Managing panic buying-related instabilities in supply chains: A COVID-19 pandemic perspective

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Abstract: Global supply chains (SCs) have been severely impacted by the COVID-19 pandemic on several levels. For example, SCs suffered from panic buying-related instabilities and multiple disruptions of supply, demand, and capacity during the pandemic. This study developed an agent-based model (ABM) to predict the effects of panic buying-related instabilities in SCs and offered strategies to improve them. The ABM model includes a simulation and optimization model of a typical SC of an essential product manufacturer (i.e., toilet paper SC) for the analysis of scenarios and strategies to observe improvements in SCs. Among the four strategies identified, the findings suggest boosting production capacity to the maximum and ensuring optimal reorder points, order sizes, and trucks helped the essential product manufacturers reduce panic buying-related instabilities in their SCs.

Keywords: Supply chain; COVID-19 pandemic; panic buying; mitigation; agent-based modeling.

1. INTRODUCTION

Global SCs have been disrupted on an unprecedented scale in the past decade. Unknown-unknown risks are posed by disruptions in the SCs on a large scale (Ivanov, 2021b). When these events occur, their complexity, timing, and location are unpredictable. Businesses are confronted with the challenge of operating in a volatile, uncertain, complex, and ambiguous environment (VUCA) (Chowdhury et al., 2021). Currently, the COVID-19 epidemic has disrupted the global SCs, and the extent of its impact is yet to be determined. As a result of the lockdowns, shutdowns, and border closures, global SCs suffered supplier failures, production capacity degradation, transportation restrictions, and insufficient inventory to meet the additional demand for essential products. There has been a significant increase in demand for essential and high-demand products, such as toilet paper, facemask, and food (Arabsheybani & Arshadi Khasmeh, 2021). However, luxury and low-demand product producers experienced a significant decline in demand. As such, they struggled to remain in business. The long-standing SCs were unable to cope with the large-scale disruption caused by the COVID-19 pandemic (Rahman et al., 2021). It is crucial to understand the risks in SCs as a result of large-scale disruptions and assess the implications of reconfigurable solutions to control uncertainty (Paul et al., 2018).

The lockdowns and shutdowns caused people to panic buy essential items, such as food and toilet paper (Paul et al., 2021). Due to the border closure, sudden fluctuations in demand, manufacturing capacity decreases, and supply delays negatively impacted retailers and essential products' manufacturers. Literature on how to manage such SC instabilities related to panic buying is scarce. In order to bridge the knowledge gap, there is a need to investigate the panic buying-related instabilities (i.e., bullwhip effects) in SCs and strategies to manage them efficiently (Saeed, 2015). Accordingly, the research questions posed here are as follows:

i)   How are panic buying-related SC instabilities likely to affect essential products' manufacturers?
ii)   Which strategies, tools, and methods can be used to predict the impacts of panic buying in SCs and justify the strategies to deal with them?

The example of toilet paper SCs is used to illustrate the instabilities caused by panic buying in SCs of essential products. This study makes three contributions. First, an agent-based model (ABM) of the SC network was developed to predict the impact of panic buying. Second, strategies and recovery plans were proposed to address panic buying-related instabilities in SCs. Finally, an optimization experiment was performed within the simulation model in *Anylogic* software to justify the proposed strategies for improving SCs. The results will guide essential products' manufacturers in handling panic buying-related instability in their SCs in future large-scale disruptions.

2. LITERATURE REVIEW

In this section, a literature review has been conducted on SC disruptions caused by the COVID-19 pandemic.

2.1. COVID-19 Pandemic's Impacts on Global Supply Chains (SCs)

Global SCs have experienced a series of simultaneous dependent and independent disruptions throughout the COVID-19 pandemic (Paul & Chowdhury, 2020a). The disruptions across SCs can be dependent, which is concurrent or parallel, as well as independent, which is non-concurrent or sequential. For instance, a manufacturing facility in one region was partially shut down due to an outbreak of COVID-19, which caused the production capacity to drop. In 5 weeks' time, the situation was expected to improve, and the suppliers were expected to resume full operation (Paul & Chowdhury, 2020b). Then, once again, a new outbreak disrupted the continuous improvement and recovery of supply networks (Yavari & Ajalli, 2021). Thus, global SCs have been continuously impacted over time.

