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Design an agent-based model of the supply chain of perishable goods in the conditions of specific disruptions

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Abstract

The primary goal of this study is to design an agent-based model of the supply chain for perishable goods during the occurrence of specific disruptions. This study is practical in terms of aim and qualitative in terms of data collection method. To validate the model, the views of the statistical population including prominent university professors and manufacturers of perishable goods and experts with experience and expertise in the area of specific disruptions of the perishable goods supply chain were used. Additionally, the snowball method was used to select the sample. In total, the views of 18 experts were used. Agent-based modeling was done using NetLogo software. In this modeling, all supply chain disruptions of perishable goods such as disruptions at the macro level (change in consumer behavior), demand, production, supply, transportation, information, and Financial were considered. Also, according to each disruption, strategies to mitigate the effects such as blockchain, robotics, etc. were determined. The results of agent-based modeling show that the simultaneous use of different strategies in the perishable goods supply chain during the occurrence of specific disruptions significantly reduces the effects of specific disruptions on the perishable goods supply chain. Vaccination along with the application of other strategies such as the use of blockchain, robotics, discounts, subsidy, online purchase methods, non-cash payment methods, awareness of product safety, green packaging, and employee safety and health have significantly reduced the effects of specific disruptions on the perishable non-necessary goods supply chain. In addition, according to the findings of the research, among the various strategies, the discount has played the most significant role in reducing the influences of specific disruptions on the supply chain of non-necessary perishable goods.

Keywords: Agent-based modeling, Goods supply chain, Perishable goods, Specific disruptions, COVID-19 pandemic

Paper Type: Original Research

1. Introduction

Supply chain design has been considered in many industries in recent years to reduce costs and improve efficiency (Li and Hai, 2019). In supply chain design, it is primarily assumed that the life of goods is unlimited, while many goods (food, medicine, human blood, vaccines, etc.) are perishable (Dai et al., 2018). Many perishable materials and goods are transferred in the supply chain from supplier to manufacturer, retailer, and customer every day. Given the limited life span, stochastic market demand, and limitations in the storage of perishable goods, their supply chain design has specific and unique challenges (Deng et al., 2019). Due to an increase in the competitive environment, various uncertainties in the perishable goods supply chain such as demand changes, waiting time, late delivery, order cancellation, changes in the market, changes in product demand, production fluctuations, loss of product quality, natural hazards, etc. are identified. These uncertainties cause the inefficiency of the supply chain (Bhardwaj & Agrawal, 2020). Thus, one of the most challenging parts of supply chain management is designing the perishable goods supply chain. Given the short life cycle of these goods, activities such as ordering, pricing, storage, etc. in the supply chain become very complicated. Additionally, one of the problems in the management of the perishable goods supply chain is that keeping a large amount of them in inventory has three major negative impacts: (1) if the products are wasted, the cost of the supply chain will increase, 2) the waste of perishable goods has negative environmental impacts and (3) the quality of these products decrease immediately after production

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(Aghaei Fishani et al., 2022). In addition to the issues mentioned above regarding the problems of the perishable goods supply chain, supply chains in recent years have faced certain disruptions that have significantly jeopardized their operational performance and the existence of individual members. There are different types of supply chain disruptions and they can be classified as general and specific disruptions (Ivanov, 2020). General disruptions in the supply chain may be caused by communication failures, excess inventory, volatility in demand, etc., while specific disruptions may also occur due to catastrophic events (earthquakes, floods), and epidemics (swine flu and COVID-19). The coronavirus pandemic has recently threatened the interconnected global supply chain. Several national quarantines have slowed down or even temporarily stopped the flow of raw materials and goods, thereby disrupting production. Currently, one of the most vulnerable groups in the supply chain due to the coronavirus pandemic is the perishable goods supply chain (Shanker et al., 2021). The most important current disruptions of the perishable good supply chain due to the COVID-19 pandemic include price fluctuations, supply and demand uncertainties, labor shortages, closure of markets and manufacturing plants, interruption in the distribution network, and Information fluctuations which directly and indirectly impact on the health and safety of consumers (McEwan et al., 2020; Pehin Dato Musa & Basir, 2021). Given what was stated above, several components in the perishable goods supply chain dynamically interact with each other and the environment outside the system, and minor changes in one component can have several consequences for the chain. It means that the behavior of each component depends on that of other components. It makes the chain investigation and its modeling complicated. Thus, in scenarios that require solving complex problems or controlling complex systems, decision-making decomposition into agent reasoning and problem-solving through negotiation are perceived as a special type of heuristic problem-solving. The overall behavior of the system is obtained from the behavior of individual agents. Thus, the appropriate model of the present study seems to be agent-based. Therefore, given the purpose of this study, which is to design a model of the perishable goods supply chain during the occurrence of special disruptions such as the coronavirus pandemic, the researcher is looking for an answer to the question of how this model can be simulated through the agent-based modeling approach, and whether it is possible to provide a proper estimate of the perishable goods supply chain in the conditions of special disruption based on the results of the model simulation?

