INVENTORY MANAGEMENT CONCEPTS AND IMPLEMENTATIONS: A SYSTEMATIC REVIEW

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ABSTRACT

Inventory is a central management function. It is a cornerstone of supply chain management and logistics in the material management system. Depending on the organisational objectives, inventories in warehouses may be needed to fulfil customer or humanitarian demands. Controlling inventory is critical to operational success and organisational performance. This research reviews inventory management concepts and implementations in the face of increasingly demanding human need. Demand is a critical variable in the inventory control system, and its characteristics affect inventory treatment. Important demand characteristics include its level of certainty, which could be deterministic (i.e., known with certainty) or stochastic/Bayesian (i.e., known but uncertain), and its structural dependency (i.e., independent or dependent). This review considers the deterministic independent and dependent natures of demand and their respective impact on inventory management in operations.

OPSOMMING

Voorraad is 'n sentrale bestuursfunksie. Dit is die hoeksteen van voorsieningskettingbestuur en -logistiek in materiaalbestuurstelsels. Afhangende van die doelwitte van die organisasie, mag voorraad in pakhuise nodig wees om aan klante of humanitêre eise te voldoen. Die beheer van voorraad is van kritieke belang vir operasionele sukses en organisatoriese prestasie. Hierdie navorsing hersien voorraadbestuurskonsepte en die implementering daarvan te midde van toenemende veeleisende menslike nood. Aanvraag is 'n kritieke veranderlike in die voorraadbeheerstelsel en die kenmerke daarvan beïnvloed voorraadbehandeling. Belangrike aanvraag kenmerke sluit in die vlak van sekerheid, wat deterministies (d.w.s. met sekerheid bekend) of stochasties/Bayesian (d.w.s. bekend, maar onseker) kan wees, en die strukturele afhanklikheid daarvan (d.w.s. onafhanklik of afhanklik). Hierdie oorsig oorweeg die deterministiese onafhanklike en afhanklike aard van aanvraag en hul impak op voorraadbestuur in bedrywighede.

1   INTRODUCTION

Inventory (stock) management is a critical operation in manufacturing and supply chain processes. The manufacturing process uses raw materials and work-in-process goods to create finished products that are stored as inventory or sold, some of which may also be used in follow-up operations. Inventory is the most important asset held by many organisations, representing as much as half of the company's expenses, or even half of the total capital investment. In addition, according to the Science Direct publication website (accessed in 2020) [48], the past two decades have seen an increase in inventory management research interest. As shown in Figure 1, the publication of articles on inventory management has seen an increase of over 525 per cent, with the number of published articles increasing from 2 544 in 1998 to 13 381 in 2020.
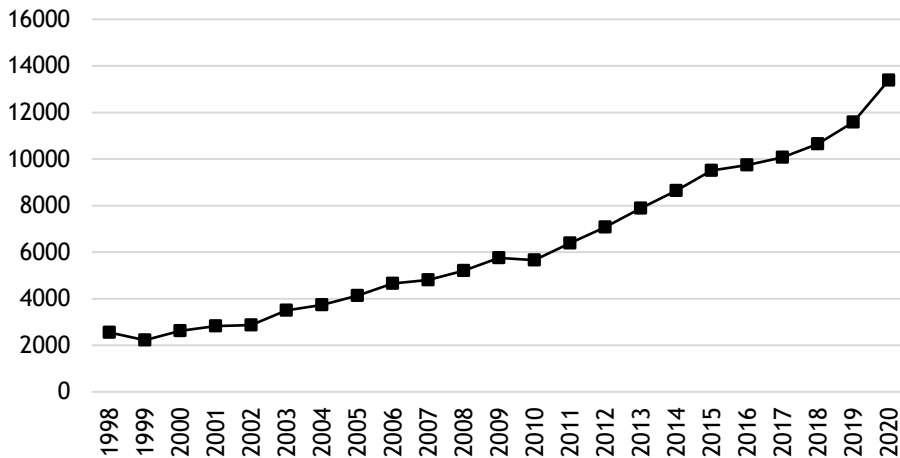
Figure 1: Science Direct publications on inventory management, 1998—2020 [48]

Inventory management models are applied in nearly all operations. The scope in the literature spans fields such as manufacturing, medicine, humanitarian aid, environmental science, engineering, agriculture, and even energy. By filtering Science Direct's search for publications on inventory management, and taking into account both open access journals and journals to which only subscribers have access, it was found that the most frequently discussed topic in inventory management is environmental science, followed by engineering, energy, and others (Figure 2). Given the increasing impact of climate change, environmental science has created the need for re-engineering, thus increasing the demand for stock management.
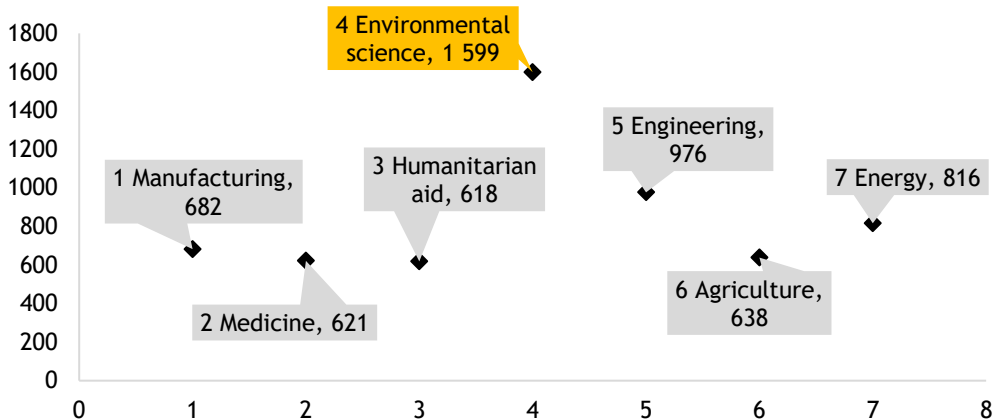

Figure 2: Science Direct publications on inventory management topics (open access and subscription) [48]

Figure 2 shows the range of areas affected by stock management. The crucial challenge for an organisation is often to have a balanced demand supply that minimises inventory costs and increases the satisfaction of the target beneficiaries. As stated by Nemtajela and Mbohwa [85], proper inventory management ensures a good balance between minimising the total cost of inventory and maintaining the desired customer satisfaction level.

The rise of online retailers such as Amazon or Alibaba over the past three decades has shown the growing importance of proper inventory management. In addition, there were situations in the past when poorly managed stocks caused companies such as Solectron to lose billions of dollars. This paper undertakes a systematic review of a number of stock management concepts and their contribution to the topics outlined in Figure 2 and to future research.

