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Which Node of Supply Chain Suffers Mostly to Disruption in the Pandemic?

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Abstract

Purpose: The Covid-19 pandemic has had excessively severe impacts on all the nodes and edges of any supply chain due to changes in consumer behaviours and lockdown restrictions from governments among countries. This article aims to provide a simulating experiment on how a supply chain deals with supply disruption risks by flexibility in the inventory level of each sector as a buffer considering the overall cost to fulfil demand in the market. **Research design, data and methodology:** Agent-based simulation techniques are used to determine the cost-efficiency and customer waiting time related to varying inventory levels of each member in the supply chain when using inventory buffers. **Findings:** This study has shown that any sudden changes in the inventory level of each sector are likely to impact the rest of the supply chain. Among all sectors, the wholesaler will be impacted more severely than others. Also, the manufacturing sector is the most suitable node to adjust inventory depending on its manufacturing ability. **Conclusion:** The findings of the study provide insightful implications for decision-makers to adjust inventory levels and policymakers to maintain manufacturing activities in the context of the pandemic restrictions to deal with the excessive demand and potential supply disruption risks.

Keywords : Agent-based Modelling, Supply Disruption, Inventory Management, Simulation Experiment

JEL Classification Code: M11, L11, L81.

1. Introduction

The supply chain is the most crucial part of the economy. The COVID-19 pandemic has had excessively severe, diversified, and dynamic impacts on all the supply chain members (nodes) and ties (edges) in any supply chain than previous epidemic outbreaks, namely SARS or H1N1 epidemic (Chowdhury, Paul, Kaisar, & Moktadir, 2021). Thus, the flows of the global supply chains have been disrupted and changed dramatically as each country is effortfully balancing disease controls and economic benefits. On the one hand, the demand for necessary goods such as facemasks, personal protective equipment (PPE), medicine, perishable and processed food has risen (Singh, Kumar, Panchal, Manoj, Tiwari, & Tiwari, 2021). Additionally, typical stockpile behaviour at times of disasters such as earthquakes, hurricanes, tsunami, and pandemics would immediately impact every entity in supply chains. On the other hand, supply sides struggle in operation due to partial lockdown or border closures, causing labour shortage and interruptions in manufacturing, shipping and international trade (Chowdhury et al., 2021). These multidimensional effects of the Covid-19 crisis profoundly impact world trade as the volume of world merchandise trade has fallen in 2020.

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The literature summary of Islam, Azeem, Jabir, Paul, and Paul (2020) has reported decreases in shareholder value, stockholder return, and operating income, return on asset, and return on sales due to supply chain disruptions. Also, there are many studies on resilience strategies to deal with the Covid-19 pandemic. To maintain three dimensions of resilience consisting of preparedness, response, and recovery, there are many available practices such as multiple and diversified sourcing and facilities, keeping backup suppliers at diversified locations, and the use of public distribution system network (Kim, 2021; Sharma, Luthra, Joshi, & Kumar, 2020; Singh et al., 2021). Nonetheless, these strategies require long-term establishments in optimal network design (Yan & Ji, 2020), supply chain flexibility, and careful selection of facility locations (Sundarakani, Pereira, & Ishizaka, 2021). This limitation might affect the supply chain's ability to react to pandemic disruption immediately.

Response plans for minimising impacts and action plans for quick recovery are essential for supply chain management to fight the devastating disruption impacts of the pandemic. In the literature, supply disruptions can be detained by formalised processes for supplier selections, lot sizing, and scheduling, along with optimal inventory levels (Islam et al., 2020). Additionally, enhancing the downstream supply chain coordination is critical for managing demand disruptions since a linear quantity discount contract is more effective than a revenue-sharing contract (Zhao, Xu, Chen, Liang, Yu, & Wang, 2020). It is noticed that supply chains have two additional buffers along with capacity available to deal with disruption problems: inventory and time (Schmitt & Singh, 2012). To make a supply chain resilient to the pandemic, there is a judicious mix approach of reliability, system buffers, as well as practical recovery logic. As Schmitt and Singh (2012) suggest, available finished goods inventory can always meet the demand, which is the added advantage of reaction in the snap of time. However, there are three issues along with this strategy, including holding cost, too many locations of inventory, committed raw material and efforts as SKU proliferation while keeping response time for demand and disruptions.