2.Literature review

Abbasian et al. (2023) used a bi-objective optimization model to solve location, inventory, and routing (LIR) problems in the design of a resilient-sustainable perishable food supply network (RSPFSN). For the resilience and sustainability of PFSN in disruptive events, they used a dynamic pricing strategy along with minimizing total cost and CO2 emissions. The results showed that for the resilience and sustainability of the dairy supply chain, the dynamic pricing strategy, according to the traffic conditions, can lead to a 20% improvement in cost and CO2 emissions. Nikounam Nezami et al. (2023) investigated the streams and performance of the studies conducted on the types of effects of the COVID-19 pandemic and different strategies for managing perishable goods supply chain disruptions during 2 years (2020-2022) using bibliometric and network analysis based on data set from Scopus database using VOSviewer software. Citation and network analysis showed that resilience and sustainability are the primary streams of studies in articles with high citations of the perishable goods supply chain. Also, strategies such as price discounts, information sharing, online delivery systems, financial sustainability, localization of the perishable goods supply chain, shortening the perishable goods supply chain, digitalization of processes, use of digital platforms, and capacity building in waste management methods were commended. Hashemi-Amiri et al. (2023) used a bi-objective optimization model for the integrated supplier selection, scheduling, and vehicle routing problem in a three-tiered perishable food supply chain (PFSC) network with multiple products under uncertainty caused by COVID-19 is addressed. The results show that the proposed model provided a suitable balance between two opposing objectives by determining the most reliable suppliers, the best feasible production schedule, and the optimal distribution flows in the PFSC network to provide perishable food products to customers in a timely and sufficient manner. Abdolazimi et al. (2023) used the TOPSIS technique to select the most suitable locations, minimize the average delivery time of blood among different levels, and optimize the cost associated with blood transportation and blood maintenance. The results showed that adding mobile blood facilities would mitigate the delivery time. Bø et al. (2023) examined the effects of the Covid-19 crisis on delivery security and firms' preparedness and responses in Norway. For this purpose, they used a semi-structured interview. The results showed that the main challenges of companies are sudden changes in demand. To control disruptions, they suggested good and long-term relationships with upstream and downstream supply chain partners. Cariappa et al. (2022) examined the effects of quarantine due to COVID-19 in India through Interrupted time series analysis with survey results of 729 consumers, and 225 farmers and combining literature evidence on food loss as well as food waste. The results show that the COVID-19 pandemic has caused a significant change in prices and panic buying. which has led to excessive wastage of food. For this purpose, they recommended improving the capacity and collective resilience of small-scale production systems through institutions, policies, and reforms. Shafiei et al. (2022) used the views of academics to identify the most significant risk, and then, used the views of pharmaceutical, food, and dairy industry experts to determine mutual relationships between risks. Then, fuzzy sets were used to consider the uncertainty of experts' judgments. Generally, three geopolitical risks, three environmental risks, seven infrastructural risks, three supply-side risks, eight production risks, and five demand-side risks were selected for investigation. Finally, the results showed that fifteen risks include product perishability period, unhealthy work environment, supply of unit resources, supplier bankruptcy, delay in delivery of raw materials, working hours, insufficient road infrastructure, power outage, labor strike, currency fluctuations, increased COVID-19, fuel price fluctuations, natural disasters, increase in transportation fare, and uncertainty of demand were categorized in the cause group.Also, the results show that fourteen risks include competitive risks, changing consumer preferences, political instability, market share