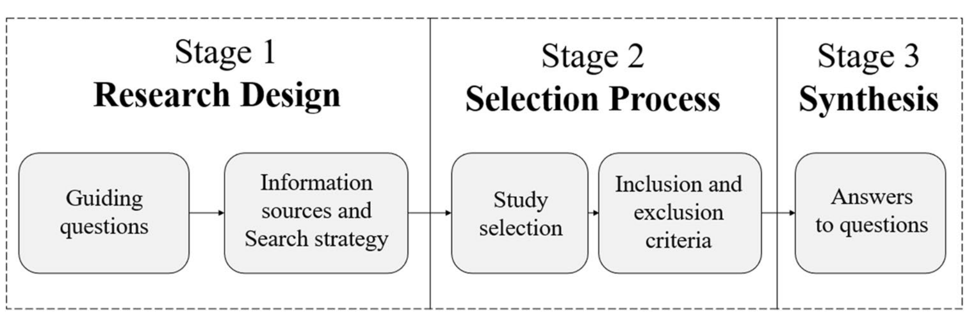
For the application of the literature review, a methodological proposal was developed that includes three stages: (i) search design, which includes guiding questions, sources of information and search strategies; (ii) selection process, which includes selection studies and inclusion and exclusion criteria; and (iii) synthesis, where the established questions are analyzed and answered (see Fig. 1).

Guiding Questions

The main problem in inventory management arises when demand is unstable and random; therefore, companies must face daily excesses or shortages in their levels. A previous study developed by (Vidal et al. 2019a) in Colombia, allowed determining that 92% of the companies present this type of inconvenience. According to (Cárdenas-Barrón et al. 2014), this management is one of the most relevant and challenging for any manufacturing organization because it represents a constant investment over time. According to (Axsäter 2015) investments in inventories are substantial and the associated capital control constitutes a potential to ensure success in today's competitive business world. Given the above, six (6) guiding questions have been defined with the objective of closing the gap in the existing theoretical aspects.

– Q1: Why are inventory models important in production systems?

Fig. 1 Schematic systematization of literature review



- Q2: How are inventory models classified?
- Q3: How is the evolution of the number of publications per year?
- Q4: Which are the most relevant countries in publications?
- Q5: Who are the authors with the most publications, citations and associations?
- Q6: What are the most related words in the subject matter?

Sources of İnformation and Search Strategy

To ensure that the guiding questions were covered, the Scopus database was used as the information search engine. This review was carried out by searching for information from the <Title> "Inventory AND Models AND Deterministic" and <Title> "Inventory AND Models AND Stochastic" path. The data cleaning provided a total of 103 and 310 research papers, respectively. The results were extracted, organized and analyzed using programs such as Excel and VosViewer.

Selection of Studies

Eligible studies were selected in three stages: (i) titles were examined for terms indicating inventory and models. (ii) abstracts of studies were reviewed and (iii) a pre-reading of each of the papers was carried out to verify the existence of the application of some type of model, relevant variables and problems addressed.

Inclusion and Exclusion Criteria

The papers were excluded according to the evaluation described in items 2.3, taking into account the title, abstract and review of the document. Regarding the inclusion criteria, only articles published in English were included. As for the time horizon of the search, only published works corresponding to the last five (5) decades were included.

Analysis and Response to Questions

The answers to each question are addressed with theoretical foundations and graphic analytical techniques such as line diagrams, bar diagrams and connection or network diagrams. Relevant elements are extracted in order to know the current state of the subject, trends and future spectra.

Results

The results obtained show the development of the questions formulated. The section is separated by six (6) sections that provide answers and analysis to each one, (i) importance of inventory models in production systems; (ii) classification of inventory models; (iii) number of publications per year; (iv) most relevant countries in publications; (v) authors with more publications, citations, and associations; and (vi) words that are most related to the subject.

Importance of Inventory Models in Production Systems (Q1)

In a production system, the existence of inventories will always be notorious, given that raw materials, intermediates and finished products are needed for the production of products. According to (Landeta and Manuel 2012), it is an inherent characteristic of the production process and performs functions such as, (i) ıt helps to avoid the risk of shortages or shortages due to changes in demand, (ii) ıt allows minimising costs by quantity or volume in procurement and manufacturing, (iii) ıt covers the needs of customers in times of inaccuracy, and (iv) ıt supports the processes through a stock of critical elements. Management by managers within an organisation generates a certain degree of complexity, due to the presence of independent variables and uncertainty in the environment, which generates an imbalance or variations in their appropriate levels. According to (Cervera 2012) this problem can be solved through the use of models, techniques and methods that facilitate planning and control activities and support decision-making. The main objective is to minimize the costs of supplying and maintaining inventory stocks (Blanco 2003). The literature distinguishes relevant and important aspects in the management of inventory models, having an integrated supply chain system (Bukhari and El-Gohary 2012), controlling a production system (Wang et al. 2012), managing an effective investment in preservation technology (He and Wang 2012), optimizing the minimum cost of delivery and optimal lot size (Yalçiner 2021), manage stock spoilage (Ferguson et al. 2007), establish an optimal production and replenishment policy (Mathur et al. 1996), reduce the risk of product shortages and duplication (Mokhtari et al. 2021), reduce imperfect quality items (Blackburn and Millen 1982), and generate effectiveness and efficiency in ordering processes (Yang et al. 2001).

Classification of Inventory Models (Q2)

A previous research developed by (Vidal et al. 2019b) classifies inventory management taking into account two general aspects (i) the product, which according to its type are subdivided into perishable (P) and non-perishable (NP), and according to the quantity appear uniproduct (UP) and multiproduct (MP) and (ii) the demand, which according to the type appear independent and dependent, and according to the randomness component are divided into deterministic and stochastic. Given the above, Fig. 2 broadens the spectrum with respect to the different models that exist in the literature, taking into account the different characteristics that arise in inventory management.

Deterministic Inventory Models

Deterministic inventory models are those where the variables involved and all the data are known with certainty (Eppen et al. 2000). For example, the demand variable, which presents a degree of certainty, but is estimated from forecasting techniques or customer order requests, as well as the delivery time variable, which are of a certain and constant nature. In the literature review we find the following: (i) single lot (SL), which considers a single order for the volume of demand. According to (Gaither and Frazier 2000) it is widely used when it is desired to place a single order, benefiting from discounts for high purchase volumes, reflected in low transportation, procurement, and preparation costs. (ii) Lot for lot (LFL), consists of obtaining what is demanded in each period (Bahagia 2006). This method is relevant because it incurs minimum inventory holding costs when transportation costs are high (Noori and Radford 1997). (iii) Economic Order Quantity (EOQ), Proposed by (Harris 1913) applied when a continuous replenishment system with deterministic variables is maintained. According to (Pérez and Torres 2014), it allows obtaining a good approximation of the optimal inventory policy in several real-life situations. According to (Chase and Aquilano 1995), it obtains the balance between setup or purchase order costs and storage costs. Similarly, (Noori and Radford 1997) state that the model provides a minimization of costs, seeking to satisfy the demand. (iv) Silver-Meal Algorithm (SM), is an algorithm that takes advantage of the structure of the problem by using a set of rules and rational procedures, in most cases good optimal solutions are obtained (Sipper and Bulin 1998). It seeks to obtain the minimum average cost based on the number of future periods that the current order will generate (Nahmias 2007). (v) Minimum Unit Cost (MUC), Similar to the Silver-Meal Algorithm (SM), it is based on the average variable cost per unit over a time horizon (Sipper and Bulin 1998; Nahmias 2007). (vi) Economic Production Quantity (EPQ), Developed by (Taft 1918) as an extension of the EOQ model, it allows determining the optimal quantities to produce, through the minimization of total manufacturing costs. The model works under the assumption of producing items of perfect quality, taking into account a deterministic demand. More recently, (Salameh and Jaber 2000) and (Goyal and Cardenas-Barron 2002) developed a model considering imperfect quality products. (vii) Wagner-Whitin Algorithm (WW), developed by Harvey Wagner and Thomson Whitin in 1958 with the objective of obtaining optimal solutions for inventory management problems. This algorithm produces a minimum cost solution that leads to an optimal quantity to be ordered. The optimization is based on dynamic programming and evaluates all possible ways of ordering to cover the demand in each period of the planning horizon ((Nunes 2015; Parra Guerrero 2020)). According to (Bustos Flores and Chacón Parra 2012), its objective is to minimize the cost of ordering (preparing) and maintaining the inventory. (viii) Deterministic simulation (S), this model is developed by means of the Monte Carlo method, based on data analysis, identification of deterministic variables, construction and solution of the model and finally scenario experimentation. The development of this methodology proposes an improvement to the system, supports decision making and seeks to minimize inventory costs in order to achieve higher profits (Nahmias 2007). (ix) Queue Model (QM) is a