The objective of this article is to provide a simulating experiment on how a supply chain deals with supply disruption risks by flexibility in the inventory level of each sector as a buffer considering the overall cost to fulfil demand in the market. Thereby, the author seeks to explore the reaction of the supply chain when there are potential supply disruption risks. The paper is constructed as follows: theoretical frameworks related to this study are represented in the next section. In Section 3, the research methodology is presented through the problem formulation based on mathematical equations to clarify each node's related costs and time in the supply chain model. Also, experiment configuration is specified to show the different assumptions in each experimental run. The result analysis and discussion in Section 4 focus on answering the following research questions of the study:

- How do the changes in the inventory level of each sector impact the cost of the whole supply chain?
- Which node should inventory be held in the network to minimise total costs and customer waiting time?

Then, the discussion about insights, limitations, and future research agenda are summarised in the final section.

2. Literature Review

2.1. Supply Disruption Risks Due to the Pandemic

In modern global supply chains, each organisation sources raw materials, work-in-process, and finished products from every corner of the globe. Even in the case local suppliers are from the domestic market, their tier 2 or 3 suppliers still locate abroad. When the pandemic outbreaks, most governments around the world have imposed full or partial lockdowns at the borders or local areas with the aim of restricting movements to control the transmission of the disease (Chowdhury et al., 2021). In the study of Guan, Wang, Hallegatte, Davis, Huo, Li, Bai, Lei, Xue, Coffman, Cheng, Chen, Liang, Xu, Lu, Wang, Hubacek, and Gong (2020), they found that supply-chain losses related to initial Covid-19 lockdowns largely depend on the number of countries imposing restrictions. They confirmed that the duration of a lockdown might generate more losses than its strictness. In line with local and international closures created by these lockdowns, the sudden restrictions of international suppliers' operations have caused supply disruptions for manufacturers and affected suppliers' ability to deliver products to customers on time.

From the perspective of production management, supply disruptions cause severe production disruptions and backlog for manufacturing firms. For example, it is governmental requirement for businesses to reduce office hours and work on alternative days to maintain social distancing in factories and offices. When employees are unable to work full-time, workforce shortages result in the obsolescence and impairment of machinery and capital assets (Dente & Hashimoto, 2020). From the perspective of logistics management, transportation disruptions including ocean shipping, air freight, trucking, and rail have negatively affected the flow of raw materials and products. Additionally, the pandemic has forced many firms to transform their business models to online or multi-channel modes. Some retailers have designed distribution centres to serve online customers exclusively, but others are still struggling to quickly implement logistical solutions to meet these new demands (Mollenkopf, Ozanne, & Stolze, 2021).

2.2. Inventory Management

Inventory is defined as the stock of any item or resource used in an organisation (Jacobs & Chase, 2018). Inventory management concerns at what level inventory should be, when stock should be replenished as well as how large orders should be. Inventory level is associated with ordering cost, shortage cost, setup cost, and holding cost as incremental cost. The objective of most companies is to maximise their profit by lowering some inventory cost parameters at a particular period (Islam et al., 2020). However, the lower inventory level is accompanied by, the lower ability to fulfil orders resulting in the next sector or customers have to wait longer. The tradeoff between cost and customers' satisfaction is the primary concern in inventory management. Hence, the optimal inventory level receives significant attention in supply chain management.

In particular, Cárdenas-Barrón, Shaikh, Tiwari, and Treviño-Garza (2020) proposed an inventory model with the assumption of negative ending inventory level. They formulated an economic order quantity (EOQ) model to maximise the retailer's total profit per unit of time under nonlinear holding cost and demand. Using a different approach, Lücker, Seifert, and Biçer (2019) focused on managing disruption considering reverse capacity for inventory decisions and stochastic demand simultaneously. The assumption of zero lead time is used to neglect the effects of safety stock in their mathematical model. This assumption is prevalent in most of the literature, which means when firms place orders, they receive shipments immediately or after a random/fixed lead time. In general, previously published studies are limited to identifying the time of replenishments and order size to prevent supply disruption. Up to now, there is little discussion about the tradeoff between inventory level and supply cost-efficiency.

