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Warehouse Optimization using Queuing Theory and Supply Chain Management

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Abstract:

As businesses see the value of developing an integrated relation with their suppliers and customers, supply chain management has become a significant problem in many sectors. Supply chain management which includes Warehousing and Logistics has evolved into a strategy for boosting competitiveness by lowering uncertainty and increasing customer service. While logistics handles the practical aspects of storing and delivering the items kept in a warehouse, warehousing focuses on the secure storage of commodities inside a structure. Over time, majority of businesses have concentrated their emphasis on the effectiveness and efficiency of these business processes. However, an increasing number of companies are starting to see the strategic significance of planning, managing, and creating a supply chain as a new way to conduct business. This paper summarises previous efforts on supply chain modelling and identifies key challenges and opportunities related to supply chain modelling. This is to assist firms in capturing the cohesiveness of inter-functional and inter-organizational integration and coordination across the supply chain network and to subsequently make better supply chain decisions. The service process, arrival process, number of system locations, number of servers and the number of customers, who may be people, data packets, automobiles, are some of the variables that we have taken into consideration while writing this research paper.

Keywords:

Cost Reduction, Customer Satisfaction, Inventory Management, Queueing Theory, Stochastic Supply Chain Network, Supply Chain Optimization, Warehouse and Logistics

1. Introduction

The mathematical analysis of how waiting lines or queues form, function and become crowded is called queuing theory. The goal of queuing theory is to optimize the use of scarce resources. When an item completes one stage of the process, it is added to a queue of other units waiting to move to the next stage.

In this research paper, we will not only be looking at queueing theory but we will look at a more niche topic in queueing theory, which includes Supply Chain Management, Warehousing and Logistics.

Warehousing refers to the storage of goods when the goods are in transit or in between two stages of the supply chain, and its essential functions include receiving, storing, order picking and shipping of goods (Boysen et al., 2019)

Performance is greatly influenced by warehouse capacity. When a warehouse's downstream capacity is reached, an order with a finite capacity may be halted. Once the warehouse releases one order, it is then blocked at the previous supplier, resulting in a longer supplier lead time than the 'normal' supplier time. This additional supplier lead time will be defined as the blocking time. (Boeck, n.d.)

Currently, there are many problems that exist in a warehouse including that of inventory being damaged, long queues of inventory piled up in the docking area with no modes of transportation for these goods, the layout of the warehouse becoming very messy and the goods in transit taking long to reach the retailers if it is B2B and the customers if it is B2C.

The transport system is a key component of a logistics system that is both cost-effective and responsive to client needs. It is also tightly integrated into global supply networks. There is an entire branch of facility location research in OR that focuses mostly on the number and location of distribution centers. (Dekker et al., 2012) The number of Distribution Centers has a large effect on transport efficiency. (Eckhardt & Rantala, 2012)

It is reasonable to ration inventory, when the inventory is low. It can be done by rejecting demand from the less valuable classes in anticipation of future demand. (Sales & Ha, 1997)

Companies strive to integrate actions across the supply chain to address two issues, namely cost reduction and customer service enhancement, as a result of the competitive business environment today (Liu et al., 2020).

In today's increasingly competitive market, managing inventory has become a significant concern for businesses as they simultaneously aim to cut costs and improve service standards. Two crucial aspects make up inventory management. The ideal number and location of distribution centers must be established first. Second, we need to figure out how much inventory each distribution location needs to keep on hand. (Shu et al., 2005)

We have collectively studied research papers starting from the 1980s till 2022 which has covered approximately 3 decades of research on Queueing Theory and Supply Chain Management in Inventory Control. Our objective for this research paper is to provide an overview regarding the methodologies followed over the last 3 decades and how these have changed for the better.

The paper is organized in the following manner. Section 2 contains the literature review of this topic wherein we analyze the work done in this field over the years, Section 3 contains the Research Methodology which includes the information about the data, Section 4 consists of the Analysis of the Research Methodology using, Section 5 consists of Findings and Discussions from the Analysis, Section 6 contains the conclusion and finally Section 7 contains the discussion about the Future Work in the following field of research followed by references.

2. Literature Review

A supply chain system is a network of nodes that represent different resources where goods or services are processed via several operations and thus experience waiting periods, service times, transit times, etc. (Kerbache & Smith, 2004). It can be viewed as a system that allows components to move across a vast network of suppliers, manufacturing facilities, assembly sites, distribution hubs, and consumer locations. The dynamics of a supply chain are driven by customer orders for finished products. (Ettl et al., n.d.)