Global SCs have been severely impacted by the COVID-19 pandemic, the impacts and uncertainties of which are unknown at this time. SC uncertainty is exacerbated by large-scale disruptions (Chowdhury et al., 2021). Environmental uncertainties, economic uncertainties, operational and technical uncertainties, and human thinking and decision-making uncertainties have been imposed on SCs throughout the world by the COVID-19 pandemic (Rahman et al., 2021). For example, both Australia and China lost economic growth as a result of the severance of their SCs during the pandemic. In contrast, the pandemic was beneficial for countries with established suppliers in safer zones (Li et al., 2021).

2.2. SC Instabilities Due to Panic Buying During the COVID-19 Pandemic

To flatten the curve of COVID-19-infected cases, countries across the globe placed restrictions on borders and imposed lockdowns inside their borders. It was difficult to obtain raw materials from suppliers in quarantined zones. Some manufacturers have only one supplier from one location. Manufacturing facilities were impacted by such supply disruptions (Ivanov, 2021a). The production capacity could not be sufficiently increased to meet the consumer demand surge for essential products. As a strict guideline, social distance was imposed by the government and most manufacturers were unable to upgrade their infrastructure to facilitate the continuation of their work. The manufacturers were unable to increase production capacity due to disruptions in supply and demand. Due to severe losses and debt, many industries were forced to shut down operations (Paul & Chowdhury, 2020a).

As a result of the pandemic, global SCs were faced with severe fluctuations in demand for both high- and low-demand products. As the suppliers failed to supply raw materials to the manufacturers in other countries, the manufacturers could not ramp up production capacity to meet the surge in demand from consumers (Dolgui & Ivanov, 2021). In supermarkets, people purchased products that were in high demand, causing severe stockouts of such products. People hoarded toilet paper owing to the fear of stockouts of essential items.

Among the four adaptation strategies—scalability, repurposing, intertwining, and substitution—scalability (i.e., increasing production capacity) operates at the level of resources and networks for a viable SC (Ivanov, 2021b). As products such as food, healthcare products, facemasks, and ventilators were in high demand during the pandemic, it was important for manufacturers to expand production capacity as well as SC networks in order to meet the increasing consumer demand (Li et al., 2021).

2.3. Research Gaps and Problem Description

During the COVID-19 pandemic, global SCs faced severe instabilities in supply, demand, manufacturing capacity, transportation and distribution, and inventory management. In SCs, the COVID-19 pandemic had dynamic and simultaneous effects. Volatility in SCs, such as panic buying or hoarding behavior, is one of the factors that has affected retailers and manufacturers. For example, during the COVID-19 pandemic, people in Australia, during any lockdown lasting up to 3 months or more, purchased food and toilet paper out of fear. As a result of hoarding behavior and panic purchases of essential items, retailers and supermarkets ran out of essential products such as toilet paper. Due to the lack of consumer demand information, retailers and supermarkets were unable to maintain stock of essential items (Shen & Sun, 2021). Lockdowns and shutdowns prevented essential manufacturers from increasing production capacity to deal with the sudden volatility of demand and capacity. Therefore, this situation motivated the researchers of this study to understand the dynamics of panic buying-related instabilities in essential SC networks.

However, the literature lacks theoretical and methodological contributions to predict the impact of panic buying in SCs and strategies to manage such impacts. Therefore, this study aims to understand the dynamics of panic buying, their impacts on SC networks, and strategies to manage them, particularly in the event of a large-scale SC disruption such as the COVID-19 pandemic.

3. MODEL FORMULATION, PROPOSED STRATEGIES, AND RECOVERY PLANS

An ABM is presented for simulating and optimizing a typical SC for toilet paper, which allows a comparison of risks and mitigate them. SC entities are represented in the real world by a set of agents (Rahman et al., 2021). The agents coordinate the SC entities and determine the optimal values of the decision variables. The typical SC network of toilet paper was considered to fulfill incoming orders for the finished products and raw materials. The model in this study is based on hypothetical data derived from secondary data. Following are the measures used to evaluate the SC's performance:

a. Total supply chain costs (TSCCs)
b. Manufacturing costs (MCs, including the raw material costs from suppliers)
c. Inventory costs (ICs) for manufacturers and retailers
d. Transportation costs (TCs) for suppliers and manufacturers
e. Shortage costs (ShCs) at the manufacturing stage
f. Discount costs (DisCs) at the manufacturing stage.