Taken together, supply disruption poses several negative impacts on supply chain management, especially on the financial performance of a company. For instance, the empirical study of Hendricks and Singhal (2009) quantified long-run stock price performance under the effect of supply chain disruptions and showed that the average abnormal stock return is nearly 40% for a year before and two years after the disruption. In order to avoid these impacts, firms in supply chains could use inventory management as a useful tool responding to supply disruption risks by adjusting the level of inventory to fulfil excessive demands and avoid backlogs. However, the tradeoff between inventory level and supply cost-efficiency is needed to explore further. For the reason that every decision is costly for businesses and inventory level is no exception.

3. Methodology

Agent-based modelling is the most recent created method to model the behaviours of adaptive actors who make up a social system and who influence one another through their interactions since 2002-2003 (Harrison, Lin, Carroll, & Carley, 2007). It is created to carefully examine systems that are not well-captured by system dynamics or discrete events methods. In an agent-based model, the level of abstraction varies from very detailed, where agents represent physical objects, to a higher stage, where agents are highly competing for subjects or markets. The agent-based model is frequently used to model the markets, supply chains, and logistics, whose cases focus on individual objects, their behaviours, and interactions are needed (Borshchev & Filippov, 2004). Following these approaches, the study also uses this method to explore which sector suffers the most to supply chain risks due to the pandemic. In detail, inventory management of each sector and the overall cost of the supply chain in fulfilling orders are examined in the model.

In this study, a simple supply chain operating 24 hours per day consists of four sectors: customers, a retailer, a wholesaler, and a factory. Each supply chain sector is a separate unit that operates independently and communicates with others by sending messages. Thus, agent-based model is suitable to capture each sector's behaviour and their interactions with the others. Usually, a supply chain consists of two opposite flows: the information flow (demand and orders) from end-customers to the retailer to the wholesaler and finally to the factory. The material flow from the factory moves backwards to the end customers via the wholesaler and the retailer.

Each sector has its own behaviour ruling by state charts and events in the agent-based model to be set up essential connections among them within an environment. Statechart is one of the most powerful tools allowing modellers to define an object's behaviour as a sequence of states and events are scheduled actions in a model (Borshchev, 2013). In the model, the demand of a single customer contains the number of requested units. An order is sent to the retailer, the wholesaler, or the factory containing the amount being ordered along with the shipping address to which sector. Shipments are from the factory to the wholesaler or the wholesaler to the retailer containing the shipped amount. Supply is the last stage where the retailer sells goods to customers.

3.1. Problem formulation

The problem formulation is a generalisation of the inventory problem proposed by Law (2014) in his book Simulation Modeling, and the model is set up by Borshchev

(2013) using AnyLogic software and Java programming language. This study applies this problem formulation and varies the inventory level of each sector in the supply chain to do the experiment in the model. The main reason for using the famous Law's model in this study is that several elements of his model represent those in existing inventory systems at firms, which helps us replicate the real inventory mechanism. This approach has been used in the work of Shahi and Pulkki (2015). They used the same model to minimise total inventory cost through the optimum inventory policy (s, S) for the three supply chain agents, including sawmill storage, merchandising yard, and forest management unit.

3.1.1. Demand

In this study, the demand is stable with the assumption that this is an essential product. Customers use it stably no matter what happens. As seen in Figure 1, to simplify the supply chain, in this experiment, only a company that sells a single product wants to decide the number of items in inventory every day within a year (365 days) to see the prolonged impacts of supply disruption as the suggestion of Hendricks and Singhal (2005). The times between demands are exponential interarrival variables with a mean of 0.1 days. The sizes of the demands D are discrete random variables with the below values:

$$D = \begin{cases} 1, 3 \; with\; probalities \; \frac{1}{5} \\ 2 \; with\; probalities \; \frac{2}{5} \\ 4, 5 \; with\; probalities \; \frac{1}{10} \end{cases}$$

3.1.2. The retailer

A stationary (s, S) policy is used by each sector to decide the amount to order. For example, the retailer uses a stationary $(s_{R,}S_R)$ policy to decide how much to order as the below formula

$$O_R(t) = \begin{cases} S_R(t) - I_R(t) \; if \; I_R(t) < s_R \\ 0 \; if \; I_R(t) \geq s_R \end{cases} \quad (1)$$

where $I_R(t)$ is the inventory level at time t, $O_R(t)$ is the order from the retailer to the wholesaler at the time t, and $s_{R,}S_R \; \epsilon \; R^+$.