A supply chain network typically has four types of functional sites: (1) Supplier sites that buy raw materials from external suppliers; (2) manufacturing facilities that turn raw materials into components; (3) Assembly facilities that combine the components to create finished goods or semi-finished products; and (4) distribution centers, which ship finished goods to clients or storage facilities. There are input stores and output stores at each site in the network. Each retailer carries a single kind of SKU. The output stores simulate the stocking of finished goods at the site, while the input stores simulate the stocking of various types of components received from upstream sites. (Dong, 2003)

The suppliers manage their inventory using base stock policy and work on a make-to-stock basis. The manufacturer, however, uses a make-to-order approach. The supply chain will be modelled as a queuing system.(Toktas-Palut & Ülengin, 2010) Purely for sake of convenience, we model space and time as discrete and data as stationary (Song & Zipkin, 1996).

Warehouses play a vital role in mitigating variations in supply and demand, and in providing value-added services in a supply chain. However, our observation of supply chain practice reveals that warehousing decisions are not included when developing a distribution plan for the supply chain. This lack of integration has resulted in a substantial variation in workload (42–220%) at our industry partner's warehouse costing them millions of dollars.(Sainathuni et al., 2014)

There has been considerable research on the environmental impact of supply chains but most of this has concentrated on the transport elements. The environmental impact of warehousing has received relatively little attention except within the context of distribution networks.(Fichtinger et al., 2015)

One of the earliest studies to include inventory costs in location models is the one by Baumol and Wolfe. Eppen looked at the impact of risk pooling and found that the cost of a centralized inventory is less than the total cost of decentralized inventories in all facilities (Diabat et al., 2017). The cited article focuses on the joint location-inventory problem wherein there are multiple retailers and multiple Distribution Centre (DC) which have uncertain demand so the DCs must maintain safety stock. The paper provides a model on how to tackle the uncertain demand and safety stock with the lead time. Lead time is the time needed to produce or procure goods and a replenishment lead time is used to figure the date by which the material will be available.

Waiting lines use queueing theory, one of the most sophisticated and time-tested analytical methods. A frequent goal is to decrease customer wait times in service systems in order to lower costs related to customer wait times and boost customer satisfaction. (Hanukov et al., 2019)

Customer satisfaction is the focus of all supply chain components. Customer satisfaction is typically regarded as a commonly desired feature. One of these characteristics is quick access to products or services. Utilizing queueing theory, providers of goods and services must choose the best course of action to minimize consumers' waiting times. (Motamedi et al., 2020).

However, during this, the impediments that firms face during inventory management are stock-outs which are typically caused by low inventories and keeping extra inventory which results in higher holding costs. Every firm would want to examine several uses for inventory management to keep the goodwill of the client and to generate comparatively large earnings, and thus, each inventory planner aims to create the best possible inventory controlling plan.

To obtain replenishments, we send orders to a supply system, representing production and/or transportation activities. The system responds to these signals, sending us the goods ordered, sooner or later, depending on its own internal operations (Song & Zipkin, 1996)

Managing uncertainty in stochastic settings is a main challenge within the supply chain management.(Teimoury et al., 2010). In many industries, the customer loyalty is directly contingent to the availability of the product required at the moment, which happens due to the extreme similarities in the products made by various companies. In such industries, there is no back order, the orders are partially or completely lost if they are not available at the time of requirement. Make-to-stock queue model is used by companies in such industry. (Teimoury et al., 2010) A large share of literature on make-to-stock queue model is available. (Jain & Raghavan, 2009) {(Teimoury et al., 2010) }, highlight the role of warehouses by considering the occurrence of demand uncertainty in the real world, especially in the industries where demand varies easily according to the consumer's behavior change, habits, taste variations, etc. Article (Jain & Raghavan, 2009) analyses the multi-echelon supply chain network (SCN) using queueing models and inventory optimization model in batch ordering.

3. Methodology

The topic under study, queueing theory in supply chain management and warehousing, was very critically selected to understand the ways of logistic management and development in the field in previous years. The research and study of the topic was mainly based on research papers, other sources of data like articles, books, chapters, or conferences were excluded.

Research papers of authors from various countries and qualifications were thoroughly studied to understand the development of topic under research. Research papers were collected from the databases of Google Scholar and ScienceDirect. The keywords used to retrieve this data were "queueing" AND "theory" AND "supply" AND "chain" AND "management" AND "warehousing".

Research papers were studied based on their area of study and relevance to the topic. They were screened based on their introduction, abstract, literature review, methodology and conclusion. Research papers from years 1991 to 2022 were selected for screening and further study.

Various areas of supply chain management such as multi-echelon supply chain, multi-product supply chain, stochastic supply chain, etc., have been analyzed using queueing theory in the research papers studied.

A database was created to maintain all the relevant research papers along with their research publication, year of publication, authors, abstract and keywords for the purpose of citation and to track the development in the study of the research area.

All the research papers were uploaded to the Mendeley app for proper and authentic citation of each research paper. All the research papers were converted to RIS form in the Mendeley app. These papers were then uploaded to VosVeiwer for further analysis of the research area.