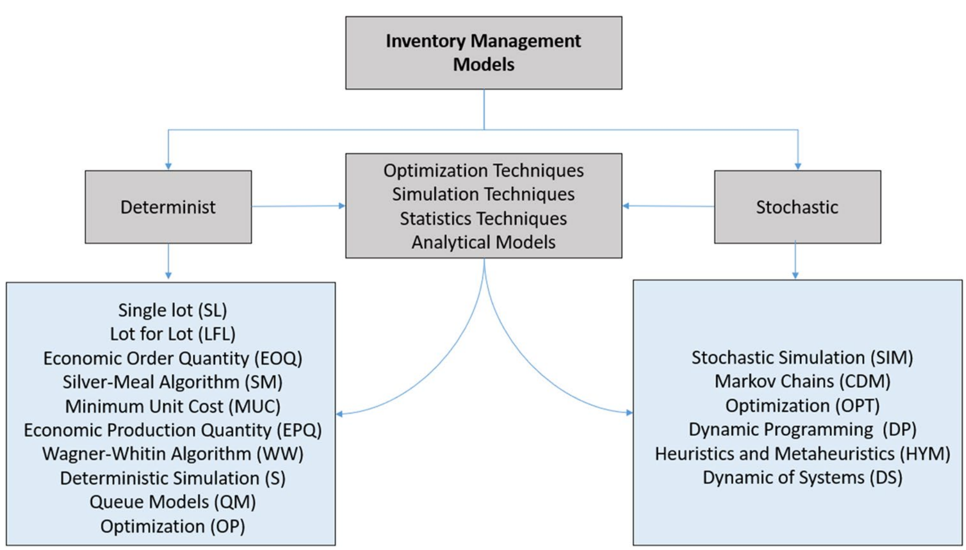


Fig. 2 Inventory management models

model with multiple stages that evaluates the performance of the systems, controlling the inventory level in each of them, with emphasis on minimizing the overall costs in the system while meeting the required service level (Liu et al. 2004; Zheng and Zipkin 1990).

Taking into account that most of the business environments develop different types of products and use different materials, inputs or raw materials. The need to find better management mechanisms or ways to find simplicity in operations, due to the high number of references and variables that are associated. Table 1 shows the researchers' interest in solving problems with the characteristics of multi-product (MP) and perishable (P) inventories, which are highly complicated aspects of inventory management, due to the life cycle of the products, the risk of deterioration and the number of references or production volumes.

A selection of 86 items analyzed in a time window of the last 5 decades, allowed to identify aspects addressed in the

Table 1 Types and models in a deterministic environment

Type	(P)	Yalçiner (2021); Jing and Chao (2021); Mareeswaran and Anandhi (2021); Rani (2020); Melikov and Shahmaliyev (2019); Chowdhury et al. (2018); Sekar and Uthayakumar (2018); Singh et al. (2017); Huang et al. (2017); Nadyatama et al. (2016); Shen et al. (2016); Chung et al. (2014); Nasr et al. (2014); Lee and Kim (2014); Wu and Sarker (2013); Das et al. (2013); Dye (2013); Sarkar (2013); Ali et al. (2013); Mahata (2012); Wee and Widyadana (2012); Lee and Chung (2012); Dye and Hsieh (2012); Bukhari and El-Gohary (2012); Wang et al. (2012); He and Wang (2012); Widyadana and Wee (2012); Baltacioğlu et al. (2011); Chung et al. (2011); Kishore et al. (2011); Wang et al. (2011); Chung and Wee (2011); Tsai (2011); Mahata (2011); Roy and Samanta (2011); Bhowmick and Samanta (2011); Hsu et al. (2010)
	(NP)	Mokhtari et al. (2021); Maulana (2021); Kian et al. (2021); Vaughan (2021); Zandi et al. (2021); Balagopal et al. (2021); Murdapa (2021); Kumar et al. (2021); Chakravarthy and Rao (2021); Hanukov et al. (2021); Rabta (2020); Gani and Rafi (2020); Nobil et al. (2020); Ruidas et al. (2019); Viswanath et al. (2019); Baek et al. (2018); Yue et al. (2018); Chowdhury et al. (2018); Albrecher et al. (2017); Otten et al. (2016); Nair et al. (2015); Baek and Moon (2014); Saffari et al. (2013); Chakraborty and Giri (2012); Schulz (2011)
	(UP)	Yalçiner (2021); Mareeswaran and Anandhi (2021); Maulana (2021); Hanukov et al. (2021); Rabta (2020); Gani and Rafi (2020); Viswanath et al. (2019); Melikov and Shahmaliyev (2019); Shen et al. (2016); Nair et al. (2015); Sarkar (2013); Schulz (2011)
	(MP)	Jing and Chao (2021); Mokhtari et al. (2021); Kian et al. (2021); Vaughan (2021); Zandi et al. (2021); Balagopal et al. (2021); Murdapa (2021); Kumar et al. (2021); Chakravarthy and Rao (2021); Nobil et al. (2020); Rani (2020); Ruidas et al. (2019); Baek et al. (2018); Yue et al. (2018); Chowdhury et al. (2018); Sekar and Uthayakumar (2018); Singh et al. (2017); Huang et al. (2017); Albrecher et al. (2017); Nadyatama et al. (2016); Otten et al. (2016); Chung et al. (2014); Nasr et al. (2014); Baek and Moon (2014); Lee and Kim (2014); Saffari et al. (2013); Wu and Sarker (2013); Das et al. (2013); Dye (2013); Ali et al. (2013); Mahata (2012); Wee and Widyadana (2012); Lee and Chung (2012); Dye and Hsieh (2012); Chakraborty and Giri (2012); Bukhari and El-Gohary (2012); Wang et al. (2012); He and Wang (2012); Widyadana and Wee (2012); Baltacioğlu et al. (2011); Chung et al. (2011); Kishore et al. (2011); Wang et al. (2011); Chung and Wee (2011); Tsai (2011); Mahata (2011); Roy and Samanta (2011); Bhowmick and Samanta (2011); Hsu et al. (2010)
Models	(SL)	Yalçiner (2021); Jing and Chao (2021); Chowdhury et al. (2018); Sarkar (2013); Mahata (2011)
	(LFL)	Yalçiner (2021); Jing and Chao (2021); Chowdhury et al. (2018); Sarkar (2013); Mahata (2011)
	(EOQ)	Mareeswaran and Anandhi (2021); Mokhtari et al. (2021); Maulana (2021); Rabta (2020); Gani and Rafi (2020); Shen et al. (2016); Sarkar (2013); Roy and Samanta (2011)
	(SM)	Kian et al. (2021); Nadyatama et al. (2016); Schulz (2011)
	(MUC)	Kian et al. (2021); Sarkar (2013)
	(EPQ)	Gani and Rafi (2020); Nobil et al. (2020); Rani (2020); Ruidas et al. (2019); Singh et al. (2017); Huang et al. (2017); Chung et al. (2014); Nasr et al. (2014); Mahata (2012); Wee and Widyadana (2012); Widyadana and Wee (2012); Chung et al. (2011); Kishore et al. (2011)
	(WW)	Kian et al. (2021); Vaughan (2021); Chowdhury et al. (2018); Ali et al. (2013); Baltacioğlu et al. (2011)
	(S)	Vaughan (2021); Zandi et al. (2021); Otten et al. (2016); Lee and Chung (2012)
	(QM)	Balagopal et al. (2021); Murdapa (2021); Kumar et al. (2021); Chakravarthy and Rao (2021); Hanukov et al. (2021); Viswanath et al. (2019); Melikov and Shahmaliyev (2019); Baek et al. (2018); Yue et al. (2018); Albrecher et al. (2017); Nair et al. (2015); Baek and Moon (2014); Saffari et al. (2013); Ali et al. (2013)
	(OP)	Sekar and Uthayakumar (2018); Otten et al. (2016); Lee and Kim (2014); Wu and Sarker (2013); Das et al. (2013); Dye (2013); Sarkar (2013); Dye and Hsieh (2012); Chakraborty and Giri (2012); Bukhari and El-Gohary (2012); Wang et al. (2012); He and Wang (2012); Wang et al. (2011); Chung and Wee (2011); Tsai (2011); Bhowmick and Samanta (2011); Hsu et al. (2010)

(x) Optimization–Linear Programming (OP), Model with three basic components: the decision variables to be determined, the objective to be optimized and the constraints to be satisfied. Based on linear programming and economic order quantity, this requires determining the parameters, defining the variables, building and solving the model (Mathur et al. 1996). A selection of 62 papers analyzed in the last 10 years showed that there is a predominance and relationship of the use of models such as (EPQ), (QM) and (OP) (see Table 1). These models contribute to the search for the efficiency of waiting line systems, optimising times, order quantities and total costs.

deterministic models, it is evident the great interest towards the solution of problems oriented to the minimisation of costs associated with the cost of ordering, cost of maintaining the inventory and cost of lost sales; in turn the deterioration of products related to the decrease of quality framed in the nature of perishable and non-perishable (see Table 2).