When a customer's demand occurs, the retailer is satisfied immediately if its inventory level is larger or equal to the demand, thus $I_R(t) = I_R(t-1)$ - D(t). If the inventory level is lower than the demand, the customer takes currently available items. Hence, the excessive demand is backlogged and fulfilled by a delivery from the wholesaler in the future. $I_R(t) = \max\{I_R(t), 0\}$ is the number of items in the on hand inventory at time t. If T is the time required for a customer to receive their entire order, then T = 0. The new inventory level is the result of the old inventory level minus demand size in a negative inventory level. To this end, T is the time from when the customer first arrives until that time future when the customer receives the remainder of their order. $I_R^-(t) = \max\{-I_R(t), 0\}$ is the backlog at time t.

At the beginning of each day, if the retailer orders O_R items, it incurs an ordering cost of $S_R + i_R O_R$, where S_R is the setup cost and i_R is the incremental cost. O_R includes the cost of shipping by the wholesaler, if $O_R = 0$, no ordering cost is incurred. The order is electronically sent to the wholesaler and arrives immediately, which means 0 lead time. $O_R(j)$ is the ordering cost incurring on the jth day, the time interval [j-1,1), by the retailer for j ϵ [1,365] where 365 days is the simulation run length. The average ordering cost per day is

$$\overline{O_R} = \frac{\sum_{j=0}^{365} O_R(j)}{365} \quad (2)$$

The retailer incurs a holding cost of h_R per item per day held when $I_R(t) > 0$. For a year, the time-average (per day) number of items held in inventory is

$$\overline{I_R^+} = \frac{\int_0^{365} I_R^+(t)}{365} \quad (3)$$

So, the average holding cost per day is $\overline{H_R} = h_R \overline{I_R^+}$

Also, the retailer incurs a backlog cost of b_R per item per day. For a year, the time-average (per day) number of items in backlog is

$$\overline{I_R^-} = \frac{\int_0^{365} I_R^-(t)}{365} \quad (4)$$

The average backlog cost per day is $\overline{B_R} = b_R \overline{I_R^-}$

Finally, the average total cost per day of the retailer for maintaining its inventory $\overline{C_R}$ is $\overline{C_R} = \overline{O_R} + \overline{H_R} + \overline{B_R}$

3.1.3. The Wholesaler

The behavior of the wholesaler is the same as the retailer. At the beginning of everyday, the wholesaler first checks whether any orders from the retailer to be shipped, including just arrived one. If so, FIFO shipping manner is applied to complete orders for which it has enough inventory. No partial orders are allowed. There is a random lead time L_W of the shipment to reach the retailer, where L_W is uniformly distributed on the interval $[\frac{1}{4}, \frac{1}{2}]$ day. The new inventory level at the wholesaler $I_W^N(t)$, is the old inventory level minus the number of items shipped. Any unshipped order is backlogged. The wholesaler uses a stationary $(s_{w,}S_w)$ policy to decide the order amount:

$$O_W(t) = \begin{cases} S_W(t) - I_W^N(t) \; if \; I_W^N(t) < s_W \\ 0 \; if \; I_W^N(t) \geq s_W \end{cases} \quad (5)$$

The wholesaler orders O_W items, it incurs an ordering cost of $S_W + i_W O_W$, where S_W is the setup cost and i_W is the incremental cost. O_W includes the cost of shipping by the factory, if $O_R = 0$, no ordering cost is incurred. The average cost per day for the wholesaler of maintaining its inventory $\overline{C_W}$ is $\overline{C_W} = \overline{O_W} + \overline{H_W} + \overline{B_W}$

3.1.4. The Factory

The behaviour of the factory is the same as the wholesaler. At the beginning of each day, the factory checks whether any orders from the wholesaler are needed to be shipped, including just arrived one. So, FIFO manner is also applied to orders for which the factory has enough inventory, no partial orders are allowed. A random lead time $\mathrm{L_F}$ for the shipment arrives at the wholesaler, where $\mathrm{L_F}$ is uniformly distributed on the interval $[\frac{1}{2}, 1]$ day. Additionally, the time required to manufacture $\mathrm{M_F}$ items is $\mathrm{t_S + t_M M_F}$ days with $\mathrm{t_S}$ is the time to set up the manufacturing line and $\mathrm{t_M}$ day is the time to manufacture each item. If $\mathrm{M_F} = 0$, no manufacturing cost incurs. When the factory completes a batch of items, the items are then added to the factory's inventory. At this time, there are no items sent to the wholesaler since shipments are only made at the beginning of a day. The factory uses a stationary (s_F, S_F) policy to decide how much to manufacture, i.e.,

$$O_F(t) = \begin{cases} S_F(t) - I_F^N(t) \; if \; I_F^N(t) < s_F \\ 0 \; if \; I_F^N(t) \geq s_F \end{cases} \quad (6)$$