This analysis will help us understand the areas that have already been researched, the development made in the research of the topic and areas that can be researched further.

4. Analysis

In this methodology, we have used VosViewer for the analysis of the Research Papers collected over 3 decades from 1992 to 2022. We have created 4 maps from VosViewer and have analyzed each map individually so as to conclude which map is most useful when analyzing the papers. We have also written down the process of looking for the research papers.

1) Review of the Authors of the Research Papers using Full Counting Method

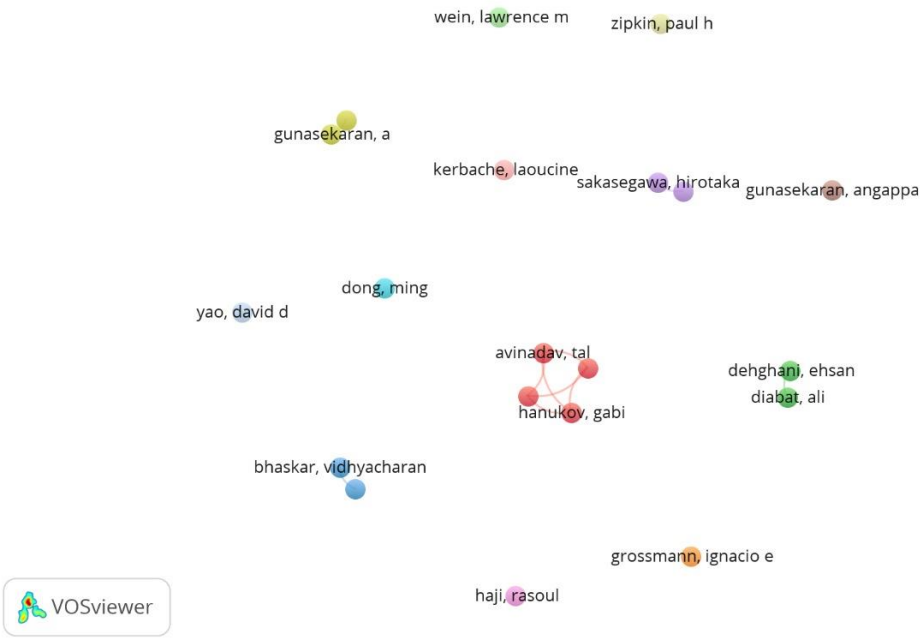


Fig. 1. Authors Map (Full Counting)

The above shown VOSviewer network is a representation of Authors of the research papers under study.
In this network visualization, each item is indicated by its label, which in this case is an Author, and by a circle. The size of the labels and circle of each item is determined by the weight of that item.
The above network is constructed using full counting method. Thus, weight of each item is determined by full counting. In this method, each of the links is assigned full weight, i.e., the total weight of each link is one. This

means that each Author has different weight in accordance of the number of research papers written. In other words, the repetitiveness of the Author, in different research papers, determines the weight of the Author.
The colour of the items indicate the cluster in which it belongs. In the above network, there are 13 clusters. Each cluster indicates the collaborative work of the Authors. This suggests that these Authors have either co-authored research papers or their work is on similar lines of research.

2) Review of the Authors of the Research Papers using Fractional Counting Method

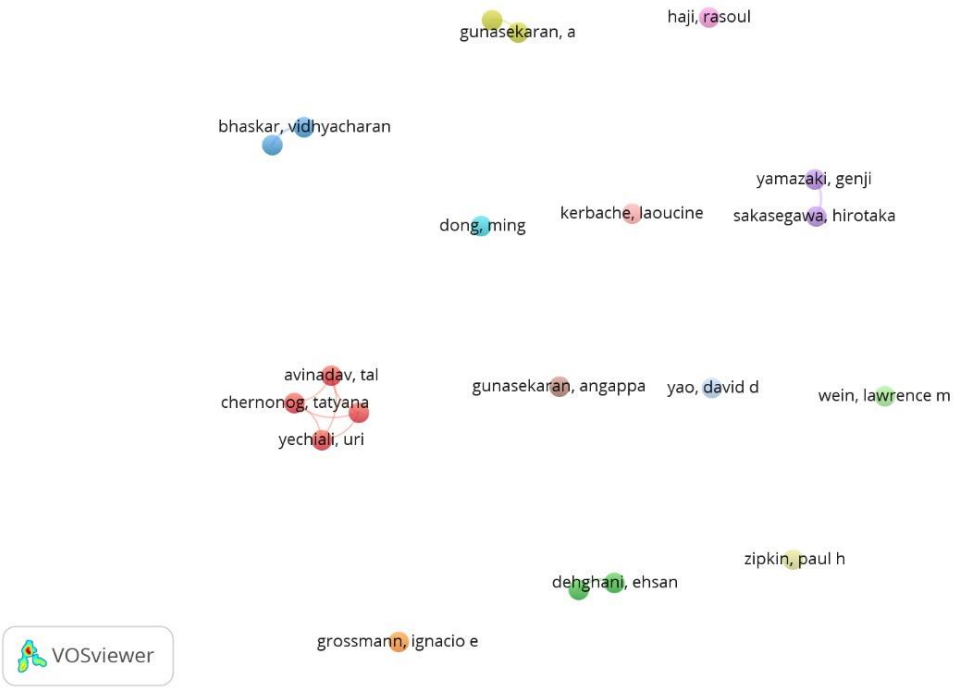


Fig. 2. Authors Map (Fractional Counting)