reduction, lean inventory, war threats, warehouse disruption, distribution network failure, labor shortage due to being infected with COVID-19, new restrictions due to the outbreak of COVID-19, information technology failures, machinery breakdowns, seasonal changes, and transport accidents were categorized in the effect group. Sharma et al. (2022) investigated the impact of the supplier's view on the adoption of sustainable practices and supply chain performance. They used a resource-based view to explain how information sharing with customers and suppliers and supply chain traceability affect the view. The mentioned study analyzed 263 responses from a survey of UK retail (grocery) store managers for perishable food during the COVID-19 pandemic. The results revealed that both supply chain traceability and information sharing (customers) positively affect the view. Moreover, the view positively affects the adoption of sustainable practices and speed and positively affects supply chain performance. However, sharing information with customers did not significantly affect the performance, and sharing information with suppliers did not have a significant relationship with the view. Kumar et al. (2022) examined the impact of the COVID-19 pandemic on cold supply chains theoretically and experimentally considering seven criteria. The developed model was analyzed using the SWARA-based multimoora approach. The results revealed that "structural impact" and "commercial and financial impact" are the two characteristics affected by the cold supply chain during COVID-19 pandemic. Additionally, COVID-19 disrupted the cold supply chain structure due to the interconnections between cold supply chain partners such as suppliers, retailers, distributors, and consumers. Also, it disrupted all financial and economic activities. Cold supply chains were forced to reduce a part of their production activities due to COVID-19 or shut down. The strategies of "developing a safer and healthier work scenario for cold chain partners" and "successful monitoring and implementation of COVID-19 protocols" are two significant recommended strategies that may help cold supply chain management in reducing the impact of COVID-19. Kumar et al. (2021) investigated the uncertainties and risks during the COVID-19 pandemic, and then, identified the strategies to reduce risks for the management of sustainable perishable food supply chain (social and economic dimension) in such conditions. Finally, the identified strategies were prioritized using the fuzzy best-worst method (F-BWM). Among risk reduction strategies, "participatory management", "continuity of active business planning", and "financial stability" were the best risk reduction strategies. Khan and Ponce (2021) investigated the impact of the COVID-19 pandemic on the perishable food supply chain in Ecuador. The data were collected from 298 questionnaires. Then, the data were processed using the structural equation model. The results show that the perception of personal risk (PPR) induced by the impact of COVID-19 has caused perishable food supply chains to adopt preventive policies (PO) to prevent contagion and ensure the performance of companies. Also, circular economy practices contribute to the high performance of the perishable food supply chain. Karwasra et al. (2021) identified and evaluated key drivers of SCU in a dairy SC. First, by reviewing past literature and experts' opinions, 12 key drivers of SCU were identified. Then, using interpretive structural modeling (ISM) and a graph theory approach (GTA), they evaluated the key drivers of SCU in a dairy SC. The results showed Outsourcing, Short Product Life Cycle, Demand Disruption, Supplier Reduction, and Supplier Uncertainty as the most influential key drivers of SCU in the dairy supply chain. Zhu and Krikke (2020) used dynamic system simulation to investigate a three-layer cheese supply chain. Thus, three scenarios that cause product shortages were simulated. Seven balanced feedback loops and two enhanced feedback loops were identified from the simulation model. Also, they identified four dominant loops that facilitate the generation of endogenous demand through the feedback loop dominance analysis. To reduce the negative impact of endogenous demand, they suggested that information sharing that causes endogenous demand should be stopped and a strategy to support decision-making should be used.