The wholesaler orders O_{F} items, it incurs an ordering cost of $\mathrm{S_F + i_F O_F}$, where $\mathrm{S_F}$ is the setup cost and $\mathrm{i_F}$ is the incremental cost. O_{F} includes the cost of shipping by the factory, if $O_{\mathrm{F}} = 0$, no ordering cost is incurred. The average cost per day for the wholesaler of maintaining its inventory $\overline{C_{\mathrm{F}}}$ is $\overline{C_{\mathrm{F}}} = \overline{\mathrm{O_F}} + \overline{H_{\mathrm{F}}} + \overline{B_{\mathrm{F}}}$

3.2. Experiment Configuration

3.2.1. Normal Condition

In normal condition, there is no risk in supply disruption, let assume that the whole supply chain is running with a stable inventory policy (s,S) = (20,80) and the initial inventory level at each sector is equal to a constant (60). The results of simulations show that the mean waiting time is 0.279 days, and the mean daily cost is $851.87 of the supply chain. With this inventory policy, the retailer spends most of its cost in ordering with 59% overall and only 19% in holding cost as seen in Figure 1. While the wholesaler deals with the backlog issue when it cannot fulfill orders from the retailer with 50% of the total cost. The factory spends most of the money in manufacturing to fulfil orders from the wholesaler with 47% and only 33% in the backlog that is lower compared to the wholesaler. Among the three sectors, the mean daily cost of the wholesaler is the highest due to the backlog issue, and the mean daily cost of the retailer is the lowest spending on ordering goods to fulfil demand from customers.

Figure 1: Mean Daily Cost of the Supply Chain (Sourced from the Author's Analysis in Anylogic)

3.2.2. Reactions in Inventory Management

When the pandemic outbreaks, it dramatically impacts the supply and might cause disruption in the supply process. The stockpile behaviour begins to show up among the sectors. Therefore, in the first experimental run, let assume that the retailer reacts to the risk of supply disruption that might happen in the near future by increasing its inventory level to the maximum level to prevent increasing backlog. In contrast, the others remain the normal policy, thus, (s_R, S_R) = (20,200) and (s_w, S_w)= (s_F, S_F) = (20,80). The results of simulations show that the mean waiting time increases to 0.344 days, and the mean daily cost is $1014.52. The changes in the inventory level and the mean daily costs of each sector are illustrated in Figure 2. Compared to the normal condition, both the waiting time and mean daily cost of the supply chain hike significantly due to the retailer's reaction. Its holding cost is nearly doubled, while the backlog cost also upsurges. Its reaction seriously affects the wholesaler's cost, especially increasing the backlog cost 1.5 times. On the contrary, the factory receives impacts of this reaction insignificantly.

Figure 2: The First Experimental Run (Sourced from the Author's Analysis in Anylogic)

In the second experimental run, let assume that the wholesaler will follow the retailer to increase its inventory level to the maximum level to prevent increasing backlog. At the same time, the factory remains the normal policy, thus, (s_R, S_R)= (s_w, S_w)= (20,200) and $(s_F, S_F) = (20,80)$. The results of simulations show that the mean waiting time decreases to 0.16 days, and the mean daily cost increase to \$1037.26. The change in the inventory level and the mean daily cost of each sector are illustrated in Figure 3.

Figure 3: The Second Run (Sourced from the Author's Analysis in Anylogic)

When changing inventory level following the retailer, the wholesaler helps to reduce the customer's waiting time noticeably but surges the total cost of the supply chain higher than the first run. Its daily costs also dramatically escalate, especially in holding and backlog costs.

In the third experimental run, let assume that the wholesaler and the retailer remain the normal policy. At the same time, the factory increases its manufacturing level to maximum level to prevent increasing backlog, thus, (s_R, S_R) = (s_w, S_w) = (20,80) and $(s_F, S_F) = (20,200)$. The results of simulations show that the mean waiting time is 0.21 days, and the mean daily cost is \$831.747. The change in the inventory level and the mean daily cost of each sector are seen in Figure 4.