The above shown VOSviewer network is a representation of Authors of the research papers under study.
In this network visualization, each item is indicated by its label, which in this case is an Author, and by a circle. The size of the labels and circle of each item is determined by the weight of that item.
The above network is constructed using fractional counting method. Thus, weight of each item is determined by fractional counting. In this method, each of the links is assigned fractional weight, i.e. the total weight of each link is equal. This means that each Author has equal weight irrespective of the number of research papers published by each Author. The repetitive rate of the Author does not determine the weight of the Author.
The colour of the items indicate the cluster in which it belongs. In the above network, there are 13 clusters. Each cluster indicates the collaborative work of the Authors. This suggests that these Authors have either co-authored research papers or their work is on similar lines of research.

3) Review of the Keywords of the Research Paper using Full Counting Method

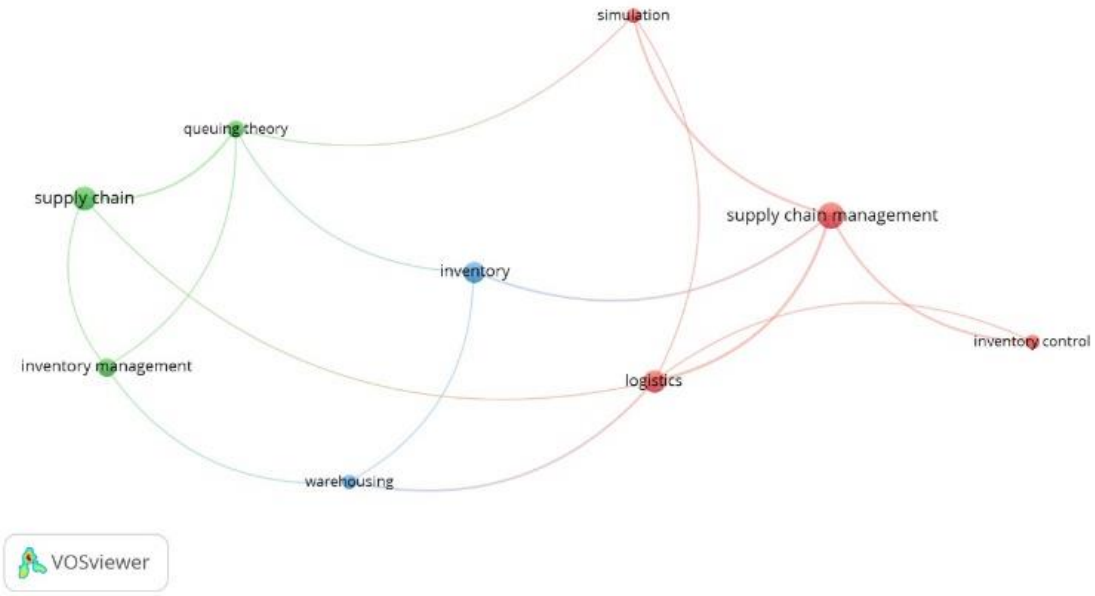


Fig. 3. Keywords Map (Full Counting)

The above shown VOSviewer network is a representation of Keywords of the research papers under study. The network has 9 keywords which form around 15 links and the total link strength is 22. In this network visualization, each item is indicated by its label, which in this case is the keyword, and by a circle. The size of the labels and circle of each item is determined by the weight of that item.

The network seen above was built using the full counting method. Thus, full counting is used to calculate each item's weight.

Under this method, each link in this approach is given its full weight, or one, making each link's overall weight one. This implies that depending on the quantity of keywords in research articles, each keyword has a varying weight.

The colour of the items indicate the score of that item. Green indicates average score, red indicates a high score and blue indicates a low score, by default.

The overlapping of the links over various keywords shows the common use of those words in each of the research papers.