2   LITERATURE REVIEW

The concepts of inventory management date back to the early days of humanity. The practice of inventory has modernised and evolved over the last 100 years, with new tools and technologies being used to support the process. For instance, in ancient times, traders counted and tallied items that were sold each day – until the Egyptians and the Greeks developed more accurate inventory record management and accounting systems, in contrast to the inaccurate and inefficient practice of hand-written notes and hunches. Over the years, progress has been made in inventory management practices. These advances have led to further cost reduction and improved customer satisfaction.

What is inventory? According to Render et al. [96], inventory is a stored resource used to satisfy a demand, current and future. Similarly, Vrat [123] defines inventory as component parts, raw materials, WIP (work-in-process), or finished products held at a specific location (a warehouse) in the supply chain. Both authors, as well as Plinere and Borisov [92], listed inventory types that included the following: 1) raw materials, work-in-process, transit, finished goods, buffer (safety stocks), decoupling (contingencies stock), anticipation (speculation inventory), and cycle (business's standing inventory), etc. These inventories differ from one organisational sector to another. For example, in humanitarian relief supply chains, the difference between life and death depends, among many other things, on decoupling stocks, whereas, in the wholesale trade, buffer stocks or even transit stocks can prevent the organisation from losing its valuable reputation. Figure 3 shows the three types of inventories commonly used in manufacturing:
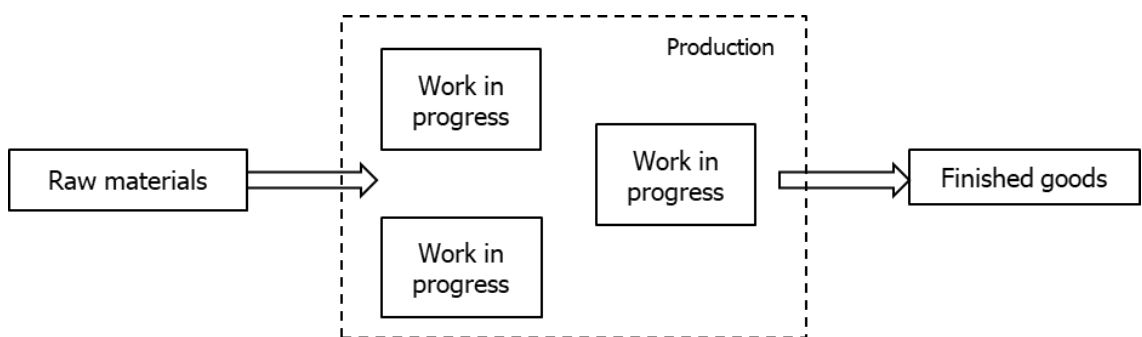

Figure 3: Types of manufacturing inventory [79]

Inventory management is viewed as a central function in the inventory management system [79], [94], [3]. For Khobragade et al. [61], inventory management, also known as materials management, is identified as the organisation, securing, storage, and distribution of the right materials, of the right quality, in the right quantity, in the right place and at the right time, in order to coordinate and organise the creative movement in an integrated way within a mechanical project. Inventory management involves maintaining some stock levels at a minimised cost while improving the value-adding measures of customer satisfaction, which are useful measures of organisational performance [85], [43], [41], [105]. According to Christopher [27], an organisation with a good inventory management system is able to establish good policies and controls that monitor the level of inventory and determine what levels to maintain, when the inventory should be replenished, and the size of the order. Inventory levels for finished goods are viewed as a direct function of demand [96]. In the event of a higher demand in the supply chain, the inventory level decreases proportionally.

There are factors that influence inventory management practices. Prominent among these are organisational and human factors, financial constraints, and, more recently, the increasing rate of technology adoption [3]. Financially, 'inventory' is considered the biggest and most important asset of an organisation, which – according to Render et al. [96] – constitutes up to about 50% of the total capital investment of the company's assets. In humanitarian operations, inventory not only represents a significant financial asset, but also has a direct impact on saving lives. In the industrial sector, firms with goods inventory management practices are able to increase their overall profit margins, and so increase their level of production capital, and overall customer satisfaction [33], [92]. The flowchart in Figure 4 details the basic stages in an inventory management system.
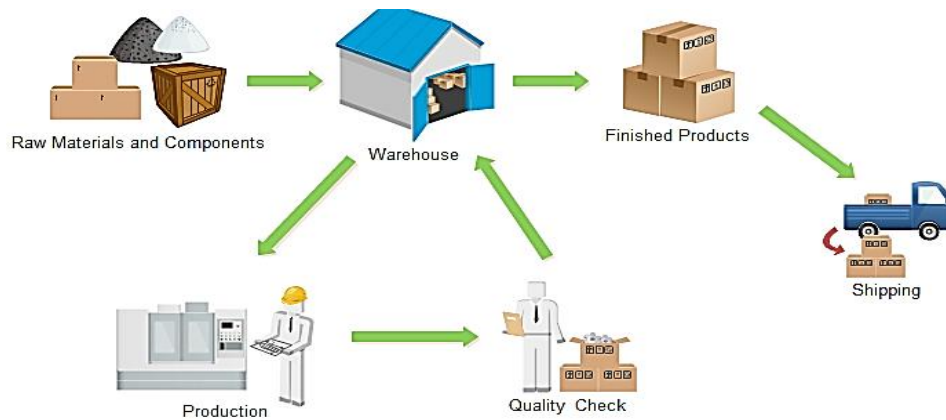
Figure 4: Basic flowchart of an inventory management system [35]

Ivanov *et al*. [54] consider the trade-off between service level and cost as one of the most important financial decisions in inventory management. Other important financial decisions include how much to order and how much physical inventory to hold in a warehouse in anticipation of a sudden increase in demand, to avoid delays in supply chains. It is also worth including the management of unused stock and the costs associated with holding physical stock in a warehouse as an important financial decision.

Another important factor influencing inventory management practices, apart from the financial, is technology. Although technology has largely influenced inventory management positively, Ahmad and Mohamed Zabri [2] believe that, since its introduction, technology has exposed the human impact on the day-to-day handling of inventory. In Table 1, Rushton *et al*. [98] compare different technological applications with different daily human processing of inventory activities. With a similar number of activities (3,000,000), Table 1 shows the error occurrence rate in processing activities using inventory management applications. The results show that the less daily human handling of stocks there is, the fewer the errors.