A practical analysis of the last decade showed a high tendency towards the applicability of models in service systems, with relevant sectors such as logistics, operations, finance and hospitals. However, there are also cases of studies in manufacturing systems, oriented towards food and beverage, agribusiness, textile, plastics, and pharmaceuticals (see Table 3).

In synthesis, a relational analysis is developed considering four fields: (i) authors, (ii) models, (iii) problem aspects, and (iv) production systems. Regarding manufacturing systems, the applicability of EOQ and EPQ models is evident, addressing aspects such as cost minimization and product deterioration. Regarding service systems, their application is directed to QM, OP and EPQ models, with problem nuclei towards operation capacity, storage and deterioration (see Fig. 3). Given the above, the current techniques applied in each of the models and production systems are identified, in manufacturing with EOQ the use of Multi-item deterministic model (Mareeswaran and Anandhi 2021), Fuzzy techniques (Gani and Rafi 2020), and sensitivity analysis (Shen et al. 2016), with EPQ Fuzzy techniques (Gani and Rafi 2020) and Particle swarm optimization technique (Ruidas et al. 2019). In services with QM the use of Queueing networks and Markovian analysis (Melikov and Shahmaliyev 2019; Viswanath et al. 2019; Baek et al. 2018; Yue et al. 2018; Albrecher et al. 2017; Nair et al. 2015; Baek and Moon 2014; Saffari et al. 2013), Mathematical theorems (Balagopal et al. 2021) and fuzzy techniques (Kumar et al. 2021) and with OP and EPQ Sensitivity analysis (Sarkar 2013; Singh et al. 2017; Chung et al. 2014; Mahata 2012; Otten et al. 2016; Sekar and Uthayakumar 2018; Lee and Kim 2014; Wu and Sarker 2013).

The identification of characteristics, aspects, and problems addressed in this section provides notions towards the development of possible research. At the same time, taking as a reference the work developed by various

Table 3 Application of deterministic modeling

Production system	Case studies
Manufacturing	**Food and Beverage Manufacturing**—Yalçiner (2021), Nadyatama et al. (2016) y Das et al. (2013); **Agribusiness**—Mareeswaran and Anandhi (2021); **Textile**—Maulana (2021); **Plastics**—Gani and Rafi (2020) y Ruidas et al. (2019) y **Pharmaceutical**—Shen et al. (2016)
Services	**Logistics Services**—Balagopal et al. (2021), Sekar and Uthayakumar (2018), Singh et al. (2017), Otten et al. (2016), Chung et al. (2014), Lee and Kim (2014), Wu and Sarker (2013), Sarkar (2013), Ali et al. (2013), Mahata (2012), Wu and Dong (2008), Rau et al. (2004), Rau et al. (2003); **Operational**—Viswanath et al. (2019), Melikov and Shahmaliyev (2019), Baek et al. (2018), Yue et al. (2018), Albrecher et al. (2017), Nair et al. (2015), Baek and Moon (2014), Saffari et al. (2013), Schwarz et al. (2006); **Financial**—Zandi et al. (2021); **Hospital**—Kumar et al. (2021)

Table 2 Aspects or problems addressed in deterministic models

Aspects or problems	Authors and year
Cost Minimization	Yalçiner (2021); Maulana (2021); Kian et al. (2021); Rabta (2020); Gani and Rafi (2020); Nobil et al. (2020); Ruidas et al. (2019); Chowdhury et al. (2018); Lee and Kim (2014); Sarkar (2013); Chakraborty and Giri (2012); Kishore et al. (2011); Wang et al. (2011); Schulz (2011); Chung and Wee (2011); Tsai (2011); Mahata (2011); Schulz (2009); Jamshidi (2009); Mahata and Goswami (2007); Ferguson et al. (2007); Kumar et al. (2003); Simpson (2001); Yang (2001); Omar and Deris (2001); Bahl and Taj (1991); Gupta and Brennan (1992); Saydam and Evans (1990); Cheng and Siu (1989); Bookbinder and Tan (1985); Veral and LaForge (1985); Choi et al. (1984); Lackburn and Millen (1982)
Storage capacity	Jing and Chao (2021); Chowdhury et al. (2018); Sekar and Uthayakumar (2018); Shen et al. (2016); Chakraborty and Giri (2012); Widyadana and Wee (2012); Baltacioğlu et al. (2011); Saydam and McKnew (1987)
Product impairment	Mareeswaran and Anandhi (2021); Mokhtari et al. (2021); Vaughan (2021); Balagopal et al. (2021); Rani (2020); Singh et al. (2017); Huang et al. (2017); Nadyatama et al. (2016); Shen et al. (2016); Chung et al. (2014); Nasr et al. (2014); Wu and Sarker (2013); Das et al. (2013); Dye (2013); Ali et al. (2013); Mahata (2012); Wee and Widyadana (2012); Lee and Chung (2012); Dye and Hsieh (2012); Bukhari and El-Gohary (2012); Wang et al. (2012); He and Wang (2012); Widyadana and Wee (2012); Chung et al. (2011); Kishore et al. (2011);Wang et al. (2011); Roy and Samanta (2011); Bhowmick and Samanta (2011); Hsu et al. (2010); Liao (2007); Rau et al. (2004); Wee and Shum (1999); Rau et al. (2003)
Capacity Operation	Zandi et al. (2021); Murdapa (2021); Kumar et al. (2021); Chakravarthy and Rao (2021); Hanukov et al. (2021); Viswanath et al. (2019); Melikov and Shahmaliyev (2019); Baek et al. (2018); Yue et al. (2018); Albrecher et al. (2017); Otten et al. (2016); Nair et al. (2015); Baek and Moon (2014); Saffari et al. (2013); Wu and Dong (2008); Schwarz et al. (2006); Jamshidi and Brown(1993); Fabens (1961)

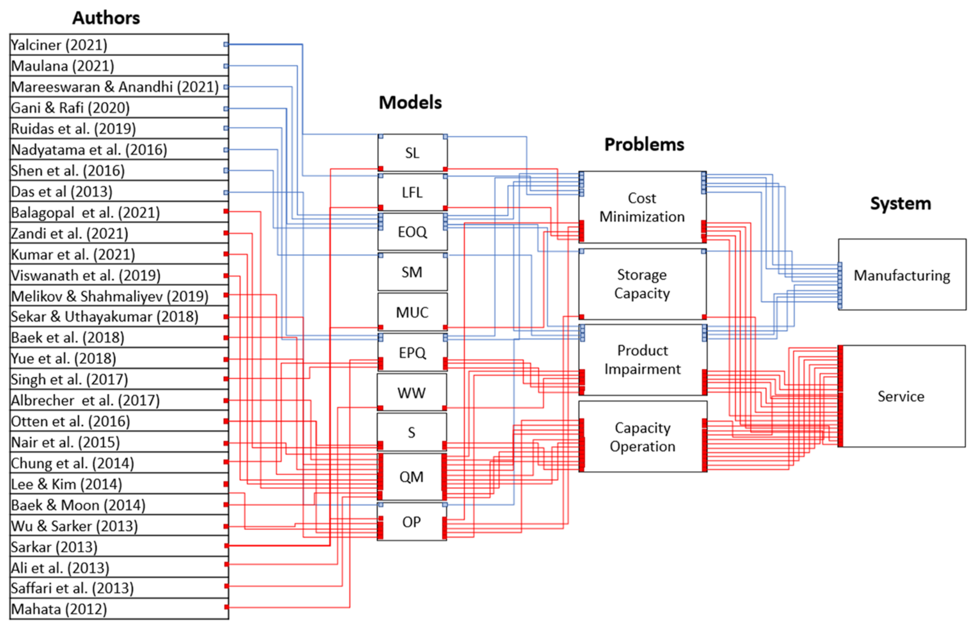


Fig. 3 Relationship between fields in deterministic models

authors in the last 5 years, it was possible to highlight some future perspectives that can continue to contribute to the research community (see Table 4). It is worth highlighting the trend towards the development of efficient techniques for the solution of problems framed in the search to improve the level of services, storage capacity and inventory policies.

