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A Survey of Modeling the Healthcare Inventory for Emerging Infectious Diseases

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Abstract. Inventory management is a critical process in the healthcare industry. Challenges to the healthcare industry, such as supply shortages or overstocking, especially during the pandemic, make healthcare inventory management highly important. Efficient inventory management can help ensure quality patient care while reducing inventory costs. Over the years, several approaches and methods for modeling healthcare inventory management have been developed by researchers. This paper aims to provide an overview of inventory management (modeling) to handle inventory management problems under several constraints, such as limited budget and resources in both deterministic and probabilistic demand scenarios by focusing on the challenges posed by the COVID-19 pandemic. In this paper, techniques and methods, including Economic Order Quantity, Mathematical Optimization Models, Stochastic Programming, and Metaheuristics are presented and critically reviewed as guidance for future research.

Keywords: Inventory management, Covid-19 pandemic, optimization models, deterministic demand, probabilistic demand

1 Introduction

In the healthcare industry, effective inventory management is critical for maintaining patient trust and providing seamless care. The drug management system is an essential component of a hospital information system, as stated by Little and Coughlan. [1] Despite its importance, inventory management in healthcare faces several challenges, such as overstocking and understocking. Overstocking can result in increased storage costs, waste, and the expiration of drugs before they are dispensed. It also exacerbates financial losses and reduces available storage space. [2], [3] Conversely, stock-outs can hinder patient care by making medical supplies and equipment unavailable when needed. The limitations of storage space and budget constraints also pose challenges for inventory management in the healthcare industry. [2], [3]

Excessive inventory ties up capital and represents a significant financial investment that could be used elsewhere.[3] Effective inventory management helps to prevent stock-outs, reduce the risk of disruptions to patient care, and ensure that medical supplies and equipment are readily available when needed. This highlights the importance of striking a balance between maintaining confidence in the system and avoiding overstocking. Inventory management in healthcare involves managing and controlling a large number and great variety of items stocked in a

healthcare system. [4], [5] A well-designed inventory management system can help healthcare organizations to address these challenges and improve their operational and managerial performance. The effective inventory management is balancing the need for adequate stock levels with the need to avoid overstocking, healthcare organizations can optimize their inventory management processes and improve their overall performance.

In the healthcare industry, striking a balance between ensuring an adequate supply of medical supplies and avoiding overstocking is a challenging task. Effective inventory management practices must be implemented to minimize the risk of stock-outs and excess inventory. This includes regularly monitoring stock levels, predicting demand, and ordering supplies in a timely manner. The use of Heuristic and Meta-Heuristic methods and regular stocktaking can also help minimize excess inventory.

However, predicting demand in a healthcare system is difficult due to uncertainties and randomness, such as changes in patient conditions, dynamics in physicians' prescriptions, and individual patient responses to treatment procedures.[6], [7] Drug shortages pose a significant challenge for healthcare institutions and often interfere with patient care. During shortages, alternate therapeutic agents are typically selected, but these agents can present challenges and raise safety concerns, leading to adverse events, medication errors, and patient complaints.[8] The timing, location, type, and amount of demand in most humanitarian settings [9], [10] bring significant challenges in developing effective inventory policies.[11]

During the Covid-19 pandemic, the sudden increase in demand for medication had a significant impact on the supply chain. Medication shortages occur when the available supply of a medication is insufficient to meet current or projected demand at the patient level. The frequency of worldwide medication shortages has been rising in recent years, partly due to pharmaceutical procurement plans facing shortages of raw materials at the national level. This is due to national lockdowns in countries that produce pharmaceutical raw materials, such as the United States, China, India, and Europe.[12] Therefore, the shortage of medicines for patients is a major problem that has been widely studied.[8], [13] Different authors have developed optimization models to address the problem of medicine inventory management by considering various constraints and approaches to model uncertainty.[14], [15] The demand for healthcare items is a significant factor affecting inventory systems, and traditional forecasting techniques can predict the stationary demand.[16] However, the demand is influenced by several sources of randomness, such as patient number and treatment stage, patient condition, medication reaction, and physician recommendation.[7]

In conclusion, an effective inventory management is crucial for maintaining patient satisfaction and trust in the healthcare system. By balancing the availability of supplies and the reduction of excessive inventory, healthcare facilities can establish a strong and dependable supply chain, promoting the delivery of high-quality patient care. The demand can be divided into two categories: 1) Deterministic Demand and 2) Probabilistic or Stochastic Demand.