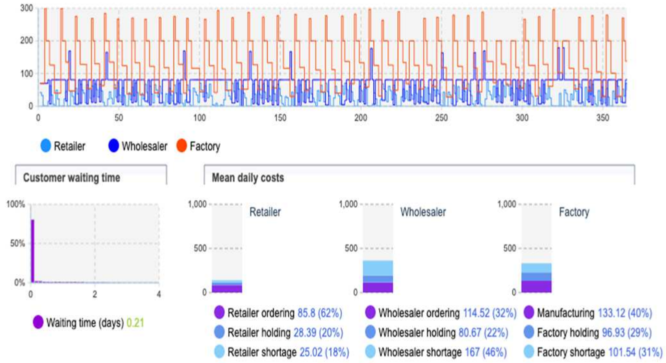


Figure 4: The Third Run (Sourced from the Author's Analysis in Anylogic)

It is likely that when the factory is able to upscale its manufacturing capacity, the waiting time and the mean daily cost of the supply chain are very reasonable since this policy enhances the efficiency of the supply chain. However, there is a slight surge in the holding cost of the factory.

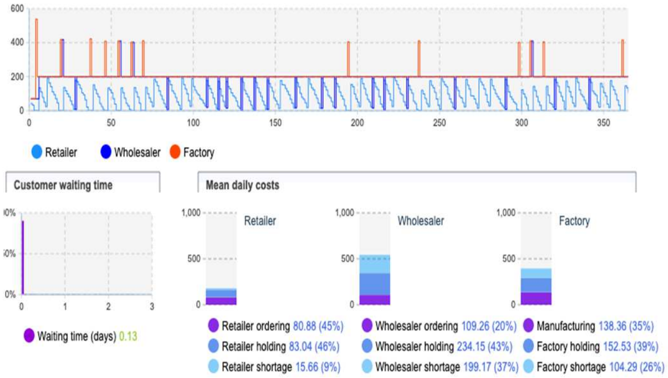


Figure 5: The Fourth Run (Sourced from the Author's Analysis in Anylogic)

In the fourth experimental run, let assume that all sectors increase their inventory level to maximum level to prevent the risk of disruption, thus, (s_R, S_R)=(s_w, S_w) =(s_F, S_F) = (20,200). The results of simulations show that the mean waiting time is very low, only 0.12 days, and the mean daily cost is the highest record, with \$1115.41. The change in the inventory level and the mean daily cost of each sector are seen in Figure 5. It seems that this practice should not be used since the waiting time and the mean daily costs are incredibly high compared to other experiments. However, the waiting time is the shortest one among the experiments. It is noticed that holding costs at each sector are doubled compared to the normal condition.

4. Results and Discussion

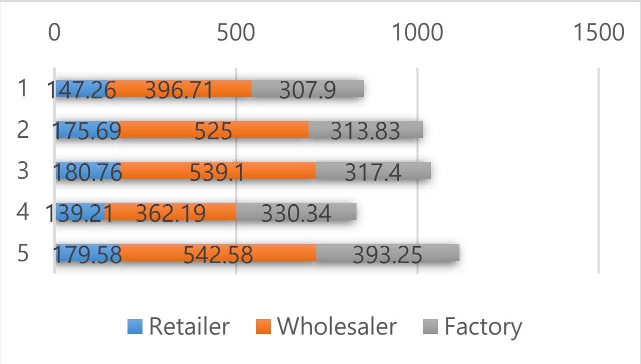
Prior studies have noted the importance of response and action plans for minimising impacts and quickly recovering that are incredibly essential for supply chain management to fight the devastating disruption of the pandemic. Inventory is an effective buffer regarding its ability to meet demand as the added advantage of reacting in the shortest time (Schmitt & Singh, 2012). On the contrary, it creates higher costs of holding, setup, and shortage within each firm. Thus, this study has been designed to determine the cost efficiency associated with daily inventory levels in the supply chain when each sector perceives potential supply disruption risks. The previous sections have represented the study's methodology reflecting through model formulation, experiment configurations, and the results of the experiments in changing inventory policies. After several times running experiments, there are many interesting findings from this study.