Stochastic Inventory Models

In a stochastic inventory model, the interacting variables are not known with certainty, they are posed under the main assumption that demand is random or there is uncertainty over a period of time, including the concept of safety stock and service level (Nahmias 2007; Chase et al. 2010; Heizer and Render 2006). According to (Ríos et al. 2008) stochastic or probabilistic inventory models are classified into two groups: periodic review and continuous review. These two differ mainly because the first one indicates a replenishment according to a constant and defined time, while the continuous review models indicate that a new order must be placed when there is a certain amount of units left in the inventory, this translates into the so-called reorder point. A review of the literature distinguishes several models that lead to the application of these groups: (i) stochastic simulation (SIM) allows understanding, predicting and understanding a system and suggesting strategies that improve performance indicators (Naylor et al. 1982). One of the techniques used is Monte Carlo Simulation, which allows to control and manage in an optimal way the amount of product and storage in the company, reducing losses and improving response times (Ruiz Vallejo et al. 2015), find an inventory policy with

Table 4 Future perspectives on deterministic modeling

Authors and year	Outlook for future work
Yalçiner (2021)	Develop applications with intelligent and heuristic approaches
Jing and Chao (2021)	Develop efficient algorithms
Mareeswaran (2021)	Include product shelf life as a variable of analysis
Mokhtari et al. (2021)	Consider quantity discounts on purchases
Maulana (2021)	Consider management in decision making
Kian et al. (2021)	Multi-item production planning
Hanukov et al. (2021)	Consider the different types of customers in service systems
Nobil et al. (2020)	Use the maximum available capacity
Ruidas et al. (2019)	Introduce marketing variables and time value of money
Baek et al. (2018)	Considering a customer's stock requirement
Yue et al. (2018)	Take into account service time and delivery deadlines
Huang et al. (2017)	Consider quantity discounting and imperfect production

safety stock that maximizes the expected daily profit (Escobar et al. 2017). (ii) Markov Chains (CDM) are useful when solving a series of real-world problems under uncertainties, such as the determination of inventory levels (Zhao et al. 2010; Gayon et al. 2009). They are effective in providing predictive information for managers and provide probability estimates for future outcomes (Wilcox et al. 2011). (iii) Optimisation (OPT), the model proposes different objective functions, minimising the total cost of inventories over the entire scheduling horizon ((Jeyanthi and Radhakrishnan 2010; Taleizadeh et al. 2011)). In other related cases, the opposite is sought; in (Song 1998) the allowable inventory level is maximized, in Dawande et al. (2006) the maximum order fulfilment is sought, and in (Jun-jun and Ting 2009) and (Chou et al. 2013) the expected profit is maximized. (iv) Dynamic Programming (DP), is an optimisation process that consists of a sequence of decisions that, where optimal solutions are obtained successively, with the objective of minimising the total costs incurred in an inventory problem (Cruz Moreno and Vargas Ortiz 2017). (v) Heuristics and Metaheuristics (HYM), according to (Zanakis and Evans 1981) heuristics are simple procedures, based on common sense, and that offer a good solution. According to (Silver 2004) it is an efficient way to speed up the decision making process regarding optimal inventory levels. Metaheuristics, commonly applied algorithms; in (Torres and Urrea 2006) tabu search algorithm is applied to find the optimal order level, in (Jeyanthi and Radhakrishnan 2010) genetic algorithms for the same purpose, in (Buffett and Scott 2004) total inventory costs are optimized. (vi) Dynamic of Systems (DS), a method for simulating problems in real time that allows understanding and analysing a system (Aracil 1983), according to (Zanakis and Evans 1981) is characterized by the fact that the outputs change over time when the system is not in equilibrium. It is of great importance for inventory management, supporting decision making based on changes in demand (Ogata and Sanchez 1987). A selection of 64 papers analyzed in a time window of the last 10 years showed that there is a predominance of the use of models such as (SIM) and (OPT) (see Table 5). These are numerical computational techniques that allow us to understand the system and make the best use of resources, both of which are of great support for decision-making in industrial and business environments.

More broadly, the variables frequently identified in the analysis of stochastic models, a selection of 85 papers analyzed over a time window of the last 5 decades, evidence an interest on the part of researchers in problem solving aimed at inventory control, policy and operations evaluation (see Table 6).

In the development of case studies found in the literature over the last decade, there is a high tendency towards the applicability of models in supply chain management systems, oriented towards integration, collaboration and cooperation between agents, levels, and storage units. This is followed by service systems with subsectors aimed at operations and commercial areas. There are also case studies in manufacturing systems, involving food, agribusiness, energy, and electronics (see Table 7).

In synthesized form, a relational analysis is developed considering four fields (i) authors, (ii) models, (iii) aspects of the problem and (iv) production systems. In manufacturing, service and supply chain management systems, the applicability of SIM and OPT models is highlighted, being

Table 5 Most frequently used stochastic models

Models	Author and year
SIM	Jeenanunta et al. (2021); Shokouhifar et al. (2021); Poormoaied (2021); Sridhar et al. (2021); Arani et al. (2021); Chołodowicz and Orłowski (2021); Ghasemi and Khalili-Damghani (2021); Hasan et al. (2020); Jackson et al. (2020); Maiti (2020); Odedairo et al. (2020); Aliunir et al. (2020); Chakravarthy and Rumyantsev (2020); Buschiazzo et al. (2020); Gou et al. (2018); Attar et al. (2016); Díaz et al. (2016); Pan et al. (2015); Jana et al. (2013); Huang et al. (2010)
CDM	Sinaga et al. (2021); Al-Salamah (2021); Esmaeili and Nasrabadi (2021); Johansen (2021); Duc et al. (2020); Ho et al. (2020); He and Jiang (2018); Díaz et al. (2016); Liu et al. (2014); Larsen and Turkensteen (2014)
OPT	Jeenanunta et al. (2021); Arani et al. (2021); Ghasemi and Khalili-Damghani (2021); Assi and Effanga (2021); Asadi and Pinkley (2021); Visentin et al. (2021); Wan et al. (2021); Fathi et al. (2021); Kumar (2021); Najafnejhad et al. (2021); Mishra et al. (2021); Aliunir et al. (2020); Buschiazzo et al. (2020); Voelkel et al. (2020); Yadav et al. (2020); Rahman et al. (2020); Van et al. (2019); Agrawal and Smith (2019); Meissner and Senicheva (2018); Yadav et al. (2018); Cheikhrouhou et al. (2018); Gharaei et al. (2017); Tiwari et al. (2017); Gharaei et al. (2017); Attar et al. (2016); Díaz et al. (2016); Sadeghi et al. (2016); Srivastav and Agrawal (2016); Sadeghi et al. (2014); Firoozi et al. (2013); Yang and Lin (2010); Huang et al. (2010)
PD	Assi and Effanga (2021); Asadi and Pinkley (2021); Visentin et al. (2021); Voelkel et al. (2020); Van et al. (2019); Agrawal and Smith (2019); Meissner and Senicheva (2018); Gharaei et al. (2017)
HYM	Karampour et al. (2020); Dordevic et al. (2017); Jana and Das (2017); Sadeghi et al. (2016); Inderfurth and Kiesmüller (2015); Mousavi et al. (2014); Taleizadeh and Cárdenas-Barrón (2013); Pasandideh et al. (2013); Fliedner et al. (2011); Wang and Hu (2010);
DS	Odedairo et al. (2020); Lee and Chung (2012); Fawcett et al. (2010)