2. The Deterministic Demand: An Overview

Deterministic demand in inventory management refers to demand for a product that can be predicted with certainty based on historical sales data and future demand forecasts. In contrast to probabilistic demand, which is subject to random fluctuations and external factors, deterministic demand is consistent and predictable. This type of demand is usually observed in stable markets where buying habits are consistent and well-established, such as seasonal demand for certain products or the demand for a single product in a steady-state market.

In the healthcare industry, examples of deterministic demand include the demand for certain medical supplies, such as gloves and masks, during a pandemic, or the demand for seasonal. In these cases, the demand can be accurately forecasted based on historical data, and the healthcare organization can make informed decisions about how much inventory to order and when to order it. By having a good understanding of deterministic demand, healthcare organizations can avoid stock shortages, which can lead to operational disruptions and negatively impact patient care, or excessive inventory, which can result in waste and increase costs.

The Economic Order Quantity (EOQ) model is a commonly used deterministic model for inventory control. This model assumes a constant and known demand for an item, constant lead time, constant unit price, inventory holding cost based on average inventory, constant ordering cost and no backorder allowed. The EOQ model has been applied in various hospital settings to improve inventory management and reduce costs, such as at Georgetown University Hospital (GUH) by Kapur and Moberg [17] in a 558-bed general hospital by Ballentine [18] at Ramathibodi Hospital by Laeiddee [19] formulas (1)

$$EOQ = \sqrt{\frac{2DS}{H}} \quad (1)$$

S = Setup costs (per order, generally including shipping and handling)
D = Demand rate (quantity sold per year)
H = Holding costs (per year, per unit)

Excess inventories in hospitals have also been studied, such as in a local hospital by Hafnika et al. [20] using continuous review policy, EOQ, reorder point, average inventory level, and ABC classification. Kritchanchai and Meesamut [21] develop the total inventory costs by EOQ model ABC classification in a large public hospital in Thailand. Other applications of deterministic demand in hospitals include blood plasma management by Ma et al. [22] using EOQ model, safety stock, and reorder point, and inventory management for a pharmaceutical company and hospital by Uthayakumar and Priyan[23]using an operations research model. Operations research has also been used to optimize a hospital's inventory costs, such as in a hospital's central pharmacy by Stecca et al. [24] and through the application of Model Predictive Control (MPC) by Maestre et al. [3] These studies demonstrate the continued efforts to improve inventory management in healthcare using deterministic demand models.

In conclusion, deterministic demand is a valuable concept in inventory management as it allows organizations to accurately predict demand and make informed decisions about inventory management. In the healthcare industry, having a good understanding of deterministic demand is critical to ensuring the availability of essential medical supplies and avoiding operational disruptions that can negatively impact patient care.

3. The Probabilistic Demand: An Overview

Probabilistic demand in inventory management takes into account the uncertainty and variability of demand for a product over time. It recognizes that demand is not always predictable with certainty and that there is a degree of randomness in the process. This randomness can be due to a variety of factors such as changes in consumer behavior, fluctuations in the economy, and unexpected events. To account for this uncertainty, organizations use probabilistic methods to model and predict demand. This involves creating a probability distribution for demand and using it to simulate different scenarios and make decisions about inventory levels. By considering the uncertainty of demand, organizations can make more informed decisions about safety stock levels, reorder points, and order quantities. This helps to ensure that inventory is always at the right level to meet customer demand, while avoiding waste and inefficiencies.

The healthcare industry can benefit greatly from the application of probabilistic demand analysis in inventory management. Due to the nature of the industry, demand for medical supplies and equipment can be highly variable and unpredictable, especially in the case of emergencies or outbreaks like COVID-19. By using probabilistic methods to model demand, healthcare organizations can better prepare for fluctuations in demand and ensure that they have the necessary inventory levels to meet patient needs. For example, during a pandemic, healthcare organizations can use probabilistic demand analysis to determine the likelihood of increased demand for certain medical supplies and plan their inventory accordingly. Moreover, probabilistic demand analysis can also help healthcare organizations reduce waste and improve cost efficiency by avoiding overstocking and excessive inventory levels. By understanding the range of possible demand scenarios, organizations can make informed decisions about the optimal inventory levels to maintain and the frequency of reordering.