Table 1: Rates of error occurrence in activities [98]

Application	Error occurrence rate	Number of activities	Processing activities
Printed entry	25,000	3,000,000	▪ Involves a human counting and recording
Keyboard entry	10,000	3,000,000	▪ Involves technicians and machinery such as a keyboard and an alphanumeric system.
Optical character recognition (OCR)	100	3,000,000	▪ Labels that are both machine- and human-readable. ▪ For example, licence plates
Bar Code (Code 39)	1	3,000,000	▪ Fast, accurate, and fairly robust Reliable and cheap technology
Transponders (Radio Frequency Tags)	1	3,000,000	▪ A tag (microchip + antenna) affixed to the goods in a container ▪ Receiver antenna ▪ Lost station that transmits information (data) to the server ▪ Can be passive or active

The study conducted by Ayad [7] examined the influence of human factors in inventory management practices by assessing different stores from the same company, each run by a store manager. The aim of the exercise was to identify human variables within the store manager's control. Findings from the study

revealed that the diversity of store types and the variety of departmental operations resulted in different outcomes within the same organisation. Furthermore, analysis of Ayad's [7] findings showed that human factor variations were the result of their useful knowledge, leadership ability, or critical thinking. Another study was conducted by Strohhecker and Grobler [107] that focused on inventory managers' physiological traits; their findings identified the following four traits: personality, knowledge, intelligence, and interests. The authors also investigated the impacts of these traits on their performance, specifically during a dynamically complex inventory management task [107]. The findings showed the 'intelligence' trait to be the sturdiest predictor of inventory routine, while 'interest' in social matters led to worse inventory performance and higher costs. Using technology in inventory control is not a novelty; but a good number of organisations still avoid using technology for economic (financial) and expertise (human) reasons. Many inventory management technology applications offer efficiency — but they come at a cost.

Other factors influencing inventory management practices are related to forecasting decisions. Rajeev [94] discussed the 'rule of the thumb' decision, which resulted in less purchasing, use of a computer, variable lead-times, less attention to forecasting, training, and development, and random ordering of material [2]. Bala [9] showed that using sophisticated computerised systems for forecasting improves the profitability of an inventory management system.

3 ROLES, INVENTORY MODELS, AND THE DEMAND VARIABLE

3.1 Role of inventory

Since the primary role of inventory management is to maintain a desired stock level of defined products or items [119], the role of inventory in operations management cannot be overemphasised. History has shown that organisations that have neglected or failed to consider the importance of inventory management have lived to regret it. According to Tanthatemee and Phruksaphanrat [114], inventory management helps to improve customer service and to cope with demand uncertainty. Demand uncertainty is a potential challenge that results in high inventory levels and high carrying costs, which can lead to higher prices and low customer satisfaction, and thus a less profitable business.

3.2 Inventory models and the demand variable

The main decisions affecting demand in an inventory management problem are a) when to purchase (creation of a purchase order), and b) how much to purchase (lot size) [82]. Resolving both problems in a decision-making process requires the development of inventory models and techniques [96]. These two decision-making problems connect the inventory model's objective function with a number of decision variables (e.g., lot size and re-order point). It also links up with several inventory-related cost parameters and situational variables, such as a) the demand nature and level (including its level of certainty); b) the lead time (including its level of certainty); c) extant constraints (if any); d) quantity discounts or inflationary trends; and e) other relevant issues.

Demand is regarded as a critical variable in inventory management. Accurately forecasting the market or the level of demand helps to make the correct inventory decisions that optimise sales and profits. Based on the level of certainty of demand, two types of inventory model are usually developed: (1) deterministic demand models, and (2) stochastic (Bayesian) demand models.

3.2.1 Deterministic demand model (demand known with certainty)

In the deterministic model, inventory operations are determined on the basis of a known (certain) demand. A deterministic model produces the same output because of certainty about the factors, conditions and parameters involved, which are clearly stated at the start. Among the parameters is demand. According to Antic et al. [4], deterministic demand is represented as a sales forecast for each product per month. The deterministic demand model aims to minimise the overall costs related to production time, setup time, and overtime, and those associated with inventory, such as ordering costs, carrying costs, and stock-out costs (overstocks and shortages).

The deterministic demand model may have two types of demand: independent and dependent. It is crucial in an inventory control system to understand the difference between those two demand types as the starting point for an inventory policy. Independent demand is the demand for finished products such as cars or books, and may involve some level of uncertainty as well; while dependent demand focuses on component parts or sub-assemblies such as box console sub-assemblies for Toyota cars, and is usually considered certain once the end item on which it depends is known. Figure 5 illustrates the nature of both kinds of demand.
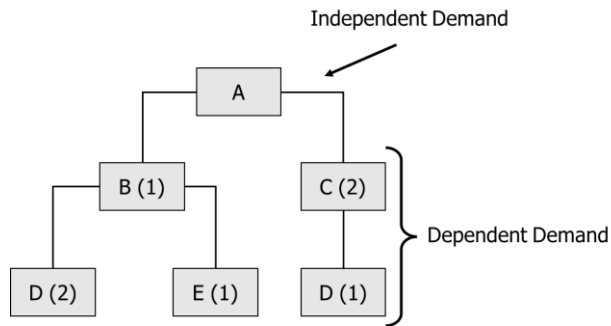
Figure 5: Independent demand vs dependent demand

In an independent demand environment, the demand for an item does not depend on the demand of another item (see Figure 5). For example, finished goods items do not depend on other items because the focus is on item sale, order processing, or sales forecast. The independent demand for inventory is founded on confirmed forecasts, customer orders, estimation, and past history.

However, unlike independent demand, dependent demand for an item depends on the demand for another item. For instance, raw material and component stocks are dependent on the demand for finished goods. Raw materials and other manufacturing components, for instance, are converted to finished goods through systems such as material resources planning (MRP), distribution resources planning (DRP), or enterprise resource planning (ERP).

3.2.2 *Stochastic (or Bayesian) model (demand known without certainty)*

In a stochastic (probabilistic or Bayesian) model, inventory decisions are made in the light of uncertainty (demand and/or lead time). According to Antic *et al.* [4], stochastic demand is generated as a random variation of sales forecast within a range of about 20 per cent. For Nemtajela and Mbohwa [85], the uncertainty in demand is the result of factors such as changes in purchase orders and unpredictable events. Furthermore, Tanthatemee and Phruksaphanrat [114] believe that uncertain inventory demand is the result of changes to orders, the random capacity of suppliers, or unpredictable events. Sil [103] listed three types of stochastic model:

a) Single period: mainly concerns fashion products, perishable products, products with a short life cycle, or even seasonal products. The single period is a one-off decision (how much to order).

b) Multiple period: concerns goods whose demand is recurrent but varies from period to period; inventory systems with periodic revisions. The multi-period stochastic model is a periodic decision (what quantity to order in each period).

c) Continuous time: related to goods with recurring demand but with variable inter-arrival time between customer orders; inventory systems with continuous revisions. The continuous period stochastic model is a continuous decision (continuously deciding how much to order).