Table 6 Frequent variables in the analysis of stochastic models

Variables	Authors and year
Inventory Level	Jeenanunta et al. (2021); Al-Salamah (2021); Dordevic et al. (2017); Mousavi et al. (2014); Firoozi et al. (2013); Wang and Hu (2010); Chen and Chang (2008); Chen and Song (2001); Clark (1960)
Delivery Time	Jeenanunta et al. (2021); Fathi et al. (2021); Kumar (2021); Inderfurth and Kiesmüller (2015); Yang and Lin (2010)
Inventory Policies	Jeenanunta et al. (2021); Poormoaied (2021); Johansen (2021); Visentin et al. (2021); Najafnejhad et al. (2021); Duc et al. (2020); Voelkel et al. (2020); Yadav et al. (2020); Rahman et al. (2020); Van et al. (2019); Attar et al. (2016); Larsen and Turkensteen (2014); Riezebos and Gaalman (2009); Kamath and Pakkala (2002); Cheng and Sethi (1999); Cheng and Sethi (1999); Chiu (1995); Haddock and Bengu (1987); Pegels and Jelmert (1970)
Impairment of inventories	Arani et al. (2021); Esmaeili and Nasrabadi (2021); Mishra et al. (2021); Hasan et al. (2020); Tiwari et al. (2017); Lee and Chung (2012); Aggoun et al. (1997); Benkherouf and Mahmoud (1996)
Operations Evaluation	Chołodowicz and Orłowski (2021); Ghasemi and Khalili-Damghani (2021); Asadi and Pinkley (2021); Maiti (2020); Aliunir et al. (2020); Chakravarthy and Rumyantsev (2020); Buschiazzo et al. (2020); Ho et al. (2020); Karampour et al. (2020); Gou et al. (2018); He and Jiang (2018); Yadav et al. (2018); Gharaei et al. (2017); Jana and Das (2017); Attar et al. (2016); Diaz et al. (2016); Sadeghi et al. (2016); Srivastav and Agrawal (2016); Taleizadeh and Cárdenas-Barrón (2013); Pasandideh et al. (2013); Huang et al. (2010); Tripathy and Pattnaik (2009); Li and Wan (2008); Abboud (2001); Arnold and Köchel (1996); Sasser et al. (1970)
Inventory Control	Agrawal and Smith (2019); Meissner and Senicheva (2018); Cheikhrouhou et al. (2018); Gharaei et al. (2017); Attar et al. (2016); Pan et al. (2015); Liu et al. (2014); Sadeghi et al. (2014); Jana et al. (2013); Fliedner et al. (2011); Fawcett et al. (2010); Yang (2008); Wikner (2005); Tee and Rossetti (2002); Aggoun et al. (1997); Wikner (1994)

Table 7 Application of stochastic modeling

production system	Case studies
Manufacturing	**Foods**—Chołodowicz and Orłowski (2021), Maiti (2020), Rahman et al. (2020); **Agribusiness**—Hasan et al. (2020); **Energetic**—Aliunir et al. (2020); **Electronics**—Asadi and Pinkley (2021)
Services	**Operational**—Jeenanunta et al. (2021); **Comercial**—Arani et al. (2021), Chakravarthy and Rumyantsev (2020), Attar et al. (2016), Liu et al. (2014)
Supply Chain Management	**Warehousing Logistics**—Ghasemi and Khalili-Damghani (2021), Shokouhifar et al. (2021), Sridhar et al. (2021), Odedairo et al. (2020), Buschiazzo et al. (2020), Yadav et al. 2018, 2020 Tiwari et al. (2017), Jana and Das (2017), Sadeghi et al. (2016), Pan et al. (2015), Sadeghi et al. (2014), Jana et al. (2013)(Odedairo et al. 2020); **Chain Integration and Collaboration**—Fathi et al. (2021), Karampour et al. (2020), Díaz et al. (2016), Firoozi et al. (2013)

these highly complementary, addressing relevant aspects such as the evaluation of operations and inventory policies, respectively (see Fig. 4).

Given the above, the current techniques applied in each of the production models and systems are identified, in manufacturing with Discrete Event Simulation (Chołodowicz and Orłowski 2021; Aliunir et al. 2020), Markov Chains (Asadi and Pinkley 2021), Fuzzy Simulation (Maiti 2020), Sensitivity analysis (Hasan et al. 2020) and metaheuristics with particle swarm (Rahman et al. 2020). In services the use of Discrete Event Simulation (Jeenanunta et al. 2021; Attar et al. 2016), AHP Analysis and ABC Classification (Arani et al. 2021), Matrix Analytical Methods (Chakravarthy and Rumyantsev 2020) and Metaheuristic Optimization with Genetic Algorithms (Liu et al. 2014). In the case of Supply Chain Management a larger number of techniques such as Fuzzy Simulation (Shokouhifar et al. 2021), Discrete Event Simulation (Sridhar et al. 2021; Pan et al. 2015), Simulation with System Dynamics (Odedairo et al. 2020; Buschiazzo et al. 2020), Metaheuristic Optimization with Genetic Algorithm (Ghasemi and Khalili-Damghani 2021; Jana et al. 2013; Fathi et al. 2021; Jana and Das 2017), Particle Swarm (Yadav et al. 2020, 2018; Tiwari et al. 2017), Simulated Annealing (Diaz et al. 2016; Firoozi et al. 2013), Hybrid Bat Algorithm (Sadeghi et al. 2014), Red Deer Algorithm (Karampour et al. 2020) and Hybrid Imperialist Competitive Algorithm (HICA) (Sadeghi et al. 2016).

Taking as a reference work developed by various authors in the last 5 years, it was possible to highlight some future perspectives in stochastic models that can continue to contribute to the research community. Table 8 shows that the most promising avenues are framed towards the search for techniques to reduce the degree of uncertainty inherent to the appearance of random variables in the models.

The inclination is marked towards supply chain management with modern approaches of integration, collaboration and cooperation, where the relationships between