Probabilistic demand analysis is a valuable tool for the healthcare industry in managing inventory and ensuring that critical medical supplies and equipment are available to meet patient needs. It helps organizations to be more proactive, efficient, and resilient in the face of uncertainty and variability in demand. Healthcare systems face many uncertainties, including changes in patient numbers, clinical conditions, and the availability of medicines, as highlighted by Addis et al. [25] In response, several studies have aimed to develop models for optimizing inventory management in hospitals.

3.1 Mathematical Optimization Models

Mathematical optimization models are a valuable tool for analyzing and optimizing complex systems. These models incorporate objectives or goals that are represented by mathematical functions, allowing for a systematic exploration of trade-offs and the identification of optimal solutions. In the healthcare sector, optimization models can be particularly useful for decision making and resource allocation. For example, Najafi, Ahmadi, and Zolfagharinia [26] applied optimization to blood inventory management, developing a model that considers uncertain demand and supply. Franco and Alfonso-Lizarazo [27] used mixed integer programming (MIP) approaches for optimizing the pharmaceutical supply chain, taking into account elements such as demand and lead times. Additionally, Khoukhi, Bojji, and Bensouda [28] presented an inventory optimization model aimed at minimizing total cost while considering constraints such as storage space, order frequency, and service level and evaluated its performance through mathematical model and Monte Carlo simulation. Overall, the use of optimization models in healthcare can lead to improved patient care, reduced costs, and a more efficient healthcare system.

Mathematical optimization models have advantages and disadvantages in decision-making. They offer a structured and systematic approach to decision-making and can formalize constraints and objectives, providing mathematical guarantees for optimality and feasibility. They can handle complex and large-scale problems and identify the best solution among a large number of alternatives. the other hand, the models also have several disadvantages. One significant disadvantage is that these models require a high level of mathematical expertise to formulate and solve. Furthermore, the models may not always reflect real-world complexity and uncertainty, leading to inaccuracies in the results. The computational intensive and time-consuming nature of these models, particularly for large-scale and complex problems, is another disadvantage. The models can also be sensitive to the choice of parameters and assumptions, which can have a significant impact on the results. Finally, the solutions generated by mathematical optimization models may not always be interpretable or have practical relevance.

3.2 Stochastic Programming

Stochastic Programming, also referred to as Stochastic Optimization is a mathematical framework that models decision-making under uncertainty.[29] In the area of inventory management in hospital pharmacies, it is utilized to minimize the expected total inventory costs while satisfying service level and space constraints. The complexity of the problem is due to the presence of a large number of variables, non-linearity, and stochastic constraints, where the latter refers to the requirement of maintaining a specific probability of no shortage of medicines. The utilization of two-stage stochastic programming has also been noted in the solution to the problem of allocating surgical supplies in multiple locations within a healthcare system. [30], [31] In 2014, Priyan and Uthayakumar [32] proposed a stochastic model to minimize the impact of drug shortages. Rajendran and Ravindran [33] created a mixed integer stochastic programming model to tackle demand uncertainty and presented three heuristic rules for determining the platelet ordering policy. In 2023, Meneses, Marques,

and Barbosa-Póvoa [34] addressed the challenges of blood product ordering policies through a two-stage stochastic programming model that considers demand uncertainty

Stochastic Programming provides several advantages for decision-making under uncertainty. The ability to incorporate uncertainty leads to more accurate and realistic models, and the use of expected value objectives results in robust solutions. Additionally, stochastic programming can deal with multiple objectives, such as cost minimization and service level maximization, in a single model. However, stochastic programming also has some limitations. The models can be complex and computationally intensive, and the solution accuracy is dependent on the accuracy of the probability distribution used to model uncertain parameters. Additionally, the models require a significant amount of data, which can be challenging to obtain, and the validity of the model depends on the accuracy of the assumptions made about the distribution of uncertain parameters.