4) Review of the Keywords of the Research Paper using Fractional Counting Method

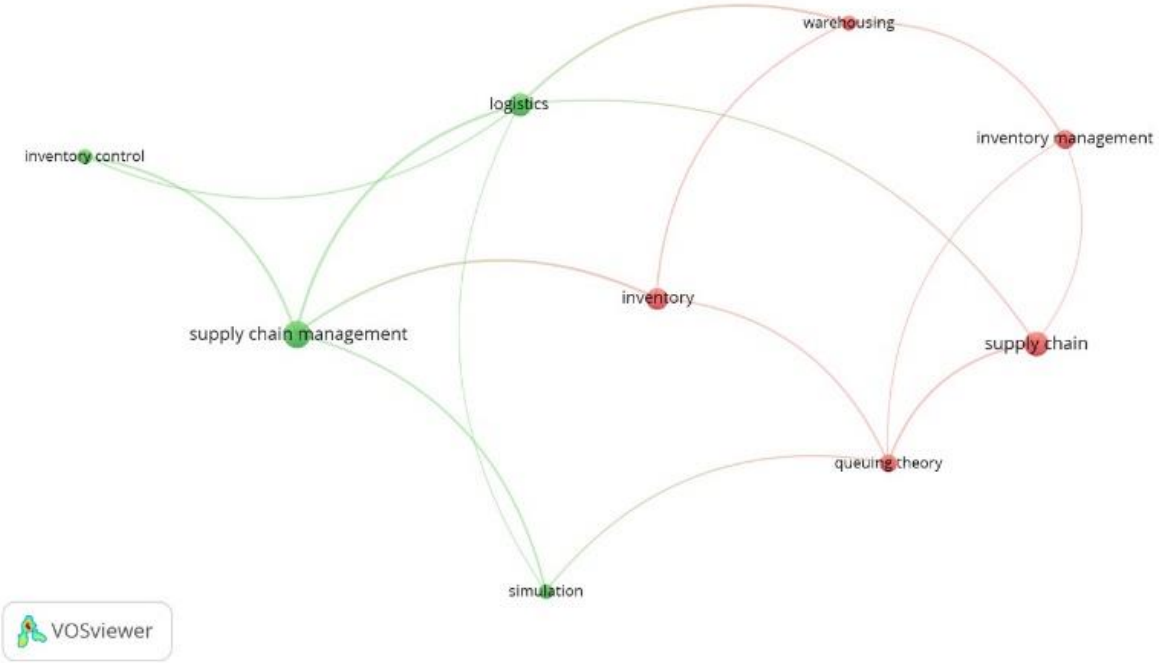


Fig. 4. Keywords Map (Fractional Counting)

The above shown VOSviewer network is a representation of Keywords used in the research papers under study.

In this network visualization, each item is indicated by its label, which in this case is the keyword, and by a circle. The size of the labels and circle of each item is determined by the weight of that item.

The above network is constructed using fractional counting method. Thus, weight of each item is determined by fractional counting. In this method, each of the links is assigned fractional counting weight, i.e., the total weight of each link is equal. This means that each keyword has equal weight irrespective of the number of times it has been used in different research papers. The repetitive rate of the keyword does not determine the weight of the keyword.

The colour of the items indicate the score of that item. Green indicates average score, red indicates a high score and blue indicates a low score, by default.

The overlapping of the circles indicate that the keywords are common among multiple research papers. This suggests that the work of these research papers treat a related subject matter or these research papers are on similar lines of study.

After analyzing the above VOSviewer networks using Full and Fractional Counting Methods, we can conclude that we, as many other Authors, prefer the Fractional Counting Method over Full Counting Method, as the more reasonable approach is to consider each item, in the network, equally important.