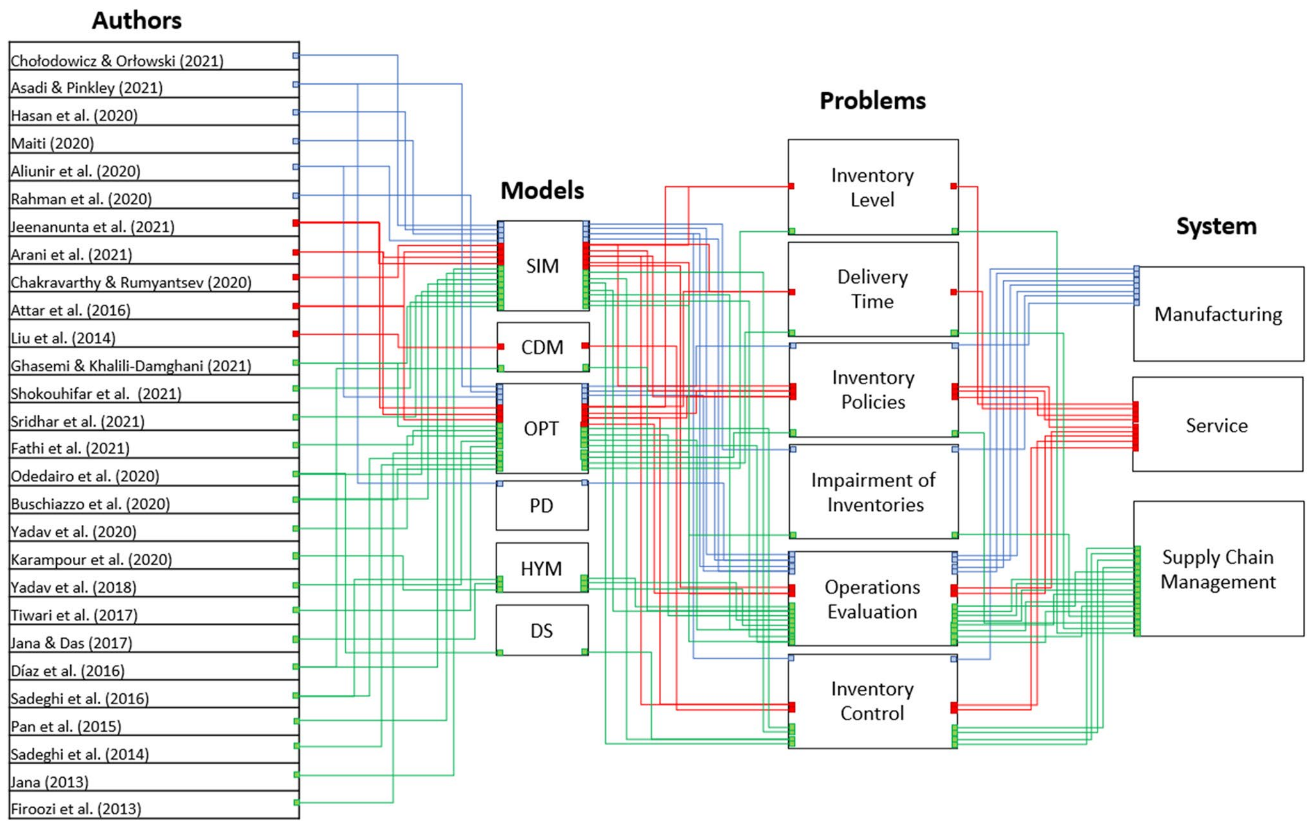


Fig. 4 Relationship between fields in stochastic models

Table 8 Future perspectives on stochastic models

Authors and year	Outlook for future work
Shokouhifar et al. (2021)	Extending models to more actors in the supply chain
Poormoaied (2021)	Develop heuristic and metaheristical algorithms for multiproducts
Arani et al. (2021)	Applying fuzzy techniques to reduce uncertainty
Chołodowicz and Orłowski (2021)	Developing control systems for perishable products
Esmaeili and Nasrabadi (2021)	Collaborative and cooperative models among agents
Assi and Effanga (2021)	Incorporate uncertainty in various model parameters
Visentin et al. (2021)	Considering multiple products and multiple actors in the supply chain
Fathi et al. (2021)	Extend the models considering location, inventory and routing
Kumar (2021)	Consider randomness in the inventory parameter

the agents or levels must prevail considering bonds of trust, shared decision-making and information exchange, so that the degree of uncertainty within the system can be reduced.

Evolution of the Number of Publications (Q3)

For the analysis of the number of publications, the decade from the 1970s to the present (1970–2021) was taken as the starting parameter. A search in the Scopus database using the <Title> "Inventory AND Models AND Deterministic" and <Title> "Inventory AND Models AND Stochastic." Fig. 5 shows that the first research and applications began in the early 1970s and have been increasing over the years in both types of models, mainly in stochastic models, due to the volatility and uncertainty generated in various random variables associated with demand, delivery times, number of orders, and others related to inventory operations.

Table 9 relates the search for research where the contexts were addressed in a hybrid or combined form, in the Scopus database using the <Title> path "Inventory AND Models AND Deterministic AND Stochastic." The inclination towards article-type products is evident, with little frequency at present towards literature review-type products, which makes the development of the present work attractive and interesting.

In more detail, starting from the different Publisher and databases, using the same combined path < Title > "Inventory AND Models AND Deterministic AND Stochastic." It was possible to analyze item-type products over the same time horizon. Table 10 shows the results found highlighting the trend towards multiple product problems with deterministic and stochastic time and quantity variables.

Top Countries (Q4)

Using the same search strategy, an analysis of the most prominent countries was carried out, highlighting the fifteen (15) countries with the most publications on the thematic area of deterministic and stochastic inventory models. India prevails as the country with the highest number of publications in both aspects. India, Taiwan, and the USA stand out as the countries with the highest production of deterministic models. Countries such as the USA, China, and India stand

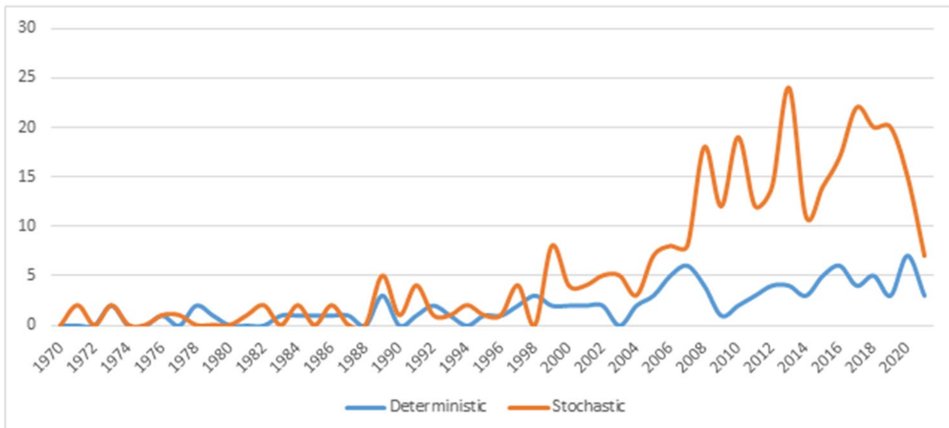


Fig. 5 Evolution of the number of publications

Table 9 Production by type of product in hybrid or combined form

Author and year	Publication	Product type
Antic et al. (2022)	Applied Sciences (Switzerland)	Article
Fattah et al. (2016)	International Journal of Engineering Business Management	Article
Choi (2013)	Handbook of EOQ Inventory Problems	Book
Chan and Karakul (2008)	Introduction to Logistics Engineering	Book Chapter
Taylor (2007)	Logistics Engineering Handbook	Book Chapter
Hariga and Ben (1999)	European Journal of Operational Research	Article
Goyal and Satir (1989)	European Journal of Operational Research	Review
Rosenkranz (1973)	Zeitschrift für Operations Research	Article

Table 10 Ratio by type of publishers and database in hybrid or combined form

Author and year	Publisher	Hybrid or combined problem
Antic et al. (2022)	Mdpi	Multiple products with deterministic demand and stochastic lead time
Azoury and Miyaoka (2020)	Elsevier	A product with stochastic and deterministic demand
Fattah et al. (2016)	SageJournals	Multi-product with average stock and deterministic and stochastic supply frequency
Labadi et al. (2007)	IEEExplore	Multi-product with deterministic batch sizes and stochastic customer orders
Labadi et al. (2005)	Elsevier	Multi-product with stochastic and deterministic demand
Hariga and Ben (1999)	Elsevier	Multi-product with deterministic and stochastic lead time
Ståhl (1994)	Taylor & Francis	Multi-product with deterministic and stochastic inventory level
Goyal and Satir (1989)	Elsevier	Multi-product with deterministic and stochastic demand
Haneveld (1980)	Springer	A product with deterministic and stochastic demands
Rosenkranz (1973)	Springer	Multi-product with deterministic and stochastic demand functions

out with more publications in stochastic models (See Fig. 6). Based on the data and information provided by the World Trade Organisation (WTO), it can be established that the countries that invest the most in the research development of models and inventory management in production systems are those that also stand out for their high production and marketing volumes worldwide.

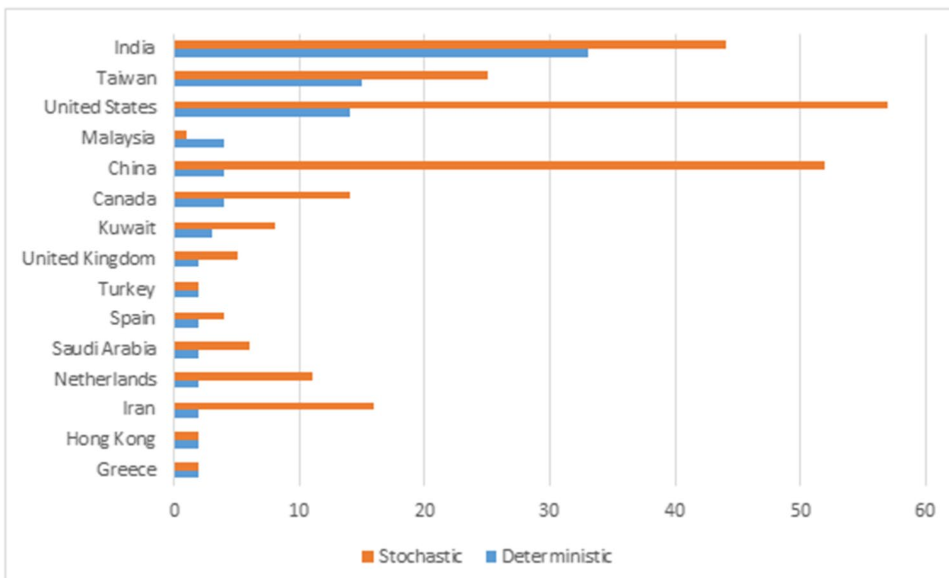
Authors with the Most Publications and Citations (Q5)

For the analysis of the authors, VosViewer was used as a computer tool, which allowed the visualization and construction of bibliometric networks to be identified. Figures 7 and 8 represent the most relevant authors in terms of number of publications and citations. These are represented with larger circles and a larger font size. In the deterministic inventory models, Bhunia, A.; Benkherouf, L.; Maiti, M.; Teng, J.; Rahim, M. and Uthayakumar, R. stand out. In the stochastic inventory models, Benkherouf, L.; Levi, R.; Jauhari, W.; Maiti, M.; Shmoys, D.; Nasri, F.; Ouyang, L.; Roundy, R. and You, F. stand out.