4 INDEPENDENT DEMAND INVENTORY MODELS

The main objective of an inventory management is to minimise operational costs. Minimising cost in independent demand inventory models consists of the following functions:

- optimisation of fast-moving stock to avoid stock-out (understocking)

- proper definition of safety stock (involving ordering point to prevent any risk of premature depletion of inventory)

- reduction in excessive inventory (overstocking)

Among the most significant inventory-related costs in a decision support system are: 1) ordering cost, 2) carrying or holding cost, 3) goods purchase cost, 4) stockouts and shortages cost, and 5) storing cost. According to Vrat [123], Inventory carrying (holding) costs, cost of shortage and stockout, and ordering costs are the three types of inventory-related cost that are primarily associated with inventory decision-making models. Independent demand inventory is composed of two main types of models: a) single-period (perishable) inventory models, and b) multi-period inventory models, as shown in Table 2.

4.1 Single-period (perishable) inventory model or the newsboy problem

A single-period inventory model is one that is applied by organisations that order perishable or one-time items. Such models require the order to be of the right quantity, fearing overstocks and waste as soon as the product has passed its perishable or expiry date. The same rule applies to seasonal items or any item that is no longer of value after the time it is required. A single-period inventory model does not include only perishable items, but also a wide variety of items such as style items, spare parts, or special season items. As items become obsolete at the end of the cycle, decision-makers face challenges such as managing the demand for single or multiple items. The key differences between a single-period (perishable) inventory model and a multi-period inventory model are listed in Table 2 below.

Table 2: Single-period inventory model vs multi-period inventory model

	Single-period	Multi-Period (EOQ)
Demand	Deterministic demand, uniform demand	Variable demand and stochastic (random) demand
Type of product	Perishable products, fashion products	Imperishable
Cost/profit	Maximises profitability	Minimises costs
Time	Single period of time	Infinite time horizon
Ordering opportunity	Single ordering opportunity	Multiple ordering opportunities
Selling season	Single selling season	Multiple selling seasons

In addition to the above differences, a single-period inventory model requires that orders for items be placed before the start of the period, and replenishment cannot be done during the period. Furthermore, the stock remaining at the end of the period is considered obsolete and so is eliminated from the inventory; and its value is deducted from the profit of another order at the beginning of a new period. When the order is larger than the demand, the extra items ordered are counted as lost.

Research into the single-period inventory model is essential for businesses as well as for humanitarian aid organisations, as determining the exact number of perishable or seasonal items an organisation needs maximises the productivity expected from that particular organisation and reduces waste. In a humanitarian environment, little research has been conducted on disaster inventory systems that focus on perishable or seasonal items, particularly in the aftermath of a disaster. Among the few notable researchers are Yadavalli *et al.* [127]. Their analysis proposed a continuous review disaster inventory model with a doubly substitutable perishable item. Using an emergency situation, they proposed to replace an out-of-stock item with a similar item available in the inventory, thus avoiding a long waiting time and favouring instant replenishment. For example, a particular blood type that is not available in the blood bank at the time of application or that is past its expiry date may be replaced by an acceptable and available universal type.

Researchers on the newsboy (*Single-period [perishable])* inventory model also called the Christmas tree problem, particularly deal with (1) *single perishable items* (see, for example, [56], [88], [57], [10], [40]) and (2) *multi perishable items* (see, for example, [90], [126], [34], [12]). According to Satyendra *et al.* [99], a newsboy must achieve a stock decision quantity that maximises the expected profit while minimising the expected loss under stochastic demand conditions (see the first statement in Table 2).

4.1.1 Single perishable item problem

According to Joy and Jose [55], a perishable product is one whose value decreases over a given period. Perishable items make inventory management more challenging, as they affect the inventory, service, and re-order levels. Some examples of perishable item are vegetables, fruit, baked products, and fashion items. The deterioration or loss of value of perishable products can be explained by their short life (fruit and vegetables), changes in trends (fashion items), etc. The application of the perishable inventory model is broad, and needs to be assessed on a case-by-case basis. Since the first study on perishables by Whitin [124], models have been developed that take into account perishable aspects such as items on display, the freshness of items, and price dependency [39]. Avinadav *et al.* [5] developed a single perishable item model that optimises the price, order quantity, and replenishment periods of a perishable item with price- and time-dependent demand. Taleizadeh *et al.* [112] studied discounted inventory models, focusing on the

customer decision as a key factor, while Liu [73] studied a perishable inventory model with product lifetime incorporated into it. Under specific assumptions, single perishable item models are developed.

4.1.2 Multi perishable Items problem

A multi perishable items problem was initially solved by Hodges and Moore [47] using stochastic demand competing for a number of limited resources. Authors who have been solving problems related to multi-constraint or multi-item single period inventory intend to maximise the probability of targeted profits [103], [68]. In addition, an approach to solving the multi perishable items inventory model with constraints was developed by Ben-Daya and Raouf [12], considering both financial and space constraints, with items demand following a uniform probability distribution function. Further studies were conducted by Layek *et al.* [69] that targeted the investigation of a two-fold solution space with constraints for a multi perishable item problem. Rahimi *et al.* [93] introduced a two-stage stochastic mixed integer non-linear programming (MINLP) model that assists companies that are considering discount policies. With regard to the multi-product single-period inventory problem, Bhattacharya [14] and Kar *et al.* [59] developed a multi-item inventory model for items that are deteriorating. With Kar *et al.* [59], the main focus was on multi perishable items with constraints in the storage space available and the level of investment. A multi-item inventory model for items that are deteriorating was further studied by Tayal *et al.* [115], targeting an acceptable shortage level and the product expiration date.

Kumar *et al.* [65] presented a multi-item, multi-constraint problem with stochastic demands for different types of item. The model also considered the replenishment time, constraints in storage space, and the level of stock-out associated with the cost of understocking and overstocking per unit shortage, and surplus inventory. The notation used in the Kumar *et al.* [65] model is as follows:

- r — Set of retailers (1 to R).
- p — Set of products (1 to P).
- x — A random variable representing the demand.
- $f_{rp}(x)$ — Probability density-function of demand of product 'p' at retail outlet 'r'.
- US_p — Understocking cost of product 'p' (Rs. per unit).
- OS_p — Overstocking cost of product 'p' (Rs. per unit).
- Cap_r — Storage capacity at retail outlet 'r' (units).
- Sup_p — Available supply of product 'p' (units).
- E_{rp} — Expected cost of product 'p' at retail outlet 'r' when supply quantity is Q_{rp}.
- μ_{rp} — Mean demand for product 'p' at retailer 'r'.
- σ_{rp} — Standard deviation of product 'p' at retailer 'r'.
- $z_{rp}()$ — Standard normal deviation of product 'p' at retailer 'r'.
- $\Phi_{rp}()$ — Cumulative density function of product 'p' at retailer 'r'.
- $\phi_{rp}()$ — Probability density function of product 'p' at retailer 'r'.