5) *Review of number of articles published country wise*

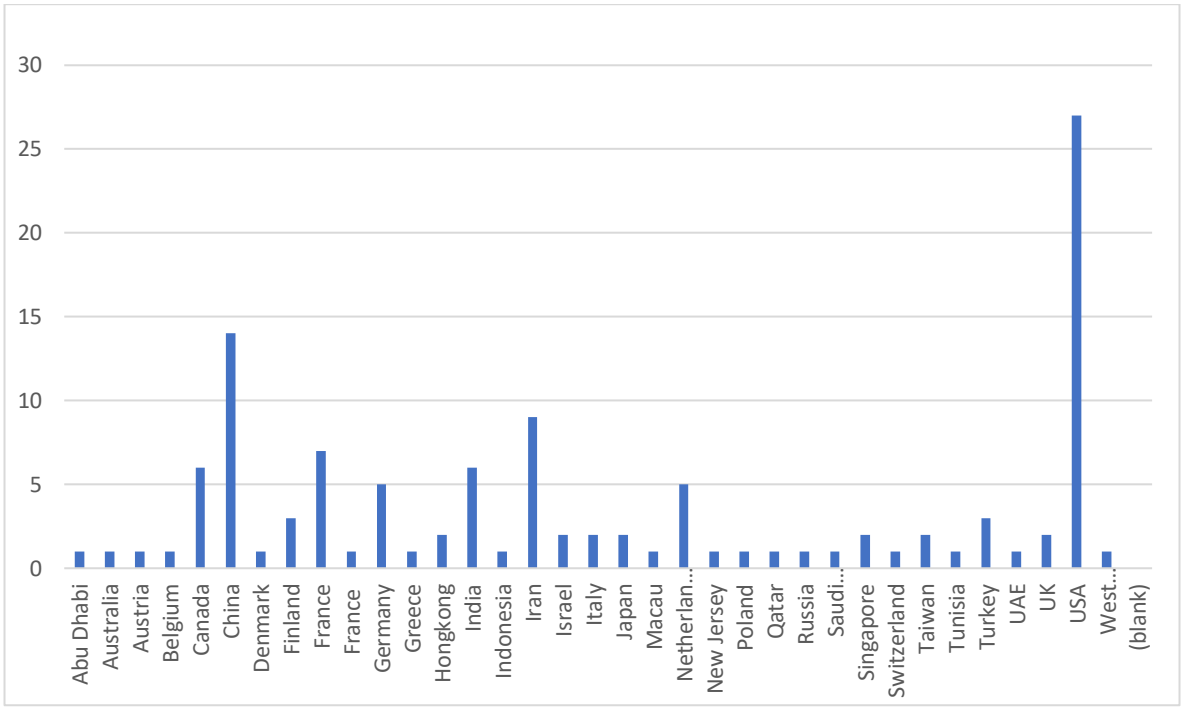


Fig. 5. Number of Articles published on Queueing Theory in Warehousing & Logistics in different countries

Figure 5 is a graphical representation of number of research paper articles published in different countries. The horizontal axis indicates the Countries in which the research papers on 'Queueing Theory in Warehousing & Logistics' were published. The vertical axis indicates the values, i.e., in this case, the number of research papers published in each of these countries. It can be seen that the maximum number of papers are published in USA, followed by China and then Iran. Comparatively maximum number of papers are published in countries like France, India, Canada and Netherlands.

6) *Review of number of articles published Year Wise*

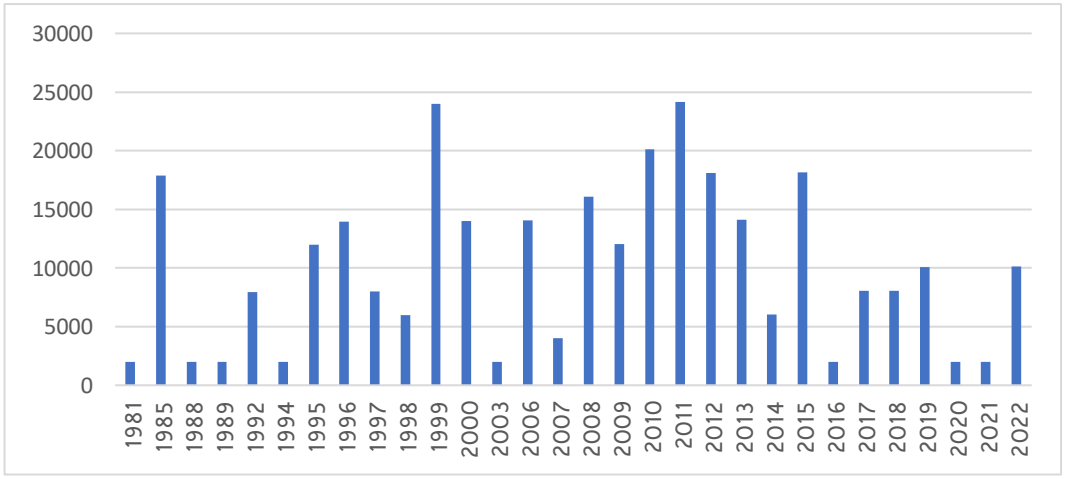


Fig. 6. Number of Articles published on Queueing Theory in Warehousing & Logistics from 1981 upto 2022

Figure 6 is a graphical representation of number of research paper articles published each year from 1981 to 2022 (present). The horizontal axis indicates the Year in which the research papers on 'Queueing Theory in Warehousing & Logistics' were published. The vertical axis indicates the values, i.e., in this case, the number of research papers published in each of these years. It is evident that maximum number of papers were published in the years 1999 and 2011, followed by 2010 and then 1985, 2012 & 2015. There can be seen many spikes in the number of research paper publications in the last 4 decades, which indicates that the research on 'Queueing Theory in Warehousing & Logistics' hasn't been consistent and many gaps were found in the research papers of this topic in the subsequent years.