Most Related Words (Q6)

A study of the most used words, taking into account the title, summary and keywords in the research carried out, allowed visualizing a number of words related to deterministic and stochastic inventory models. In the first one, the following stand out: Deterministic demand; Inventory

Fig. 6 Top countries



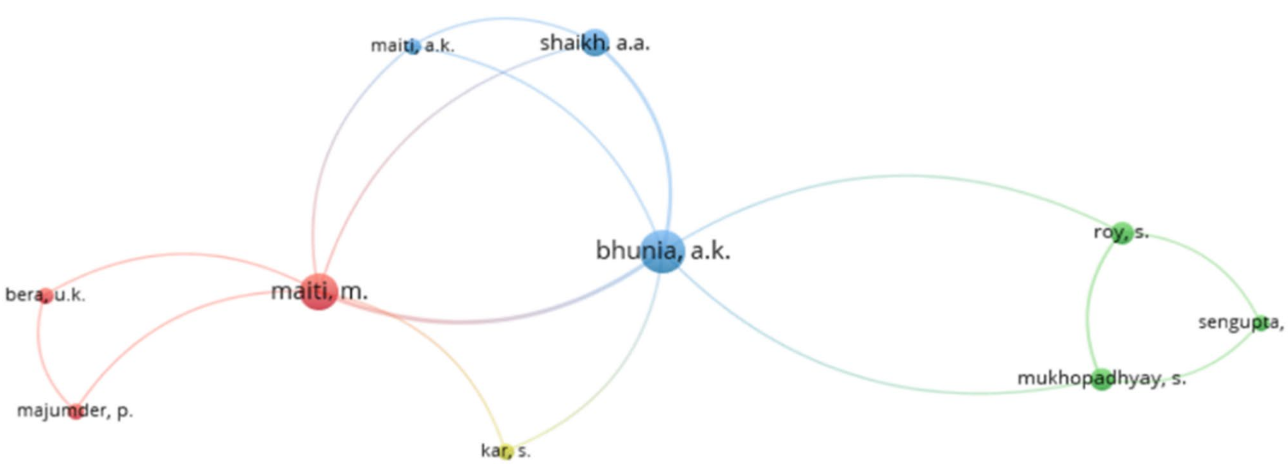


Fig. 7 Most important authors—deterministic model

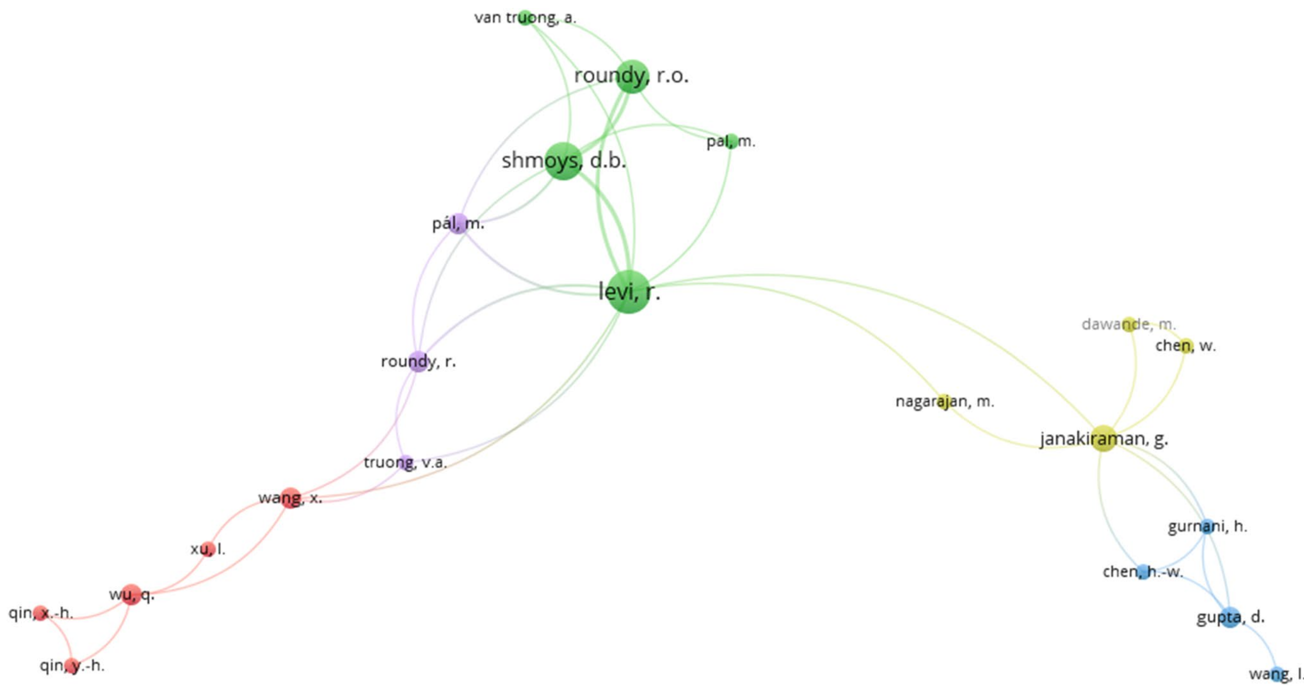


Fig. 8 Most important authors—stochastic model

policies; Warehousing and Order levels; in the second one: Stochastic lead time; Stochastic demand; Integrated models; Optimization; Simulation and Algorithms (see Figs. 9 and 10). This extraction corroborates the trend and the current or future stakes of inventory models in production systems.

Discussion

The deterministic and stochastic inventory models in production systems establish alternatives for obtaining primary objectives such as minimising costs and increasing service levels. The review of the literature by means of the proposed methodology allowed obtaining satisfactory results that support decision making at the managerial levels of the companies.

The research work provides answers to six (6) questions, (i) for Q1, the management of inventory models takes relevance in decision making, based on quantitative methods that allow finding optimal and objective solutions. The literature clearly shows aspects that justify their application, framed to minimize costs, risks and imperfect items and in turn maximize effectiveness, efficiency and service levels. (ii) in Q2, the classification depends on the variables