The objective function of the optimization experiment is to minimize TSCCs. The study includes 7 suppliers, 3 manufacturers, and 18 retailers. Agents work together to meet various performance goals (such as lead times and total SC costs) in order to satisfy incoming orders from retailers. The ABM model in this paper is an extension of the model of Rahman et al. (2021). As such, the attributes and description of the model agents can be found in Rahman et al. (2021). The present study suggests four main dynamic adaptation and resilience strategies to manage panic buying-related instabilities in SCs during the COVID-19 pandemic. These strategies are as follows:

Strategy 1: Scaling up production capacity
Strategy 2: Increasing raw material supply
Strategy 3: Enhancing transportation capacity
Strategy 4: Maintaining optimal inventory

The recovery plans considered in the four scenarios (see Table 1) in this study are:

Scenario 1 (S1): In S1, the production capacity was increased up to 100% for a long period with an optimal value of the *reordering point (s_j), order size (S_j),* and *number of trucks (l).*

Scenario 2 (S2): In S2, the production capacity was increased up to 50% for a long period with an optimal value of s_j, S_j, and l.

Scenario 3 (S3): In S3, the production capacity was increased up to 100% for a couple of short-term periods during the disruptions with an optimal value of s_j, S_j, and l.

Scenario 4 (S4): In S4, the production capacity was increased up to 50% for a couple of short-term periods during the disruptions with an optimal value of s_j, S_j, and l. See Fig. A2 in Appendix for the recovery plans.

Table 1: Recovery plans in four scenarios

| Scenarios	Recovery period	Increase in production capacity
S1	Long-term	High (+100%)
S2	Long-term	Low (+50%)
S3	Short-term	High (+100%)
S4	Short-term	Low (+50%)

The optimal value of the *reordering point (s_j), order size (S_j),* and *number of trucks (l)* was determined by running a single objective optimization experiment within the simulation model using *Anylogic's* in-built optimization algorithm for each scenario (see Table 3).

4. RESULTS, SCENARIO ANALYSIS, AND DISCUSSIONS

4.1. Baseline Scenarios

This section compares the performance of the toilet paper SCs under normal and disrupted baseline conditions.

Normal baseline scenario: For better anticipation, simulation was undertaken for 5 years. As shown in Fig. 1, normal conditions were simulated in which there was no disruption and people did not panic buy essential products and the business was running normally. The shortage cost incurred was normal.
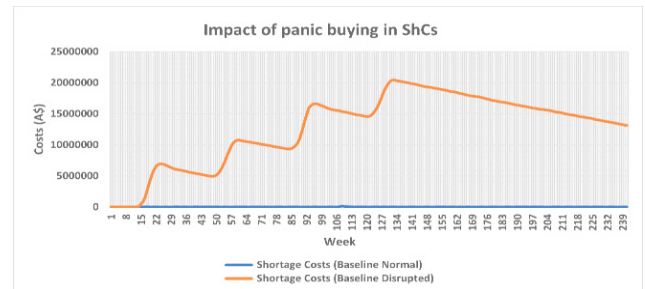
Fig. 1. Baseline scenarios (normal and disrupted)

Disrupted baseline scenario: In the simulation run for the baseline disrupted scenario, the impact of the COVID-19 pandemic was mimicked. In the days following the outbreak of COVID-19, the government imposed strict lockdowns in several places that raised fear among people, causing them to panic purchase necessities such as toilet paper. As a result of the pandemic, the demand of toilet paper increased up to 400%, manufacturing capacity degraded, and manufacturing firms struggled to obtain raw materials from suppliers due to the closure of borders. See Fig. A1 in the appendix for the assumed changes in demand due to panic buying, production capacity decrease, and supply delays. As a result of simulating a disrupted scenario (see Fig. 1), a significant increase in shortage costs in the SCs was observed, degrading the overall performance of the SCs.