5. Findings And Discussions

The following points present a summary of the key points highlighted in the analysis and review of the paper. The analysis states that only 4 authors have worked together in different combinations while the rest of the authors have not worked together but have written research papers involving similar keywords as suggested by the Keywords Map made of Vosviewer. This map also depicts the most commonly used keyword for this entire paper is "supply chain management" and "queueing theory" since these are the only keywords in red with the greatest number of links to other keywords used in the previous papers taken into consideration.
Graphs have also been considered in the analysis other than Author Maps and Keyword Maps. This is to analyze the number of papers that are related to the "Warehouse Optimization using Queueing Theory and Supply Chain Management". We can conclude that the greatest number of papers have been published in the US as compared to any other country. In the years 1999 and 2011, the most amount of research papers relating to this topic were published while there were many years in the last 3 decades where only a few papers related to this topic were published.
The papers have discussed about how to reduce queueing time in the warehouses so as to increase the inventory turnover and reduce idle stock and optimize warehouse functions and everyday activities of a warehouse as well as a transporter.
Researchers have discussed Critical Path Analysis as one of their Research Methodologies where CPA helps in the calculation of the maximum time taken for goods to reach from one place to the other or for the production process and time taken for the good to reach its final form from its raw form. We will also be looking at inventory control options such as Just in Time Inventory and First in First Out as well as the various stacking options which include pallet stacking so as to reduce time taken to load the goods on the pallet.

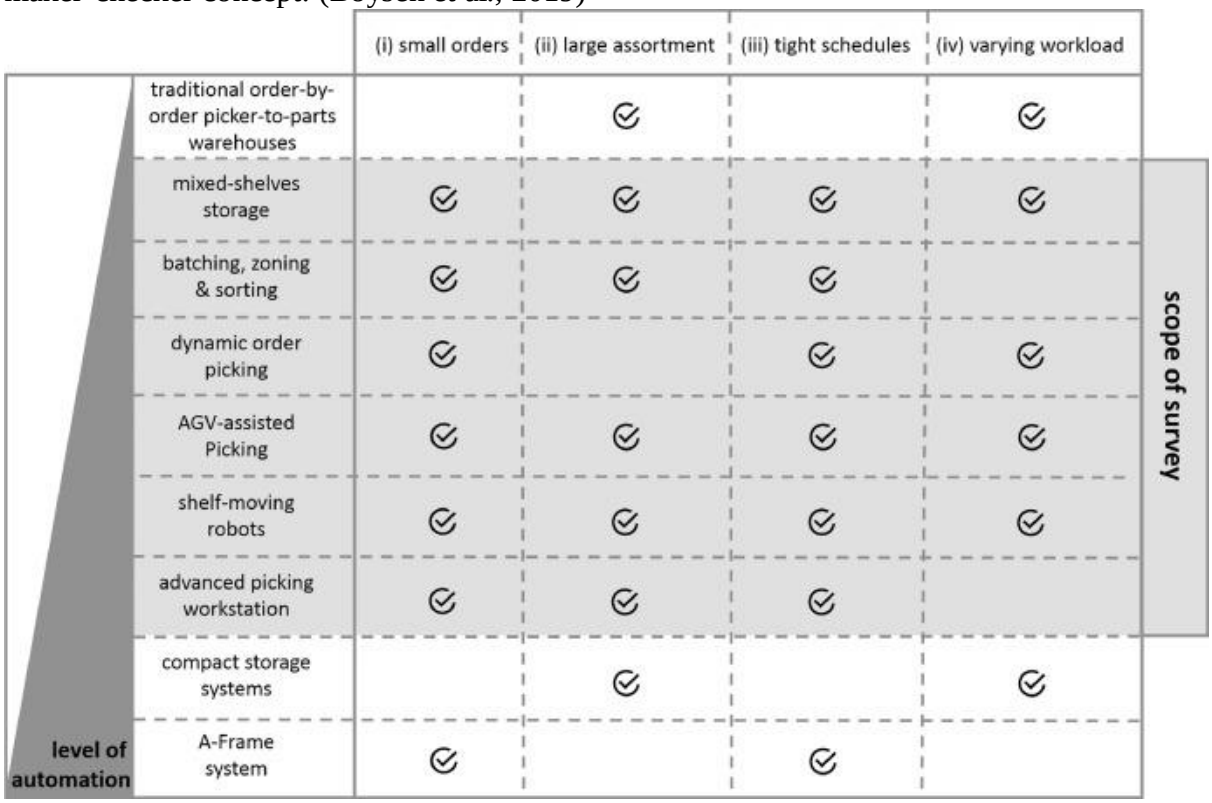
6. Conclusion

Queuing models are used to obtain data on a variety of performance metrics, including (a) the likelihood that any delay will occur; (b) the likelihood that the total delay will exceed a predetermined value; (c) the likelihood that all service facilities will be idle; (d) the anticipated idle time for the entire facility; and (e) the likelihood of turn-away due to insufficiency. (Bhaskar & Lallement, 2011) When optimizing warehouse management, we also consider the synchronization of technology, transportation, storage, and service operations throughout the logistics chain process to achieve the shortest natural flow of materials from supplier to consumer. By applying queuing theory to the model created, it is important to determine the fundamental characteristics and expected course of these processes, as well as the behaviour of the warehouse for an optimum outcome. (Masek et al., 2015)