First, the most prominent finding emerging from the analysis is that any sudden changes in the inventory level of each sector are likely to impact the rest of the supply chain. It is evident that the retailer and the wholesaler change their inventory levels, respectively, or simultaneously, resulting in higher total costs and increasing or decreasing waiting time to fulfil those orders as presented in the first and second run (Table 1). In the second run, increasing inventory reduces the waiting time to gain higher customer satisfaction since the greater majority of the customers do not wait for the product. Contrarily, the total costs of the supply chain are incredibly high compared to the normal condition. Therefore, any stockpile behaviours will affect the whole supply chain. It is recommended that each sector should coordinate with other nodes in the supply chain to inform their changes in orders and inventories ahead of time. Otherwise, other sectors cannot handle extra orders and potential backlogs on time.

Table 1: The Summary Results of the Experiments (Sourced from the Author's Analysis)

Experiment	**Waiting time (days)**	**Total cost ($)**	**Retailer ($)**	**Wholesaler ($)**	**Factory ($)**
Normal	0,279	851,87	147,26	396,71	307,9
1st run	0,344	1014,52	175,69	525	313,83
2nd run	0,16	1037,26	180,76	539,1	317,4
3rd run	0,21	831,74	139,21	362,19	330,34
4th run	0,12	1115,41	179,58	542,58	393,25

Second, the wholesaler receives the most considerable impact whenever fluctuations in inventory levels happen in any sector, as seen in Figure 6. The results show that the wholesaler suffers major impacts of any changes in the others' inventories in all the experiment runs.



Note: 1 - normal condition; 2 - first run; 3 - second run; 4 - third run; 5 - fourth run

Figure 6: Mean Daily Cost of the Supply (Sourced from the Author's Analysis)

This interesting result may be explained due to the fact that the wholesaler is the central node in the supply chain. Any reactions from both sides - upstream or downstream, surge backlog and holding costs in this sector. Therefore, this sector should be cautious in the pandemic when varying demands, shipping restrictions, and delayed production might incur from the end customers, both downstream and upstream nodes in the supply chain. Solutions for this sector are accurate forecasting and planning, as they are essential tools for helping and providing guidance for the utility and timing of prevention strategies (Nikolopoulos, Punia, Schäfers, Tsinopoulos, & Vasilakis, 2021).

From the above findings, it is recommended that carrying inventory to react supply variance may have unforeseen benefits and limitations in protecting from disruptions, which is in line with previous conclusions of many authors (e.g. Islam et al., 2020; Schmitt and Singh, 2012; Singh et al., 2021). Also, the whole system must be taken into account for finding the appropriate mix and prioritising actions regarding using inventory as a buffer to deal with supply disruption. As Schmitt and Singh (2012) emphasised, extra inventory will not be helpful, and this study confirms this statement, especially for retailing and wholesaling sectors.

Additionally, disruptions may be local that is an assumption of the experiment, but the impact of each sector's reaction can be widespread both upstream and downstream of the supply chain. An emerging issue from these findings is the volume of backlog at any time that should be considered a key indicator of system performance by each sector of the supply chain management, especially for the case of the wholesaling nodes. In this study, backlog costs take over the majority of daily supply chain costs from the lowest of 9 up to 59 per cent of overall costs over the experiments. The retailing sector suffers from this cost the least, while wholesaling and manufacturing sectors should beware of this indicator the most.

Finally, increasing manufacturing inventory is the best solution with the aim of boosting supply ability to deal with supply disruption risks. It is somewhat surprising that if only the factory raises its inventory level, either the waiting time and the total costs of the supply chain decrease. This finding emphasises the critical ability to maintain stable production during the pandemic outbreak. Islam et al. (2020) argued that in many small and medium scale manufacturing industries, addressing the supply and demand uncertainty issues is usually absent the role of inventory policies. In detail, maintaining production is the balance between supply and demand within factories. This requirement asks for full-time working workforce, non-interrupted operations, stable level of inventory, and continuous supply inputs such as fuels, raw materials, MRO products, etc., to fulfil orders.