3.3 Metaheuristics

In recent years, metaheuristics have become a popular tool for healthcare inventory management due to their fast and efficient solution-finding capabilities. Metaheuristics were first proposed by Glover in 1986 and have since been widely used in various optimization problems. The most commonly used metaheuristics in healthcare inventory management are the Tabu Search Algorithm (TS), Simulated Annealing Method (SAM), Ant Colony Optimization (ACO), Genetic Algorithm (GA), Emperor Penguin Optimizer (EPO), Seagull Optimizer, and Guided Local Search. The Genetic Algorithm (GA) is one of the most widely used metaheuristics in healthcare inventory management due to its ability to provide near-optimal solutions in a relatively short amount of time. This algorithm is based on Charles Darwin's theory of natural selection and genetics, which is referred to as "Survival of the Fittest"[35] The GA has been applied to various problems in healthcare inventory management, including reducing the total cost of the pharmaceutical supply chain from manufacturer to patient [36] and developing an optimal inventory of platelets.[37] In addition, Du, Luo, Wang, & Liu [38] proposed a model for a hospital pharmacy system using a combination of genetic algorithms and a BP neural network to improve the efficiency of pharmaceutical inventory management. The model was based on actual conditions and performed a sensitivity analysis to provide guidelines for drug inventory management in hospitals.

Metaheuristics have proven to be a valuable tool in healthcare inventory management, offering a fast and efficient way to solve complex optimization problems. Despite some disadvantages, such as computational intensity and potential limitations in finding the global optimum solution, metaheuristics are a versatile and adaptable tool that can provide near-optimal solutions in a variety of inventory management scenarios. Overall, the use of metaheuristics in healthcare inventory management can lead to improved decision-making and better outcomes.

Table 1. Research papers of healthcare inventory

Author	Published year	Demand		Methodology			
		Deterministic	Stochastic	EOQ	Mathematical model	Stochastic Programming	Genetic Algorithm
Ballentine et., al.[18]	1976	√		√			
Kapur et., al.[17]	1987	√		√			
Laeiddee[19]	2010	√		√			
Kelle et., al.[30]	2012		√			√	
Ma et., al.[22]	2013	√		√			
Uthayakumar et., al.[23]	2013	√			√		
Priyan et., al.[32]	2014		√			√	
Kritchanchai et., al.[21]	2015	√		√			
Hafnika et., al.[20]	2016	√		√			
Stecca et., al.[24]	2016	√			√		
Najafi et., al.[26]	2017		√		√		
Rajendran et., al.[33]	2017		√			√	
Maestre et., al.[3]	2018	√			√		
Khoukhi et., al.[28]	2019		√		√		
Rajendran et., al.[37]	2019		√				√
Franco et., al.[27]	2020		√		√		
Du et., al.[38]	2020		√				√
Nasrollahi et., al.[36]	2021		√				√
Meneses et., al.[34]	2023		√			√	

Table 1 appraises a number of research papers on modelling and analyzing inventory management systems in healthcare. The papers discuss types of healthcare inventory problems, existing modelling approaches, and solution methods.

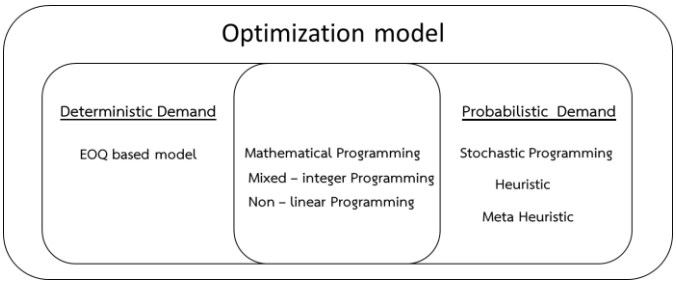

Fig. 1. Optimization model between deterministic and probabilistic demand

Figure 1, various approaches for managing healthcare inventory are presented, which includes both items with deterministic demand, such as masks and gloves, as well as items with probabilistic demand arising from uncertainty. Therefore, a joint analysis may be necessary for optimizing healthcare inventory management.