An effective, efficient and robust supply chain is a sustainable competitive advantage for countries and firms and helps them to cope with increasing environmental turbulences and more intense competitive pressures.(Pishvaee et al., 2011)

7. Future Work

While going through the research papers, we found that there was scope of improvement in the area of the time consumed when stacking and unstacking goods. The conventional form of picker going to the SKUs continuously is very unproductive since the growth of ecommerce and the demand increasing ten-fold hence this article puts forth a different warehousing system wherein the transfer of the goods will be automated and the picker will just have to verify the goods at the docking area. This can be considered as a new use of the maker-checker concept. (Boysen et al., 2019)



The above diagram has been taken from the above cited research paper and it represents an overview of the warehousing systems that are suited for ecommerce. As we go down the grid, the level of automation in the warehouse activities increases, but complete automation is not the optimal solution to reducing queueing time since some amount of manual work has to be involved in the process for its smooth running. AGV Assisted Picking and Shelf Moving Robots are the most efficient form of automation since these processes are suitable for all kinds of warehousing activities including small orders, large assortments, tight schedules and varying workloads.

Now that it is understood that both the forward and reverse supply chains must be controlled simultaneously, the idea of closed-loop supply chains is gaining a lot of interest. The performance of both forward and reverse supply chain networks is significantly influenced by their configuration. (Pishvaee et al., 2011).

8. References

1) Bhaskar, V., & Lallement, P. (2011). Queuing network model of uniformly distributed arrivals in a distributed supply chain using subcontracting. *Decision Support Systems*, *51*(1), 65–76. https://doi.org/10.1016/j.dss.2010.11.029
2) Boeck, L. De. (n.d.). *The Performance of a Supply Chain System with Three Successive Suppliers*. file:///C:/Users/swast/OneDrive/Desktop/Research Papers OR/The_Performance_of_a_Supply_Chain_System20211001-12257-z6931j-with-cover-page-v2.pdf
3) Boysen, N., de Koster, R., & Weidinger, F. (2019). Warehousing in the e-commerce era: A survey. *European Journal of Operational Research*, *277*(2), 396–411. https://doi.org/10.1016/j.ejor.2018.08.023
4) Dekker, R., Bloemhof, J., & Mallidis, I. (2012). Operations Research for green logistics - An overview of aspects, issues, contributions and challenges. *European Journal of Operational Research*, *219*(3), 671–679. https://doi.org/10.1016/j.ejor.2011.11.010
5) Eckhardt, J., & Rantala, J. (2012). The Role of Intelligent Logistics Centres in a Multimodal and Cost-effective Transport System. *Procedia - Social and Behavioral Sciences*, *48*, 612–621. https://doi.org/10.1016/j.sbspro.2012.06.1039
6) Hanukov, G., Avinadav, T., Chernonog, T., & Yechiali, U. (2019). A multi-server queueing-inventory system with stock-dependent demand. *IFAC-PapersOnLine*, *52*(13), 671– 676. https://doi.org/10.1016/j.ifacol.2019.11.124
7) Jain, S., & Raghavan, N. R. S. (2009). A queuing approach for inventory planning with batch ordering in multi-echelon supply chains. *Central European Journal of Operations Research*, *17*(1), 95–110. https://doi.org/10.1007/s10100-008-0077-8
8) Liu, Y., Dehghani, E., Jabalameli, M. S., Diabat, A., & Lu, C. C. (2020). A coordinated location-inventory problem with supply disruptions: A two-phase queuing theory–optimization model approach. *Computers and Industrial Engineering*, *142*(May 2019), 106326. https://doi.org/10.1016/j.cie.2020.106326
9) Masek, J., Camaj, J., & Nedeliakova, E. (2015). Application the Queuing Theory in the Warehouse Optimization. *World Academy of Science, Engineering and Technology, International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering*, *9*(11), 3713–3717.
10) Pishvaee, M. S., Rabbani, M., & Torabi, S. A. (2011). A robust optimization approach to closed-loop supply chain network design under uncertainty. *Applied Mathematical Modelling*, *35*(2), 637–649. https://doi.org/10.1016/j.apm.2010.07.013
11) Shu, J., Teo, C. P., & Shen, Z. J. M. (2005). Stochastic transportation-inventory network design problem. *Operations Research*, *53*(1), 48–60. https://doi.org/10.1287/opre.1040.0140
12) Teimoury, E., Modarres, M., Ghasemzadeh, F., & Fathi, M. (2010). A queueing approach to production-inventory planning for supply chain with uncertain demands: Case study of PAKSHOO Chemicals Company. *Journal of Manufacturing Systems*, *29*(2–3), 55–62. https://doi.org/10.1016/j.jmsy.2010.08.003