The model's objective was to minimise (Z_1) the total expected cost of all products associated with understocking and overstocking in all the retail outlets. The model is presented next.
Minimise (Q_{rp})

$$\sum_p(\sum_r(\int_0^{Q_{rp}}(Q_{rp}-x).f_{rp}(x).dx)*OS_p) + \sum_p(\sum_r(\int_{Q_{rp}}^{\infty}(x-Q_{rp}).f_{rp}(x).dx)*US_p) \tag{1}$$

Subject to

$$\sum_p Q_{rp} \le cap_r \qquad\qquad r \in \{1 \dots R\} \tag{2}$$

$$\sum_r Q_{rp} \le Sup_p \qquad\qquad p \in \{1 \dots P\} \tag{3}$$

$$\sum_r Q_{rp} \le Sup_p \qquad\qquad p \in \{1 \dots P\} \tag{4}$$

Equation (2) deals with retail outlets' storage capacity constraint, while Equation (3) makes sure that the product supply is not exceeded by delivery. Finally, Equation (4) is the non-negativity constraint. Kumar *et al.*'s [64] model is most applicable in the distribution of high-quality perishable foods chain.

4.2 Multi-period deterministic inventory models

A multi-period inventory model is a lot-sizing model that optimises the procurement of both single and multiple products, with cases of both a particular supplier and multiple suppliers, and from one period to another. A multi-period inventory model further involves the option of focusing on the economies of scale in the procurement process instead of accruing inventory costs from one period to the next [97]. Lot sizing, both static and dynamic, involves determining the number of items required during a manufacturing process. A multi-period inventory model has two variations:

- *Fixed order quantity systems* (Q model): a fixed order is placed each time the minimum stock level (re-ordering point) is reached.

- *Fixed time period models* (P model): orders are placed at allocated times, with the amount of inventory being determined in the aftermath of a review of the stock levels.

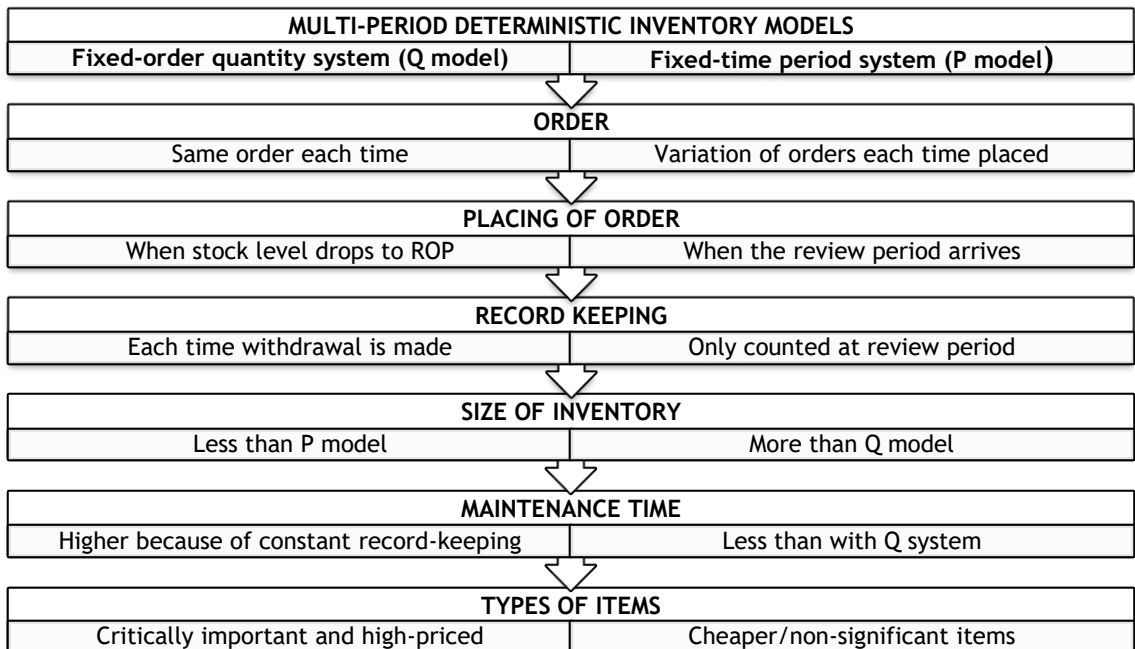Figure 6 below compares both types of multi-period inventory model for further understanding:

MULTI-PERIOD DETERMINISTIC INVENTORY MODELS	
Fixed-order quantity system (Q model)	**Fixed-time period system (P model)**
ORDER	
Same order each time	Variation of orders each time placed
PLACING OF ORDER	
When stock level drops to ROP	When the review period arrives
RECORD KEEPING	
Each time withdrawal is made	Only counted at review period
SIZE OF INVENTORY	
Less than P model	More than Q model
MAINTENANCE TIME	
Higher because of constant record-keeping	Less than with Q system
TYPES OF ITEMS	
Critically important and high-priced	Cheaper/non-significant items

Figure 6: Q model vs P model

4.2.1 Fixed-order quantity models (Q model)

A fixed-size ordering system is a pre-defined standard inventory system of a quantity of items that gradually decreases from the maximum level (Q) to the minimum level ($Zero$), until it reaches the ROP (re-order point), and then a new order of size EOQ (economic order quantity) is placed.

Fixed-order quantity models generally deal with certain demands; therefore, a new order of a fixed size is lodged as soon as the stock reaches the ROP (Figure 6). However, schedule orders can be scheduled to arrive at an increased lead time (L), introducing uncertainty to the demand and the system. In such cases, the precise demand throughout the lead time (ROP in the EOQ) becomes unknown. Barros *et al*. [11] listed a variety of uncertainty and risk factors associated with the procurement process (Table 3):

No	Variety of Uncertainty	Authors
1	Lead time uncertainty	[26], [32], [128], [24], [95]
2	Demand fluctuations	[26], [128], [24], [95], [86], [66], [17]
3	Price uncertainty	[128], [25]
4	Yield uncertainty	[128], [95]
5	Supplier delays	[8], [128], [95]
6	Supplier constraints	[16], [20], [44], [106], [128], [95]
7	Order crossover	[100], [118], [45], [128], [95]