Table 1. Research conducted in the field of research

Reference	Year	Methodology	Type of perishable goods supply chain	Disruption of perishable goods supply chains	Disruption management strategies
Abbasian et al.	2023	bi-objective optimization model	Dairy supply chain	Logistical Disruption	Dynamic pricing strategy
Nikounam Nezami et al.	2023	Qualitative	Food supply chains	Demand, Supply, Logistical, Financial, Waste management and information Disruption	Price discounts + online delivery systems + financial sustainability + localization of the perishable goods supply chain + shortening the perishable goods supply chain + digitalization of processes + use of digital platforms
Hashemi-Amiri et al.	2023	Bi-objective optimization model	Livestock supply chain	Demand and Supply Disruption + routing problem	Collecting and analyzing data + Demand and supply prediction + installing transshipment facilities located between the manufacturer and retailers
Abdolazimi et al.	2023	TOPSIS	Blood supply chain	Demand Disruption	Adding mobile blood facilities
Bø et al.	2023	Qualitative	food and pharmaceutical supply chains	Demand Disruption	long-term relationships with upstream and downstream supply chain partners
Cariappa et.al.	2022	Interrupted time series analysis	Food supply chain	Waste Increase	Collective resilience of small-scale production systems through institutions, policies and reforms
Shafiei et al.	2022	Fuzzy DEMATEL	Pharmaceutical, food, and dairy supply chains	Demand and Supply Disruption + Perishability period of products	New propaganda, discount, new products, innovative marketing strategies + multiple-sourcing, making a contract with backup suppliers + Use technologies
Sharma et al.	2022	Quantitative (Linear Regression)	Food supply chain	Waste Increase	Information Sharing with Customers & Suppliers + Information Gathering and Tracking Supply chain
Kumar et al.	2022	SWARA-based Multimoora approach	Cold supply chains	Production Disruption	Development of safe and healthier work + Monitoring and implementation of COVID-19 protocols
Kumar et al.	2021	Fuzzy best-worst method (F-BWM)	Food supply chain	Market Disruption + Shortage of Resources + HR Disruption	Collaborative management+ proactive business + continuity planning + Financial Sustainability
Khan and Ponce	2021	PLS-SEM	Food supply chain	Demand and Price Disruption	Preventive policies (PO) + Circular economy practices
Karwasra et al.	2021	ISM and GTA	Dairy supply chain	Demand and Supply Disruption	Supply chain Collaboration
Zhu & Krikke	2020	System dynamics	Cheese supply chain	Endogenous Demand	Loosely coupled strategy

2.1. Research gap

According to the above-mentioned literature, none of the previous studies have focused on the design of the agent-based model of the supply chain for perishable goods under specific disruptions has not been done. Although many studies have been conducted on necessary perishable goods such as dairy products, blood, etc, little attention has been paid to unnecessary perishable goods. In addition, in most past research, only a few cases of specific disruptions such as supply and demand disruptions have been addressed (Zhu & Krikke. (2020), Karwasra et al. (2021), Abdolazimi et al. (2023)). To design the supply chain of perishable goods, it is necessary to examine all specific disruptions on demand, supply, production, logistical, financial, information, and macro level (change in consumer behavior) that this review has not been done until now. Also, disruption management strategies in the supply chain of perishable goods have not been done comprehensively so far. The main contributions of this research can be summarized as follows:

- Designing an agent-based model of the supply chain for perishable goods in the conditions of specific disruptions. from raw materials supply to delivery of final products to customers, which is compatible with real-world assumptions. To the best of our knowledge, this paper is the first to consider all specific disruptions in the supply chain of perishable goods.

- Integration of different strategies to reduce the effects of specific disruptions on demand, supply, production, logistical, financial, information, and macro level (change in consumer behavior) in the supply chain of perishable goods that have not been covered in other previous studies.
- Assessing the impacts of the use of different strategies such as blockchain, robotics, discounts, subsidies, etc, on the behavior of agents (suppliers, producers, stores, distributors, retailers, returned goods collection centers, recycling centers, trash-disposal centers) have not been conducted in other previous studies.

3. Methods

Since the primary purpose of the study is to design a perishable goods supply chain model during specific disruptions, this study is considered applied in terms of its purpose. Also, this study needs to collect people's views and views and study documents regarding the studied subject. Accordingly, it is a qualitative study regarding the method of data collection. Also, due to the presentation of an agent-based model, the study method is based on design science. To confirm the model, the views of prominent university professors and manufacturers of perishable goods and experts with experience and expertise in the area of specific crises of the perishable supply chain such as COVID-19 were used. Also, the snowball method was used to select research experts. The primary criteria for selecting these experts were theoretical mastery (level of specialized knowledge) and having scientific experience in the perishable goods supply chain. After conducting interviews with each of the identified experts, they were asked to introduce other qualified people to us. In total, the views of 18 experts were used.

Table 2. Operational definition of research experts

	View 1	View 2	View 3
Education	Ph.D. and higher	Master and higher	Master and higher
Employment history	Less than 20 years	Less than 20 years	Less than 20 years
Job rank	University professor	Top manager	Manager
Number of experts	7	6	5

In this study, the agent-based modeling method was used in NetLogo-6.3.0 software. First, the agents were defined and created in the simulation environment. Then, the designed model was validated so the coded model in the software was compared with the documentation and the conceptual model of this study. Then, the coding errors and mistakes were corrected. Finally, the different implementation scenarios and the results were discussed.