4.2. Impact Analysis of Panic Buying in SCs

Simulation results in a disrupted situation, as during the COVID-19 pandemic, illustrate the impact of panic buying on the SC network of essential products. A summary of the impacts on SCs is shown in Table 2. Following the emergence of the virus, the government was forced to

implement lockdowns in several cities. People panic purchased essential products such as toilet paper in Australia, and manufacturing facilities had to forcefully shut down, and raw materials could hardly be imported. In retail outlets and super-stores, there was a severe stock-out of toilet paper due to the sky-rocketing demand. Due to manufacturers' limited production, in the simulation, the shortage cost increased by 345804.46% as there was no strategy adapted. Due to the backlog of toilet paper, the manufacturers had to offer higher discounts, resulting in a discount cost increase of 34979.46%. There were no significant increases in manufacturing costs, inventory costs, or transportation costs as production was shut down during lockdowns for months. The manufacturing firms were unable to increase inventory, and there was a deterioration in delivery support due to the scarcity of transportation and regulations. Thus, the total SC costs increased to 794.73%, which resulted in significant degradation of the SCs. In these situations, failing to meet consumers' panic buying demands led to diminished reputations and financial shocks for manufacturing firms.

Table 2: Panic buying related instabilities in SCs

	Instabilities in SC performances compared to normal situation					
	Financial performances					
	TSCCs	**MCs**	**ICs**	**TCs**	**ShCs**	**DisCs**
Variations	794.73%	+25.28%	+38.14%	-7.04%	+345804.46%	+34979.46%

4.3. Mitigation Scenarios, Recovery Plans, and SC Improvement Analysis

The strategies and recovery plans adopted in four scenarios of this study are aimed at managing the impacts of panic buying related instabilities in SCs. Optimization experiments were conducted to identify the optimal value of the reordering point, order size, and trucks for each scenario described in Table 1 to understand how to make raw materials available from suppliers, products available in manufacturing facilities, products available in inventory, and products available for retailers to purchase. For optimal values of the decision variables, see Table 3. Below is an analysis of the improvement in SCs after implementing the strategies.

Table 3: Optimal value for decision variables

Scenarios	Optimal value for decision variables		
	ROP (s_j)	**Order size** (S_j)	**Trucks** (l)
Normal situation	1000	3000	10
S1	1550	5925	16

|			
S2	1429	4493	14
S3	1449	4625	14
S4	1239	3796	12

TSCCs: The recovery plans adopted in the four scenarios of this study improved the SCs. Increasing production capacity to 100% for long periods with optimal ROP, order size, and trucks reduced TSCCs to 84.24% in S1 (see Fig. 2 and Table 4). In S1, the ROP was increased by 55%, order size was increased by 97.5 %, and the number of trucks was increased by 60% as a result of optimization experiments. Additionally, in S2 and S3, TSCCs decreased to 81.28% and 82.79%, respectively. Increasing production capacity by 100% for a few short periods when there is disruption also reduced TSCCs significantly, as opposed to increasing production capacity by 50% for a long period. Furthermore, increasing production up to 50% for a few short periods during disruptions did not yield significant reductions in TSCCs. TSCCs were significantly reduced in each scenario based on optimal ROPs, order sizes, and truck numbers.
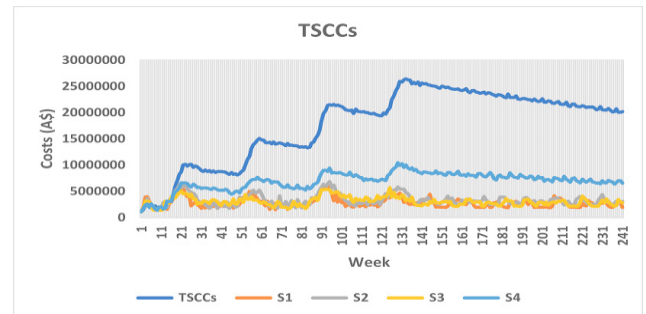