To avoid stockouts, extra stock, called *safety stock,* is kept on hand (Figure 7). Safety stock prevents stockouts in case the demand is higher than expected.
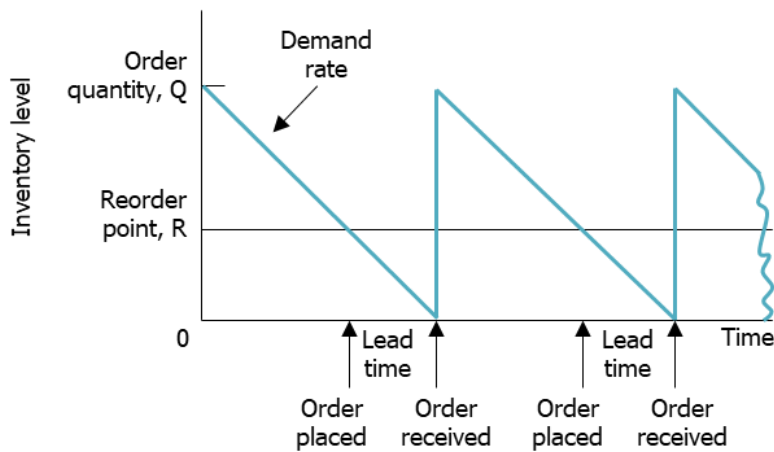

Figure 7: ROP in the EOQ without safety stock (SS) [116]

Figure 8 focuses on a stock level that will trigger re-ordering, while in Figure 7, although there is a re-order point, a safety stock (minimum stock) is applied. Table 4 below lists relevant publications discussing the application of the fixed-order quantity model.
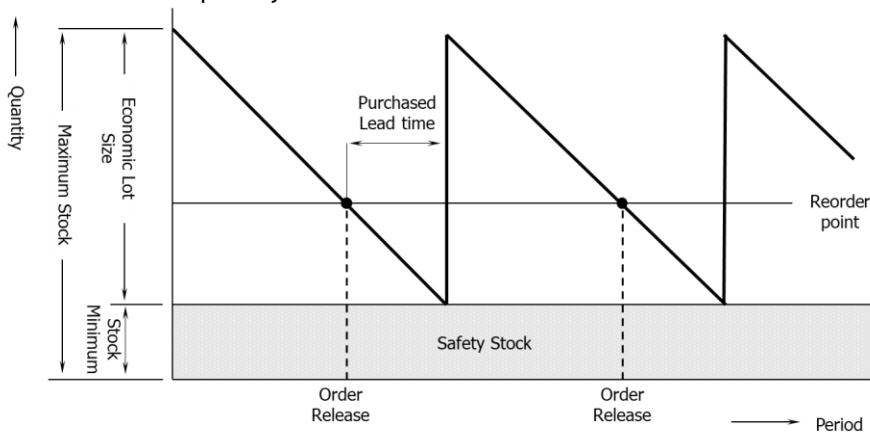

Figure 8: ROP in the EOQ situation with safety stock (SS) [78]

Table 4: Fixed-order quantity model application

No	Fixed-order quantity model	Authors
1	Economic order quantity (EOQ)	[23], [30], [31], [17], [83], [120], [62], [64], [125]
2	Economic production order quantity (EPQ)	[70], [28], [51], [117], [49], [19], [63], [72], [75], [108], [22], [39], [87], [74], [110], [113], [111]
3	Quantity discount model	[18], [77], [71], [42], [67], [101], [102], [129]
4	Re-order point (ROP)	[6], [90], [1], [123]

4.2.2 Fixed-time period model (P model)

Maintaining an optimal stock is a challenge faced by all organisations. Unlike in the fixed-order quantity system (Q model) in which orders are only placed after the item has reached the determined re-order point (ROP), in a fixed-time period model (P model), each item's stock position is reviewed periodically, as shown in Figure 9 below. When a stock level of a given item is determined, the decision to place an order is made, taking into account the following elements: 1) the customer's request for the item in question, and 2) the adequacy of the current stock level of the item in the supporting chain or production operation until the next revision.
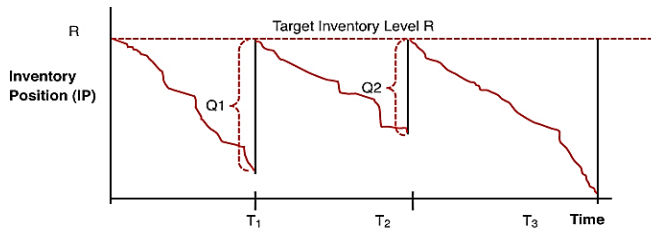

Figure 9: Fixed-time period model (P model) [53]

Using diverse service levels, Mahfuz *et al.* [76] applied the fixed-time period model while conducting a study in a services environment from 2004 to 2006. The study found that applying the P model saved an average cost for the services that ranged between 65 and 80 per cent of inventory investment, with a 98 to 100 per cent service level being provided. The capital raised through savings gives organisations a competitive advantage, as it can be used to purchase new technologies such as those for stock counting and stock location within the system.

According to Huang *et al.* [50], the fixed-time period ordering is conducted at a fixed and predetermined interval with some assumption such as 1) a variable demand, 2) a regular Lead time, 3) an ordering to restock the system to its full capacity, 4) non fixed ordered quantity, while the order timing is fixed, 5) the ordered quantity is much lower than the safety levels.

Following the above assumptions of Huang *et al.* [50], Equation (Eq 5, 6, 7 and 8) was generated below:

$$Maximum\ inventory\ (I_{max}) = average\ demand\ volume\ during\ the\ covered\ period\ +\ safety\ magin\ of\ inventory \tag{5}$$

$$I_{max} = \bar{d}(t + L) + Z_a * \sqrt{t + L * \sigma_d} \tag{6}$$

where

$\bar{d}$ is the average demand,

t is the fixed interval for re-order,

L is the lead time,

σ_d is the standard deviation of demand and

Z_a Is the standard normal Table

$$Ordered\ volumes\ (Q_i) = maximum\ capacity\ for\ inventory - existing\ level\ of\ inventory\ (I_i) \tag{7}$$

$$Q_i = I_{max} - I_i = \bar{d}(t + L) + Z_a * \sqrt{t + L * \sigma_d} - I_i \tag{8}$$

5   DEPENDENT DEMAND INVENTORY MODELS

Unlike independent demand inventory models, in which the demand for one item is independent of the demand for other items, in dependent demand inventory models, items are interconnected. Therefore, the demand for one item is directly dependent on the demand for another item. In an engine assembly plant, for example, the demand for the console, tyres, engine, etc. depends on the demand for a car. To manage the manufacturing process of finished products in the case of dependent demand for raw materials and other components, material resource planning (MRP) is mainly used. This management tool is applied with the help of models or applications such as just-in-time (JIT) and Kanban. In addition to MRP, enterprise resource planning (ERP) software is used to integrate all the departmental functions of organisations into one system. Software such as Oracle, SAP, and Microsoft Dynamics are also used in distribution resource planning (DRP) situations.