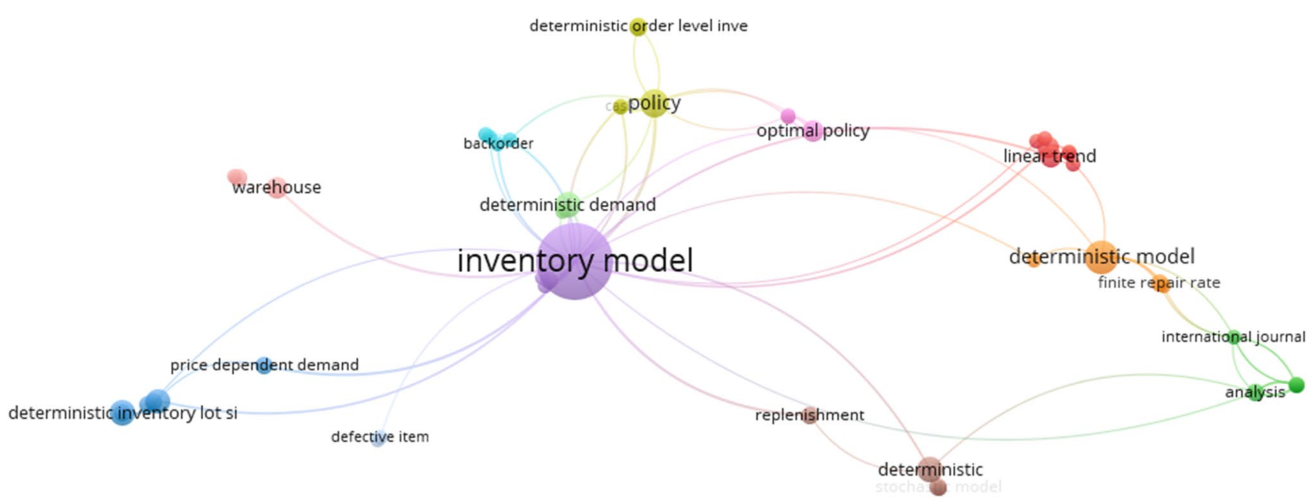


Fig. 9 Most related words—deterministic model

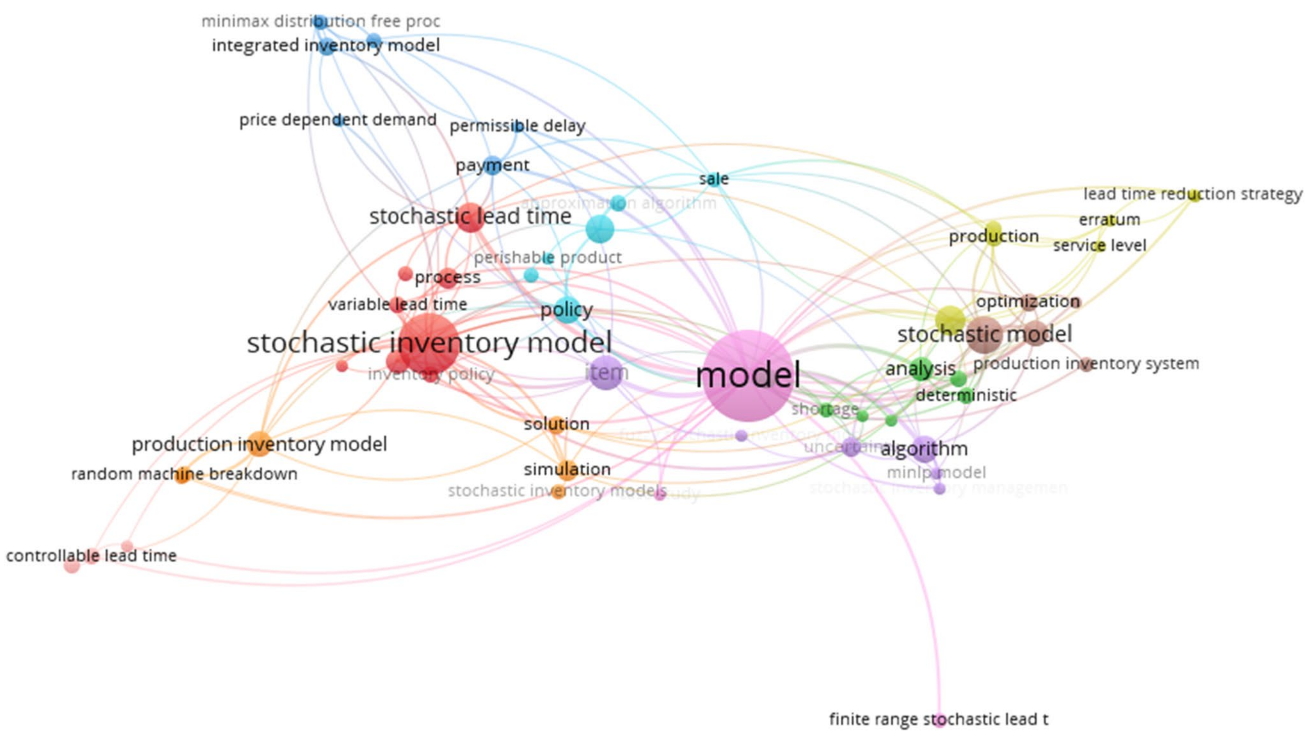


Fig. 10 Most related words—stochastic model

involved in the models, being deterministic or stochastic, finding different types of methods for their analysis, problematic aspects and techniques for their solution, the results show a high inclination for service systems towards aspects of deterioration and capacity in deterministic environments. (iii) in Q3, the positive trend over time towards both types of models, mainly in stochastic models, which study and analyze environments that generate greater uncertainty. (iv) for Q4, geographically, a large volume of research is framed in the Asian continent, specifically in South Asia with India and Malaysia and East Asia with China and Taiwan, likewise the country of the USA stands out in North America. (v) in Q5, regarding the authors with more publications, citations and associations, in the deterministic models three (3) clusters stand out, with red color Majumder, P., Bera, U.K., Maiti, M; with blue color Bhunia, A.K., Shaikh, A.A., Maiti, A.K., Maiti, M. and with green color Roy, S., Mukhopadhyay, S., Sengupta, P.P. that point to research elements associated with the variable demand, lead time and product deterioration. In stochastic models five (5) clusters, green with Levi, R., Roundy, R.O., Shmoys, D.B., Van Truong, A.; Violet with Pál, M., Roundy, R.,Truong, V.A.; red with Xu, G.-F., Wang, X.-J., Wu, Y.-Y., Yang, S.-L.; blue with Chen, H.- W., Gupta, D., Gurnani, H. and yellow with Janakiraman, G., Chen, H.-W., Nagarajan, M. focused on inventory control models for perishable products with fast shipping commitments and lost sales. Finally, (vi) Q6 that corroborate the trend and current or future stakes of inventory models in production systems.

In synthesis, an adequate inventory management in the different schemes can prevail if there is an integrated supply chain, operations optimization and process simulation system. These allow, from models such as EPQ, QM, and OP (deterministic) and SIM and OPT (stochastic), through the application of current quantitative techniques associated with queuing networks, markovian processes, metaheuristic optimizations and fuzzy simulations, to find answers to adequate levels in obtaining variables such as times, order quantities and total costs. This is based on different configurations of systems such as multi-product and perishable inventories, which are the most commonly addressed or worked on due to their degree of complexity and uncertainty, due to the high variability in the life cycle of the products, the risk of deterioration and the quantities of references or production volumes.

Conclusion

The research focuses on a literature review, based on a search for information in the Scopus database. From the proposed method, based on three (3) stages (i) search design, (ii) selection process and (iii) synthesis. These initially contain the formulation of six (6) guiding questions

Q1 to Q6, giving answers based on the information search path "Inventory AND models AND < Title > Deterministic" and < Title > "Inventory AND models AND Stochastic." Given the above, a refinement of the data was made providing a total of 103 for the deterministic models and 310 research papers for the stochastic ones. having as time horizon from the seventies (70 s) to the present. For their adequate treatment and analysis, computer techniques such as Excel and VosViewers were used. The development allowed concluding that there is a greater scientific interest in stochastic inventory models, without forgetting the deterministic ones. Important aspects for their management are highlighted (i) having an integrated system in the supply chain, (ii) optimizing cost and lot size, (iii) establishing production and replenishment policies, (iv) reducing the risk of shortages and excess, (v) managing stock deterioration, (vi) controlling lead times, (vii) reducing imperfect quality items and (viii) generating effectiveness and efficiency in the ordering process. Aspects related to the different types of models have been studied, with a greater proportion in the deterministic models EPQ, QM and OP, oriented more to the application of service systems and the use of techniques focused on attention processes, queuing theory and Markovian. Regarding the stochastic models SIM and OPT framed towards supply chain management systems, in search of integrality, cooperation and collaboration, with techniques used as metaheuristic algorithms, discrete event simulation and fuzzy. Regarding the highlighted words, the tendency towards the frequent approach of deterministic and stochastic demand; inventory policies; storage and order levels, stochastic lead time; integrated models, heuristics, metaheuristics and algorithms is corroborated. There is also a high volume of production and citation of research on the thematic axis in Eastern countries such as India, China, Taiwan, Malaysia, and in North America such as the USA. The results show that there is scientific interest in the different types of inventory models in an independent and hybrid form. A more detailed study revealed an inclination towards article-type products, with low frequency at present towards literature review-type products, which makes the development of the present work attractive and interesting. The research suggests future avenues based on common characteristics, problems addressed and frequent variables, use of quantitative solution techniques, as well as perspectives or suggestions from recent authors, relevant to the literature to support decision making.

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Data Availability The data supporting the findings of this research paper are available and may be requested from the corresponding author.

Declarations

Ethics Approval The authors hereby state that the present work is in compliance with the ethical standards.

Consent to Participate Not applicable.

Consent for Publication The manuscript has not been published before and is not being considered for publication elsewhere.

Conflict of İnterest The authors declare no competing interests.

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