Fig. 2. Improvement in TSCCs

MCs: Table 4 indicates that in S1, S2, and S3, the MCs were slightly higher than in the disrupted scenario, but not so much in S4 (see Fig. 3). This increase can be explained by the fact that manufacturing firms produced more goods to meet increased demands caused by panic buying among general consumers. TSCCs decreased due to increased production.
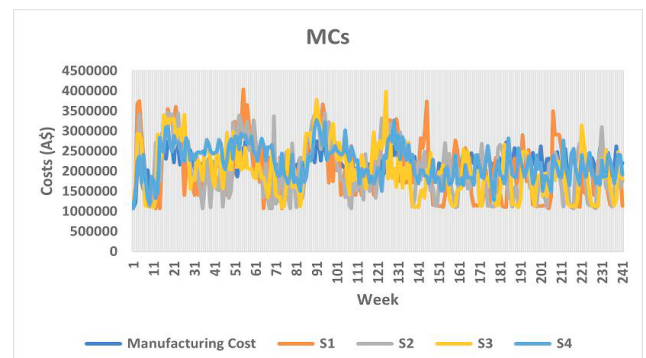

Fig. 3. Improvement in MCs

ICs: In S1 and S3, ICs increased significantly, while in S2 and S4, ICs increased slightly. As a result of S1 and S3 recovery plans, manufacturing facilities received sufficient raw materials through optimal ROP and order size, thereby increasing inventory levels in comparison to S2 and S4 (see Fig. 4).
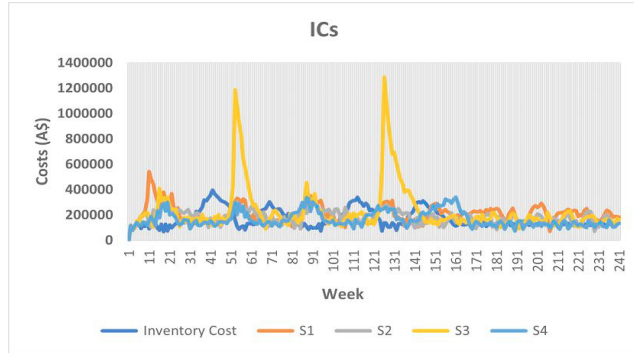

Fig. 4. Improvement in ICs

TCs: An optimization experiment was conducted for each scenario to improve the smooth delivery and distribution system. The result was that TCs slightly increased in each scenario as a result of an increased number of trucks that helped satisfy consumers' demand and reduce TSCCs (see Table 4 and Fig. 5).
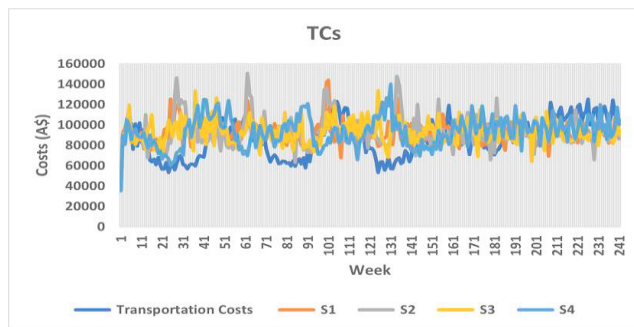

Fig. 5. Improvement in TCs

ShCs: An increase in production capacity of 100% over long periods of time (S1) significantly reduced ShCs. Table 4 and Fig. 6 show that in S2 and S3, production capacity increases by 50% for long-term periods and 100% for a few short-term periods also reduced ShCs. However, a 50% increase in production capacity did not improve SCs.
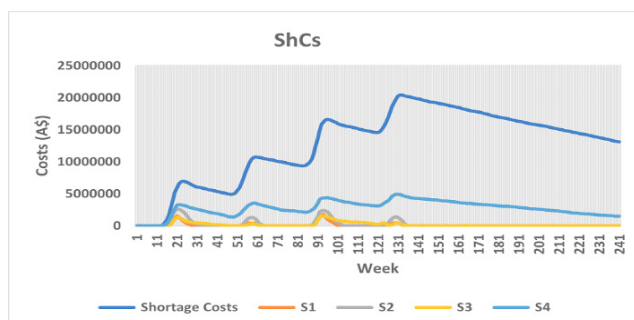
Fig. 6. Improvement in ShCs