The association between independent demand and dependent demand is shown in a bill of material. The dependent demand is derived from the independent demand, and helps to find the quantities ordered for the dependent demand. For example, determining the quantity of finished products, such as automobiles, that are expected to be sold (independent demand) can help to determine the dependent quantities of components, such as wheels, tyres, and braking systems, that are needed to complete the production of the automobiles. For one car produced, for example, four wheels, two windscreen wipers, and two headlights are needed, among other components.

5.1 Material resources (requirements) planning (MRP)

The order quantities for dependent demand are found through the material requirements planning (MRP) system. MRP takes into account of the quantities of the required components, as well as the time needed to produce and receive them. Moustakis [80] defines MRP as a time-phased priority planning technique for computing the material requirement and scheduling supply to meet the allocated item demand [52]. This planning technique is a computer-based production as well as inventory control system that ensures a better customer order response. According to Heizer and Render [46], some areas where MRP implementation are useful include the following: (1) production scheduling, (2) quicker response to market variations, (3) improved adherence, (4) enhanced labour and facilities utilisation, and (5) control of inventory levels. Furthermore, as a starting point for further actions, MRP is dependent on the sales forecast for finished goods. Handling raw materials is far more challenging than handling finished goods, as it involves the analysis and coordination of delivery capacity, logistical processes, lead time, transportation, warehousing, and scheduling, before their final supply to the production shop floor. Raw materials administration also involves the periodic review of inventory holding and inventory tally and audit, followed by a comprehensive analysis report, leading to good financial management decisions.

A successfully implemented MRP system is able, simultaneously: (1) to ensure that the required materials (including components and other items needed for production) are available and meet customer delivery targets; (2) to ensure that inventory levels are kept as low as possible, and (3) to plan manufacturing and purchasing activities and delivery schedules.

The MRP system has three main inputs that help the system to function: (1) the master production schedule (MPS); (2) the bill of material (BOM), also known as product structure records; and (3) inventory status records. The MPS indicates the quantity of finished goods desired and the expected time of receipt of the delivery, including the necessary safety stock. The BOM consists of data on each material or process required to produce that material. The information included in the BOM includes the type of raw materials (parts and components), the item number, and the description and quantity per assembly and sub-assemblies needed to manufacture an item. Finally, the stock status file also has the role of maintaining the integrity of the record by recording and maintaining information about all of the items in stock, including stock on hand and scheduled receipts.

5.1.1   MRP applications in a material structure tree

MRP is used for both single and multiple items. Its application to a single material is illustrated in the following example. '10 units of A' means that 10 units of material A are needed, while '20 units of B' means that 20 units of material B are needed. This illustration shows that one unit represents one material for A and B respectively. But MRP is also successfully applied to multiple materials with two or more complex BOMs. For example, when 10 units of material A are to be produced within seven weeks, material A requires seven units of material B and five units of product C, while material C requires 10 units of material D and eight units of material E. In addition, item B requires three units of item D and eight units of item C; and item B requires three units of item E. From the BOM, the material structure tree is developed (as in Figure

10 below), and the stock items to be produced at each level have been calculated, the demand for B, C, D, and E being dependent on the demand for A (10 units). The demands for items B, C, D, and E were calculated as follows: Req(B)=10 x 7 = 70 units; Req(C)=10 x 5 = 50 units; Req(D) = 50 x 10 = 500 units; Req(E)= (8 x 50) + (3 x 70) = 610 units.
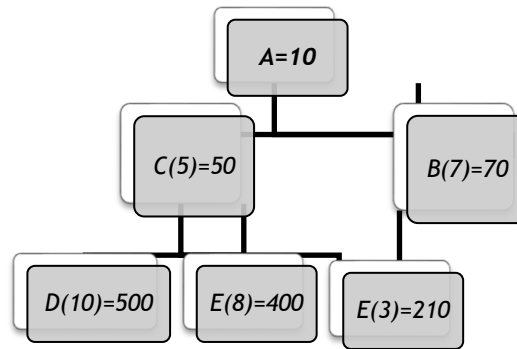

Figure 10: Material structure tree for item A

The material structure tree in Figure 10 has three levels, defined as follows: Level 0, Level 1, Level 2; the 'parent' elements being A, B and C, while the 'component' elements are B, C, D, E. It can be seen that elements B and C are both components and parents.

5.1.2   An outline of the MRP process

After constructing the material structure tree as in Figure 10, a schedule needs to be constructed that reveals: 1) the schedule of items ordered from suppliers in case there is no stock available, and 2) the schedule of production of the final items in order to satisfy the customer's demand for the finished products in time.

Five scheduling steps are used to determine the schedule in an MRP process. The schedules used for the production of the required material A in seven weeks, as shown in Table 5, are as given below:

(1) Gross material requirements plan

The raw material requirements plan is the step in the schedule that determines when a material is needed and when its production is required to meet the customer's demand for finished goods. A key aspect of establishing or constructing gross material requirements is determining the lead times. Using the above example of producing 10 items of A, assume that the lead time for item A is one week, for item B two weeks, for item C two weeks, and for items D and E one week each, while for parent item B it is two weeks. Since the lead time of parent item A is one week (level 0), items B and C must be available at the end of the sixth week. Since the lead time of item B is two weeks, it must be released for production at the end of the third week. Similarly, item C and its units must be released for production at the end of the third week. Finally, items D and E and their units from parent item C are to be released to production at the end of the second week, while item E from parent item B is released to production at the end of the first week.

(2) Net material requirements plan.

The net material requirements plan is constructed in a similar way to the gross requirements plan. As with the gross requirements plan, the scheduling work starts with parent A and is scheduled backwards (from week 7) to the last components, as shown in the material structure tree in Figure 9. Determining the lead times for each item is another critical aspect in the calculation of the net material requirements plan. Using the same data for A, B, C, D, and E as shown in the material structure tree, the net material requirement plans are also calculated using the available inventory. As shown in Table 5, the net requirements balance the quantity needed to meet the demand (the gross requirement).

The on-hand inventory is the number of inventory items available to a store, ready for production and shipment. In an MRP process, the on-hand inventory is the parent materials and components available before the next batch of materials is received. Looking at the material structure tree and its number of materials in Figure 9, it is assumed that material A has two units of stock, materials B and C have 10 units of stock, material D has 20 units of stock, material E has 15 units of components for material C and 20 units of components for material B. The stock on hand has a direct impact on the net material requirement and the receipt of the planned order, as it is the value subtracted from the gross material requirement plan.