As the world is currently facing the Covid-19 pandemic, and it continues to offer significant challenges for healthcare supply chains, therefore, ensuring the availability of healthcare facilities by balancing the demand and supply to avoid high storage costs as well as stockouts is very important. The Covid-19 situation also suggests that not only must patients be treated, but they must be treated in a timely manner. So, efficient healthcare inventory management will benefit patients, especially when lives are at stake, by providing quick and quality care. A refined and optimized approach to this challenge is essential to ensure that patients receive prompt and effective treatment, even in the face of the pandemic. The techniques and methods proposed in this study can be improved for managing the healthcare inventory under demand uncertainty, and will be beneficial for future research for handling the healthcare inventory problems, such as unpredictable demand caused by Emerging Infectious Diseases.

References

1. Little, J., & Coughlan, B.: Optimal inventory policy within hospital space constraints. Health care management science. 11(2), 177--183 (2008)
2. Bijvank, M., & Vis, I. F.: Inventory control for point-of-use locations in hospitals. Journal of the Operational Research Society. 63, 497--510 (2012)
3. Maestre, J. M., Fernández, M. I., & Jurado, I. J. C. E. P.: An application of economic model predictive control to inventory management in hospitals. Control Engineering Practice. 71, 120--128 (2018)
4. Gebicki, M., Mooney, E., Chen, S. J., & Mazur, L. M.: Evaluation of hospital medication inventory policies. Health care management science. 17, 215--229 (2014)
5. Nicholson, L., Vakharia, A. J., & Erenguc, S. S.: Outsourcing inventory management decisions in healthcare: Models and application. European Journal of Operational Research. 154(1), 271--290 (2014)
6. Montoya, R., Netzer, O., & Jedidi, K.: Dynamic allocation of pharmaceutical detailing and sampling for long-term profitability. Marketing Science. 29(5), 909--924 (2010)
7. Vila-Parrish, A. R., Ivy, J. S., King, R. E., & Abel, S. R.: Patient-based pharmaceutical inventory management: a two-stage inventory and production model for perishable products with Markovian demand. Health Systems. 1(1), 69--83 (2012)
8. McLaughlin, M., Kotis, D., Thomson, K., Harrison, M., Fennessy, G., Postelnick, M., & Scheetz, M. H.: Effects on patient care caused by drug shortages: a survey. Journal of Managed Care Pharmacy. 19(9), 783--788 (2013)
9. Hughes, D., & McGuire, A.: Stochastic demand, production responses and hospital costs. Journal of health economics. 22(6), 999--1010 (2003)
10. Darmian, S. M., Fattahi, M., & Keyvanshokooh, E.: An optimization-based approach for the healthcare districting under uncertainty. Computers & Operations Research. 135, 105425(2021)
11. Whybark, D. C.: Issues in managing disaster relief inventories. International journal of production economics. 108(1--2), 228--235 (2007)
12. Goodarzian, F., Taleizadeh, A. A., Ghasemi, P., & Abraham, A.: An integrated sustainable medical supply chain network during COVID-19. Engineering Applications of Artificial Intelligence. 100, 104188. (2021)
13. Caulder, C. R., Mehta, B., Bookstaver, P. B., Sims, L. D., Stevenson, B., & South Carolina Society Of Health-System Pharmacists.: Impact of drug shortages on health system pharmacies in the Southeastern United States. Hospital pharmacy, 50(4), 279--286 (2015)
14. Fox, E. R., Sweet, B. V., & Jensen, V.: Drug shortages: a complex health care crisis. In Mayo Clinic Proceedings, vol. 89, No. 3, pp. 361--373. Elsevie, (2014, March)
15. Kwon, I. W. G., Kim, S. H., & Martin, D. G.: Healthcare supply chain management; strategic areas for quality and financial improvement. Technological Forecasting and Social Change. 113, 422--428 (2016)