DisCs: An increase in production capacity of 100% over long periods (S1) significantly reduced DisCs. DisCs were also reduced when production capacity increased by 50% for long-term periods and 100% for short-term periods in S2 and S3. A 50% increase in production capacity did not reduce DisCs (see Fig. 7).
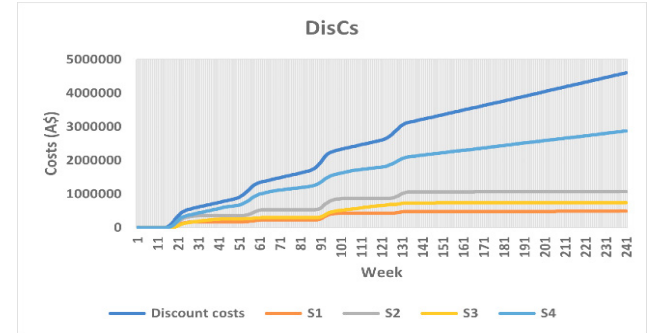
Fig. 7. Improvement in DisCs

Table 4: SC performance improvement analysis

Scenarios	SC performance improvement analysis compared to a disrupted situation					
	Financial performance					
	TSCCs	**MCs**	**ICs**	**TCs**	**ShCs**	**DisCs**
S1	-84.24%	-7.58%	+22.85%	+6.53%	-99.13%	-85.99%
S2	-81.28%	-7.82%	+8.79%	+7.45%	-98.01%	-69.65%
S3	-82.79%	-7.88%	+38.09%	+6.90%	-98.51%	-81.59%
S4	-60.96%	-0.45%	+0.32%	+8.14%	-78.22%	-39.96%

5. CONCLUSIONS

5.1. Theoretical and Managerial Implications

The study makes several theoretical contributions. First, it identified strategies and recovery plans for managing panic buying-related instability. Secondly, an ABM was developed to simulate toilet paper SCs and predict the impact of panic buying during the COVID-19 pandemic. Finally, optimization experiments were conducted within the simulation model of ABM in order to optimize several parameters and justify the strategies to improve SCs.

This study has several managerial implications.
1. Scalability strategies enable manufacturers to meet extra consumer demand. It is possible to reduce panic buying-related instabilities by increasing production capacity up to 100% in the long-term as well as in the short-term.
2. The optimal reordering point and order size help manufacturers to source more raw materials and maintain inventory at an optimal level in order to meet consumer demands.

3. Through optimization experiments, manufacturers can increase the number of transportation vehicles/trucks to efficiently deliver products to retailers.

5.2. Limitations and Future Research Directions

The study has some limitations. First, secondary data was used in this study. In future studies, primary data can be used to support the strategies. Second, consumer behavior has not been considered in this study. Including consumer behavior in future research will enhance its results. Finally, this study considered only a few recovery plans and scenarios. Future studies could consider more recovery plans to strengthen the results. Further, manufacturing companies can use the results to manage panic buying related instabilities in their SCs in the future.

REFERENCES

Arabsheybani, A., & Arshadi Khasmeh, A. (2021). Robust and resilient supply chain network design considering risks in food industry: flavour industry in Iran. *International Journal of Management Science and Engineering Management*, *16*(3), 197–208. https://doi.org/10.1080/17509653.2021.1907811

Chowdhury, P., Paul, S.K., Kaisar, S., & Moktadir, M.A. (2021). COVID-19 pandemic related supply chain studies: a systematic review. *Transportation Research Part E: Logistics and Transportation Review,* *148,* 102271. https://doi.org/10.1016/j.tre.2021.102271

Dolgui, A., & Ivanov, D. (2021). Ripple effect and supply chain disruption management: new trends and research directions. *International Journal of Production Research*, *59*(1), 102–109. https://doi.org/10.1080/00207543.2021.1840148

Ivanov, D. (2021a). Exiting the COVID-19 pandemic: after-shock risks and avoidance of disruption tails in supply chains. *Annals of Operations Research*. https://doi.org/10.1007/s10479-021-04047-7