For item A, with a gross requirement of 10 units and an assumed available stock of two units, the net requirement and planned order receipt are both eight units, as shown in Table 5. Table 5 also shows that the net requirements and the planned incoming order are planned for week 7.

(3) Planned-order receipt.

The planned receipt of order, also known as the planned receipt, is the projected quantity of planned material receipt based on the net material requirement. For example, item A in Table 5 has a net material requirement of 40 units, so the planned receipt is estimated to be the same quantity − 40 units.

(4) Planned-order release.

In contrast to the previous stages of the schedule, planning delivery schedules, as shown in Table 5, take into account the lead times of each material, starting with zero level materials (A) up to level 2 materials (D, E). With 40 units of item A cleared and staggered in time in the seventh week of production, and considering that item A has a lead time of one week, the planned order release for item A is therefore 40 units that are scheduled in the sixth week of production. The process continues until all materials are broken down

Table 5: Gross vs net material requirements plan for 10 units of A

	ITEM	1	2	3	4	5	6	7	LEAD TIME
A	Gross							10	1 week
	On-hand							2	
	Net							8	
	Order receipt							8	
	Order release						8		
B	Gross						56		2 weeks
	On-hand						10		
	Net						46		
	Order receipt						46		
	Order release				46				
C	Gross						40		2 weeks
	On-hand						10		
	Net						30		
	Order receipt						30		
	Order release				30				
D	Gross				300[C]				1 week
	On-hand				20				
	Net				280				
	Order receipt				280				
	Order release			280					
E	Gross			138 [B]	240 [C]				2 weeks
	On-hand			20	15				
	Net			118	225				
	Order receipt			118	225				
	Order release	118		225					

5.1.3   Just-in-time (JIT)

Just-in-time (JIT) is a famous Japanese concept of material planning, initially used by Japanese manufacturing companies before spreading worldwide. According to Vrat [123], JIT (or the zero-inventory system) is an idealised concept of inventory management in which a supply is delivered just-in-time, whatever material is required, wherever it is required, whenever a maximum supply is needed, and without keeping any stock on hand. In terms of material resource planning, the just-in-time concept allows companies to manage their warehouses with greater efficiency, avoiding inventories, shortages, or replenishment orders.

5.2 Enterprise resources planning (ERP)

An ERP is an integrated software that includes a set of functional modules (production, human resources, sales, finance, etc.) and incorporates all the departmental functions of organisations into one system, meeting the needs of all of the departments [15].

An ERP system, when implemented, can improve departmental performance and increase productivity. According to Bhamangol et al. [13], ERP improves access to and the accuracy and timeliness of information. It improves workflow, reduces dependence on paper trails, improves knowledge sharing, enhances control, and automates all processes by integrating and coordinating the flow of information across departments. ERP systems that are implemented in software such as Oracle, SAP, SYSPRO, or Microsoft Dynamics help large organisations to manage the large amount of data they process. Table 6 below lists the advantages of ERP systems.

Table 6: Benefits of an enterprise resource planning (ERP) system

Benefit(s)	Author(s)
An ERP system centralises information through a centralised database.	[121]
An ERP system preserves the centralised database and data flow between different departments, which reduces human error and the duplication of data, and automates routine tasks.	[60], [121]
An ERP system links the different departments of an organisation, from suppliers to customers, into one integrated system, sharing a common database.	[21]
If successfully implemented, an ERP system can potentially form the backbone of an organisation's business intelligence, through its integrated view of all business processes.	[84], [89]
An ERP system provides a solid informational basis for the entire business process and improves decision-making, with successful implementation being the condition.	[37]
The implementation of an ERP system enables a seamless flow of data throughout the organisation, leading to improved overall operational performance and addressing the information fragmentation issues faced by many organisations.	[29]
With the help of an integrated IT system capable of covering all the needs of an organisation, an ERP system brings integration to all departments and functions within an organisation.	[58]

5.3 Distribution resources planning (DRP)

Enns and Suwanruji [36] defined distribution requirement planning (DRP) as a time-based replenishment approach with revised inventory status and periodically generated shipping plans. The main objective of the distribution system is to provide maximum service to the customer. The concepts and logic used in the DRP system are similar to those used in the material requirements planning system, with the notable difference that DRP focuses on the distribution of remote goods rather than on the flow of parts (materials, components) within a warehouse or operating facility. Figure 11 illustrates the flow of DRP materials from the factory to the retailer and then to the end user.
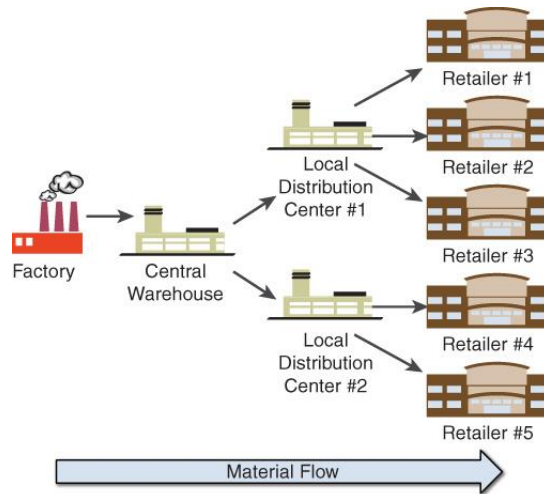
Figure 11: Distribution requirement planning for material flow [81]

In a DRP, the retailer's demand is treated as an independent demand because it is closely related to the end user, while the factory's demand (upstream) is treated as a dependent demand with a time logic that is used to anticipate needs. DRP has many benefits, including better service to customers and reduced inventory [36]. In addition, DRP for material flow is compatible with other supply chain systems [36].

6   CONCLUSION

A systematic review of inventory management concepts was discussed in this article. The study showed a growing level of interest in this process of supply chain management. With the increasing range of problems related to climate change, environmental science has been among the sectors with the most interest in stockpile management. The article reviews the literature on the deterministic demand model, highlighting the implementation of independent and dependent demand in a real situation. In the independent demand models, decision variables were developed based on the demand, type of products, cost/profit, time, ordering opportunity, and selling season. In contrast to independent demand inventory models, in which the demand for one material is independent of the demand for other materials, in dependent demand inventory models the materials are interconnected. In implementation, to manage the manufacturing process of finished products in a case of dependent demand for raw materials and other components, material resource planning (MRP) is mainly used. Enterprise resource planning (ERP) software integrates all of the departmental functions of organisations into one system. Examples of well-known ERP systems have been listed. On the other hand, like the material requirements planning system, the concepts and logic used in the DRP system focus on the distribution of goods at a distance rather than on the flow of parts (materials, components) within a warehouse or operating facility. This systematic review provides the research community with the tools to implement an inventory management project.

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