Nevertheless, during the pandemic, these factors may not be able to deliver the desired amount to factories due to pandemic restrictions. In particular, supply disruption happens worldwide, resulting in one-quarter of the total model-implied real GDP decline due to transmission through global supply chains (Bonadio, Huo, Levchenko, & Pandalai-Nayar, 2021). Meanwhile, excessive demand due to the Covid-19 pandemic, especially for groceries and electronics, is cumulatively higher if the lockdown lasts longer (Nikolopoulos et al., 2021). Additionally, Guan et al. (2020) proved that the longer the lockdown is, the more economic losses are. They also confirmed that the complexity of global supply chains will exaggerate economic losses overmuch the direct effects of COVID-19. Thus, along with the preparations for fluctuations in demand, particularly in view of a lockdown, the study suggests that governmental efforts in maintaining manufacturing activities should be the top priority to cope with supply disruption. This finding emphasises the role of government in pandemic control as it requires collective efforts and supports from each involved organisation.

5. Conclusion

In 2020 and 2021, many research papers focus on dealing with the Covid-19 pandemic, which is an unprecedented event impacting every aspect of society. Supply chain management, which is the primary concern due to its critical role in facilitating economic development, has been strongly impacted by social distancing and lockdown practices as the governments' efforts in containing the pandemic. Many authors discuss supply disruption could lead to a decrease in shareholder value, in stockholder return, and decline in operating income, return on asset and return on sales (Bonadio et al., 2021; Chowdhury et al., 2021). Inventory is a buffer to fulfil demand as a valuable advantage of supply chain reaction. However, there is too little research using simulation modelling to evaluate the changes in inventory as a method to cope with supply disruption risks in the pandemic. The main objective of the current study is to determine the tradeoff in the cost-efficiency related to inventory levels through two research questions addressed in Section 1. Agent-based simulation techniques are used to understand the performance of the supply chain models. To answer the first research question, this study has shown that any sudden changes in the inventory level of each sector are likely to impact the rest of the supply chain. Among sectors, wholesalers will be impacted more severely than others. Concerning the second question, the manufacturing sector is the most suitable node to adjust inventory thanks to its manufacturing ability. The findings from these research questions have a number of theoretical and managerial implications and future research agenda discussed in the below subsections.

5.1. Implications

First, the findings of this research provide insightful implications for decision-makers of each sector in the supply chains to adjust inventory levels when there is a potential risk on the supply side. The study contributes to our understanding of reactions using inventory management to deal with supply disruption through agent-based modelling. Second, these findings have significant implications for finding potential solutions for each node of supply chains in the context of the pandemic restrictions to deal with the excess demand. Third, this study is the evidence showing how important for governments in the effort to keep manufacturing activities going on when the pandemic outbreaks. Response and action plans for minimising impacts and quick recovering are essential for supply chain management to fight the devastating disruption impacts. Consequently, this is a critical finding supporting much previous research for policymakers to lift restrictions and stimulate supply chains recovery. Last but not least, in line with previous simulation research, the study shows what simulations are and how they work in business and management analysis to find the best solution in a specific context. This study is an illustrated experiment in supply chain management, in which simulation modelling is flexible, easy to use, and suitable for running different scenarios to see how firms react to disruption risks in the context of a pandemic.

5.2. Limitations and Future Works

The generalisability of these findings is subject to certain limitations. For example, this study is limited by the highly abstracted replication of a supply chain containing only a retailer, a wholesaler, a manufacturer, and customer representatives for each sector. In addition, the supply disruption effect could be represented better by a variable in the model to reflect its dynamic characteristics or sudden changes in pandemic restrictions of governments. One other thing, conditions for running experiments may be varied to generate full pictures of all possibilities in reality. Like reading any simulation study, the readers should bear in mind that greater accurate replication of reality creates a greater complexity level of the model’s inputs and outputs. Finally, the units of analysis could be more diversified to elaborate the current model.

In spite of the aforementioned limitations, it certainly adds to our understanding of the comparison experiments in the different inventory levels described in this paper. The study has thrown up several questions in need of further investigation. Firstly, the study should be repeated using more complicated supply chain configurations on the same set of objects, adding more tiers and nodes or multi-echelon supply chains. Secondly, complicated behaviour of each sector can be added, namely product discards, limited waiting time for customers behaviour, and continuous changes in inventory levels for each sector of the supply chain. Further modelling research can be carried out to see the effects of different models in such complex systems. Finally, other simulation methods should be used to replicate the study, such as discrete or multi-method modellings as different system designs to explore this research issue.

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