Ivanov, D. (2021b). Supply Chain Viability and the COVID-19 pandemic: a conceptual and formal generalisation of four major adaptation strategies. *International Journal of Production Research*, *59*, 3535-3552. https://doi.org/10.1080/00207543.2021.1890852

Li, Y., Chen, K., Collignon, S., & Ivanov, D. (2021). Ripple effect in the supply chain network: Forward and backward disruption propagation, network health and firm vulnerability. *European Journal of Operational Research*, *291*(3), 1117–1131. https://doi.org/10.1016/j.ejor.2020.09.053

Paul, S. K., & Chowdhury, P. (2020a). A production recovery plan in manufacturing supply chains for a high-demand item during COVID-19. *International Journal of Physical Distribution and Logistics Management,* *51,* 104-125. https://doi.org/10.1108/IJPDLM-04-2020-0127

Paul, S. K., & Chowdhury, P. (2020b). Strategies for Managing the Impacts of Disruptions During COVID-19: an Example of Toilet Paper. *Global Journal of Flexible Systems Management, 21,* 283-293. https://doi.org/10.1007/s40171-020-00248-4

Paul, S. K., Chowdhury, P., Moktadir, A., & Lau, K. H. (2021). Supply chain recovery challenges in the wake of COVID-19 pandemic. *Journal of Business Research,* *136,* 316-329. https://doi.org/10.1016/j.jbusres.2021.07.056

Paul, S. K., Sarker, R., & Essam, D. (2018). A reactive mitigation approach for managing supply disruption in a three-tier supply chain. *Journal of Intelligent Manufacturing,* *29,* 1581-1597. https://doi.org/10.1007/s10845-016-1200-7

Saeed, K. (2015). Jay Forrester ' s operational approach to economics. *System Dynamics Review*, *30*(4), 233–261. https://doi.org/10.1002/sdr.1525

Shen, Z. M., & Sun, Y. (2021). Strengthening supply chain resilience during COVID-19: A case study of JD.com. *Journal of Operations Management*. https://doi.org/10.1002/joom.1161

Rahman, T., Taghikhah, F., Paul, S. K., Shukla, N., & Agarwal, R. (2021). An agent-based model for supply chain recovery in the wake of the COVID-19 pandemic. *Computers and Industrial Engineering*, *158*, 107401. https://doi.org/10.1016/j.cie.2021.107401

Yavari, M., & Ajalli, P. (2021). Suppliers' coalition strategy for green-Resilient supply chain network design. *Journal of Industrial and Production Engineering*, *38*(3), 197–212. https://doi.org/10.1080/21681015.2021.1883134

APPENDIX
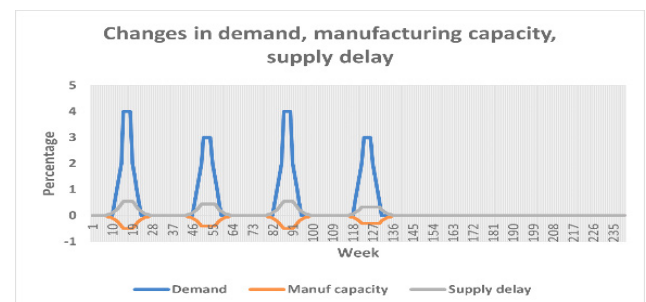
Fig. A1. Changes in demand, manufacturing capacity, and supply delay
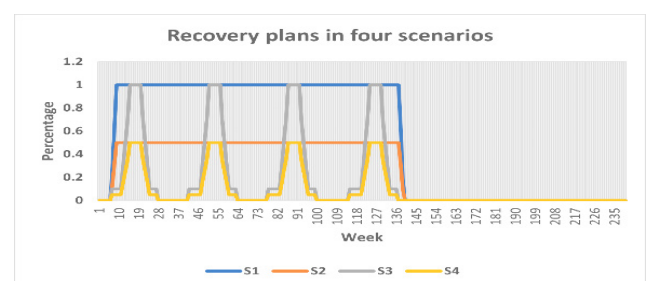
Fig. A2. Recovery plans (increasing production capacity) in four scenarios