3.1. Stages of Research

According to the research steps (Fig 1), after a literature review and interviews with experts, 7 types of effects of COVID-19 on the supply chain of perishable goods were identified. These 7 disruptions include disruption at the macro level (change in consumer behavior), disruption in demand, disruption in production, disruption in supply, disruption in information, disruption in transportation, and disruption in financial. After identifying the disruptions, different strategies were identified to mitigate the impact of disruptions in the supply chain of perishable goods. Also, to confirm the disruptions and different strategies of the supply chain of perishable goods, a model was drawn and approved by the experts (Fig 2). In addition, in the last step, agent-based modeling was done.

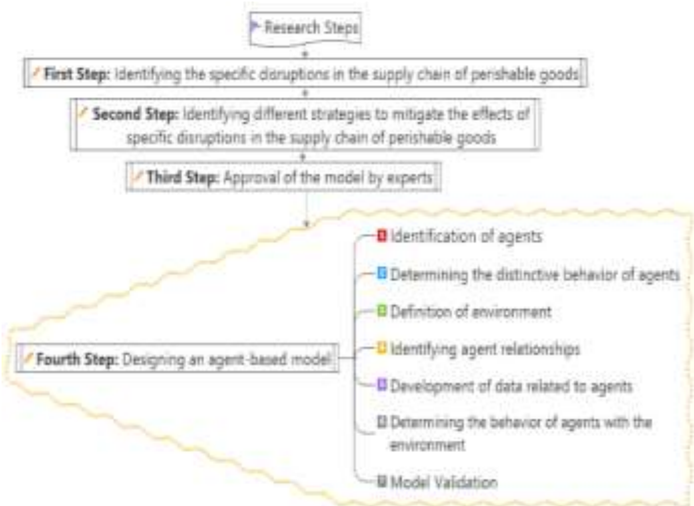

Figure 1. Research Steps

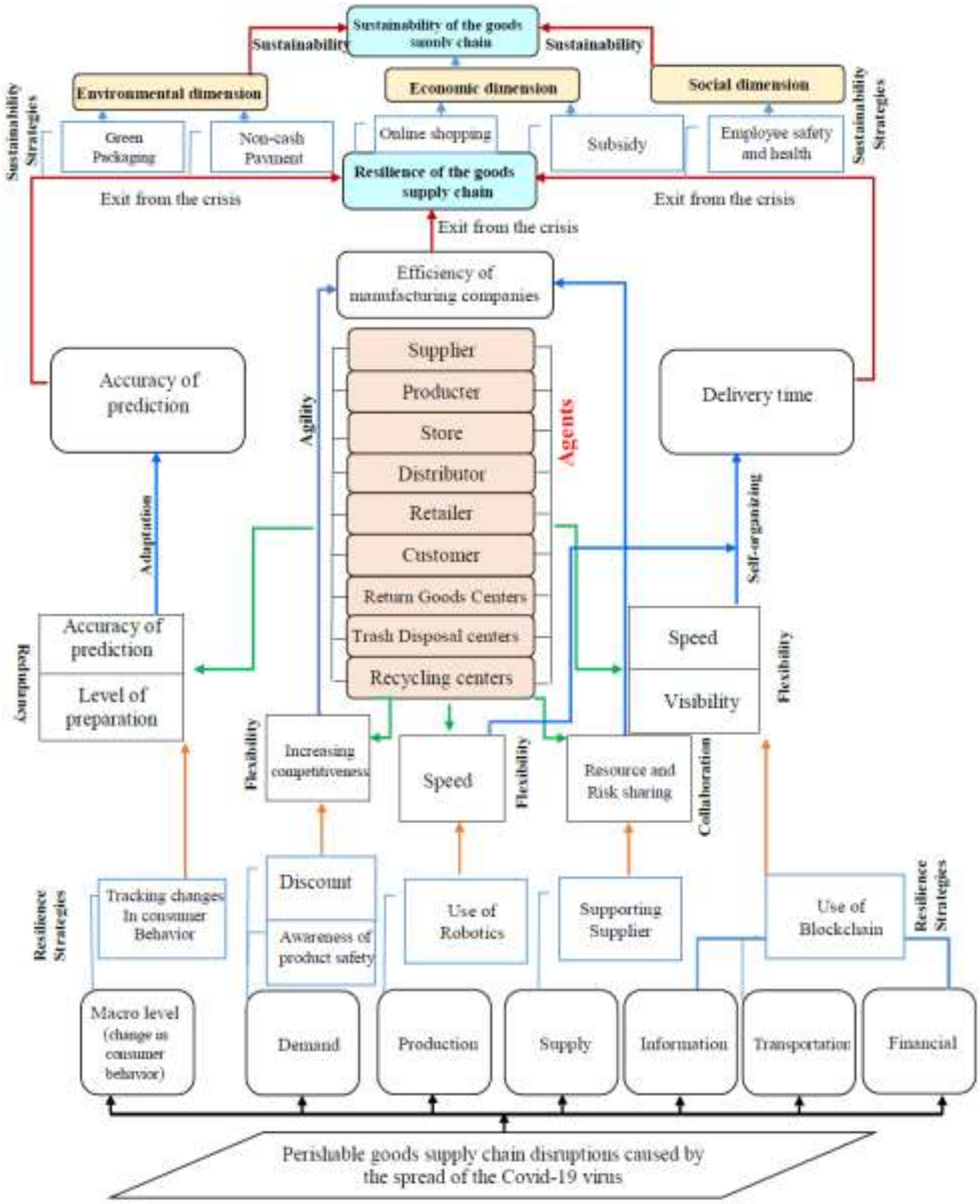

Figure 2. Conceptual model

4. Research findings

To model the agent-based model of the perishable goods supply chain during disruptions caused by COVID-19, NetLogo-6.3.0 software was used. Agent-based modeling in this study is based on these three parts:

- Agent
- Environment
- Interaction between agents

1) Agents

In this study, based on theoretical foundations and experts' views, 9 agents were determined, so each agent represents a type of behavior, based on their characteristics (type of perishable goods (necessary; unnecessary), classification of goods (kg; quantity), products (number), demand (manufacturer, store, distributor, retailer, and customers) and supply (suppliers). Table 3 shows the agents of the simulation model and their symbols.

Table 3. definition of research agents

Number	Agents	The Symbol in coding	The color of the agent in coding
1	Supplier	Supplier	white
2	**producer**	producer	Magenta
3	Store	Store	Cyan
4	Distributor	Distributor	Red
5	Retailer	Retailer	pink
6	Return Goods Centers	Return Goods	Blue
7	Recycling centers	Recycle	Green
8	Trash Disposal centers	Trash Disposal	yellow
9	Customer	Customer	Magenta- cyan- yellow- red- blue- brown

2) Environment
The simulation environment in this study includes the behavior and interactions between the members of the supply chain and the consumers of perishable goods in Shiraz City. It has been defined as 36 ticks in the software environment.
3) Interaction between agents
To investigate the interaction between the agents (behavior patterns), IF-else rules and the ASK command were used. Figure 3 shows an example of coding about interactions between agents.