16. Ramirez, A. L., Jurado, I., Garcia, M. F., Tejera, B. I., Llergo, J. D. P., & Torreblanca, J. M.: Optimization of the demand estimation in hospital pharmacy. In: Proceedings of the 2014 IEEE Emerging Technology and Factory Automation (ETFA), pp. 1--6. IEEE (2014, September)
17. Kapur, R., & Moberg, C.: Evaluating inventory turns for a hospital environment. Computers & Industrial Engineering. 13(1--4), 73--77 (1987)
18. Ballentine, R., Ravin, R. L., & Gilbert, J. R.: ABC inventory analysis and economic order quantity concept in hospital pharmacy purchasing. American journal of hospital pharmacy. 33(6), 552--555 (1976)
19. Laeiddee, C.: Improvement of re-order point for drug inventory management at Ramathibodi Hospital (Doctoral dissertation, Mahidol University) (2010)
20. Hafnika, F., Farmaciawaty, D. A., Adhiutama, A., & Basri, M. H.: Improvement of inventory control using continuous review policy in a local hospital at bandung city, Indonesia. The Asian Journal of Technology Management. 9(2), 109 (2016)
21. Kritchanchai, D., & Meesamut, W.: Developing inventory management in hospital. International Journal of Supply Chain Management. 4(2), 11--19 (2015)
22. Ma, J., Lei, T., & Okudan, G. E.: EOQ-based inventory control policies for perishable items: The case of blood plasma inventory management. In IIE Annual Conference, Proceedings pp. 1683--1692. Institute of Industrial and Systems Engineers (IISE) (2013)
23. Uthayakumar, R., & Priyan, S.: Pharmaceutical supply chain and inventory management strategies: Optimization for a pharmaceutical company and a hospital. Operations Research for Health Care. 2(3), 52--64 (2013)
24. Stecca, G., Baffo, I., & Kaihara, T.: Design and operation of strategic inventory control system for drug delivery in healthcare industry. IFAC-PapersOnLine, 49(12), 904--909 (2016)
25. Addis, B., Carello, G., Grosso, A., Lanzarone, E., Mattia, S., & Tànfani, E.: Handling uncertainty in health care management using the cardinality-constrained approach: Advantages and remarks. Operations Research for Health Care. 4, 1--4 (2015)
26. Najafi, M., Ahmadi, A., & Zolfagharinia, H.: Blood inventory management in hospitals: Considering supply and demand uncertainty and blood transshipment possibility. Operations Research for Health Care. 15, 43--56 (2017)
27. Franco, C., & Alfonso-Lizarazo, E.: Optimization under uncertainty of the pharmaceutical supply chain in hospitals. Computers & Chemical Engineering. 135, 106689 (2020)
28. KHOUKHI, S., BOJJI, C., & BENSOUDA, Y.: Optimal inventory control policy for a hospital case. In: 2019 5th International Conference on Optimization and Applications (ICOA), pp. 1--5. IEEE (2019, April)
29. Birge, J. R., & Louveaux, F.: Introduction to stochastic programming. Springer Science & Business Media. (2011)
30. Kelle, P., Woosley, J., & Schneider, H.: Pharmaceutical supply chain specifics and inventory solutions for a hospital case. Operations research for health care. 1(2--3), 54--63 (2012)
31. Ahmadi, E., Masel, D. T., & Hostetler, S.: A robust stochastic decision-making model for inventory allocation of surgical supplies to reduce logistics costs in hospitals: A case study. Operations Research for Health Care. 20, 33--44 (2019)

32. Priyan, S., & Uthayakumar, R.: Optimal inventory management strategies for pharmaceutical company and hospital supply chain in a fuzzy–stochastic environment. Operations Research for Health Care. 3(4), 177--190 (2014)
33. Rajendran, S., & Ravindran, A. R.: Platelet ordering policies at hospitals using stochastic integer programming model and heuristic approaches to reduce wastage. Computers & Industrial Engineering. 110, 151--164 (2017)
34. Meneses, M., Marques, I., & Barbosa-Póvoa, A.: Blood inventory management: Ordering policies for hospital blood banks under uncertainty. International Transactions in Operational Research. 30(1), 273--301 (2023)
35. Holland, J. H. (1992). Adaptation in natural and artificial systems: an introductory analysis with applications to biology, control, and artificial intelligence. MIT press
36. Nasrollahi, M., & Razmi, J.: A mathematical model for designing an integrated pharmaceutical supply chain with maximum expected coverage under uncertainty. Operational Research. 21(1), 525--552 (2021)
37. Rajendran, S., & Ravindran, A. R.: Inventory management of platelets along blood supply chain to minimize wastage and shortage. Computers & Industrial Engineering. 130, 714--730 (2019)
38. Du, M., Luo, J., Wang, S., & Liu, S.: Genetic algorithm combined with BP neural network in hospital drug inventory management system. Neural Computing and Applications. 32(7), 1981--1994 (2020)