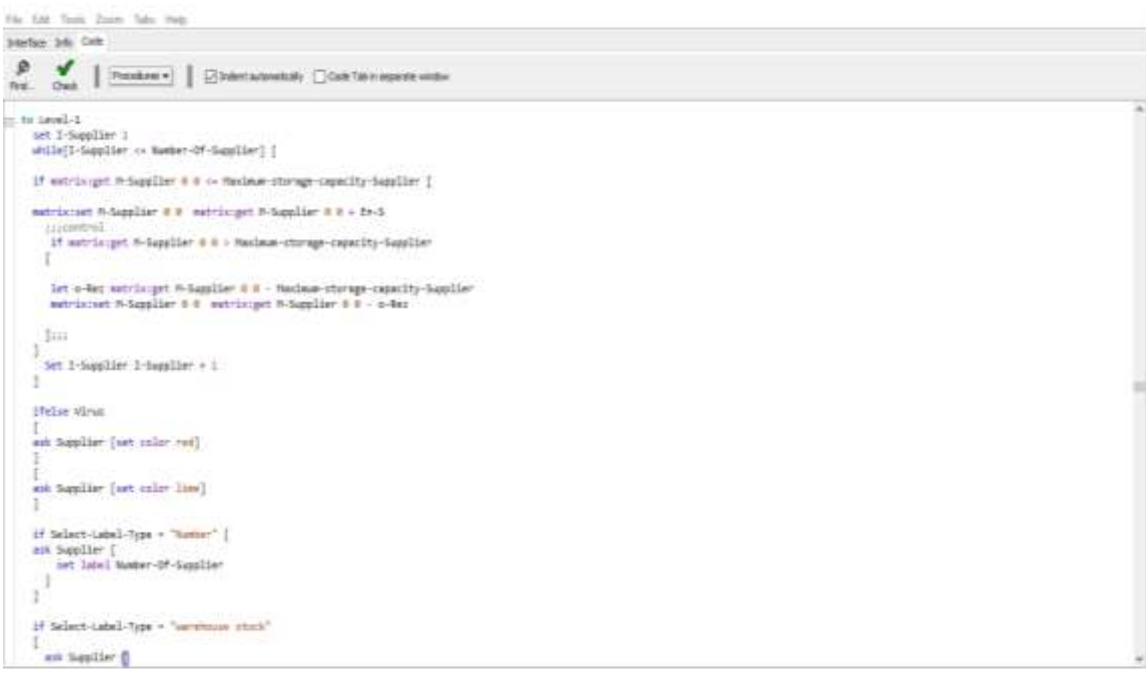

Figure 3. An example of coding interactions between agents in the Netlogo software environment

4.1. Implementation of the model

The implementation of the model includes two parts: preparation and implementation. The details of each are explained below:

1. Model preparation

The startup commands were done to prepare the environment (preparation stage), before simulation and implementing the model using the SETUP button. At the beginning of the simulation, the parameters of inputs, sliders, and on/Off switches were set so the user could observe and check the results in different conditions. Inputs and sliders include: the number of suppliers, Producers, Stores, distributors, retailers, consumers, returned goods collection centers, recycling centers and trash disposal centers, the number of products, demand (Producer, Store, distributor, retailer, and customer), shelf life of products, level of pollution, health and safety of products, level of robotics, awareness of the safety of perishable goods, accumulation of products (maximum), costs of product storage and transportation, and costs of firing and hiring labor. Also, On/Off switches include product type (necessary/unnecessary), product unit (kg/quantity), virus (On/Off), discounts (On/Off), vaccination (On/Off), purchase methods (online/in-person), payment type (cash/non-cash), and packaging type (green/non-green).

By executing the preparation command, the following commands are executed:

Behavior settings: The types of behavior of perishable goods supply chain agents can be observed and investigated with the introduction of the virus into the model, and then, with vaccination along with other strategies such as discounts, subsidies, using robotics, changing the purchase method, and type of payment.

Time settings: Based on the values of Ticks according to the defined pattern, the desired number of ticks is defined.

Patch settings: To show the relationship between agents in simulation ticks, the number of agents and their values (inventory and cost) were created.

2.Execution commands

Using the GO button, this operation is executed in the software. This section includes commands and operations that calculate the impact of each variable on each other during execution and continuously change the values determined in line with the conclusion. The coded commands in this section are as follows:

1- The command related to the condition of stopping the simulation, which is manual and automatic in this model, is defined as 120 ticks or 120 months manually. It is also automatically defined as 36 ticks or 36 months. The command to execute the model automatically is that the virus enters the model from Tick No. 12 (12 months) and vaccination is done from Tick No. 24 (24 months), and the changes in each case can be observed for 36 months.

2-Commands related to the change and movement of actors in the software environment;

3- After executing the simulation, the behavioral patterns and values of each actor will be analyzed in certain values.

4.2. Results (outputs) of model execution

In this step, the real values of the research variables were entered into the simulation model, and the model was executed. All data are 30 days old. Figure 4 shows the model inputs and Figure 5 shows the simulation results.

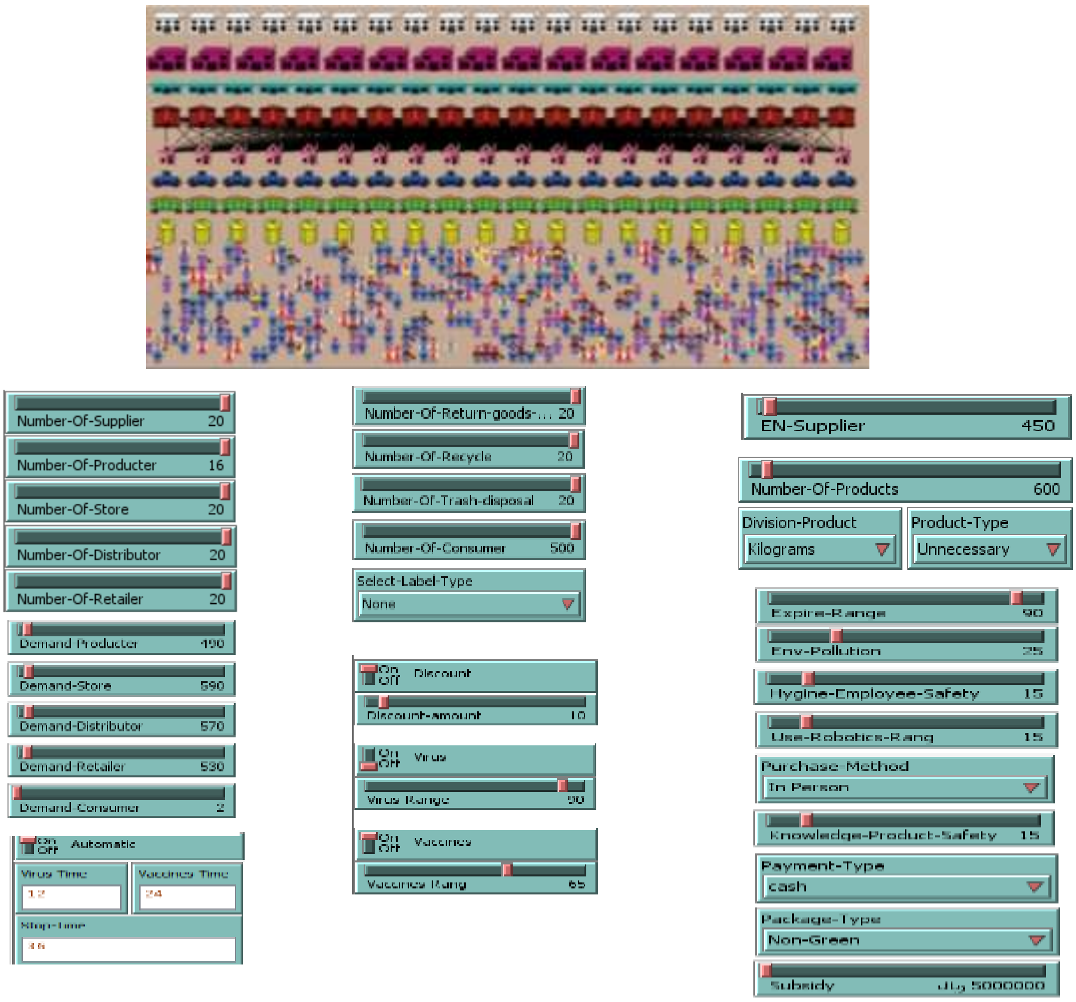

Figure 4. A view of the simulation model entries in Netlogo software

As shown in Figure (4) and Table (4) of model inputs, 20 suppliers, 16 producters, 20 stores, 20 distributors, 20 retailers, 20 returned goods collection centers, 20 recycling centers, 20 trash-disposal centers, and 500 consumers, product unit per kilogram, type of unnecessary product, 600 perishable goods, 450 supplies, 490 producter demands, 590 store demands, 580 distributor demands, 550 retailer demands, and 2 customer demands were entered into the model as initial values.

Table 4. initial values of the simulation model

Agents	Producter	Number of agents	16	Number of perishable goods	600	demand	490	Total demand	490×16=7840	Total supply	450×20=9000
	Store		20				590		590×20=11800		
	Distributor		20				580		580×20=11600		
	Retailer		20				550		550×20=11000		
	Customer		500				2		2×500=1000		
	Return Goods Centers		20				-		-		
	Recycling centers		20				-		-		
	Trash Disposal centers		20				-		-		
Virus infection rate	%90	Vaccination	%65	Product Type	Un-nec-es-sary good s	discount	%20	subsidy	5,000,000 Rials	use of robotics	%15
Expire range	%90	Knowledge of the safety of perishable goods	%15	Hygine-Employee-safety	%15	Payment Type	cash/n on-cash	Package Type	Green/non - green	purchase methods	in-per-son/Online

Figure (5) shows the generated values of the model variables in the simulation process. Black color shows the suppliers, Gray shows the producers, red shows the stores, Orange shows the distributors, Purple shows the retailers, Blue shows the returned goods collection centers, Green shows the recycling centers, Pink shows the trash disposal centers (landfills), and yellow shows the consumers.

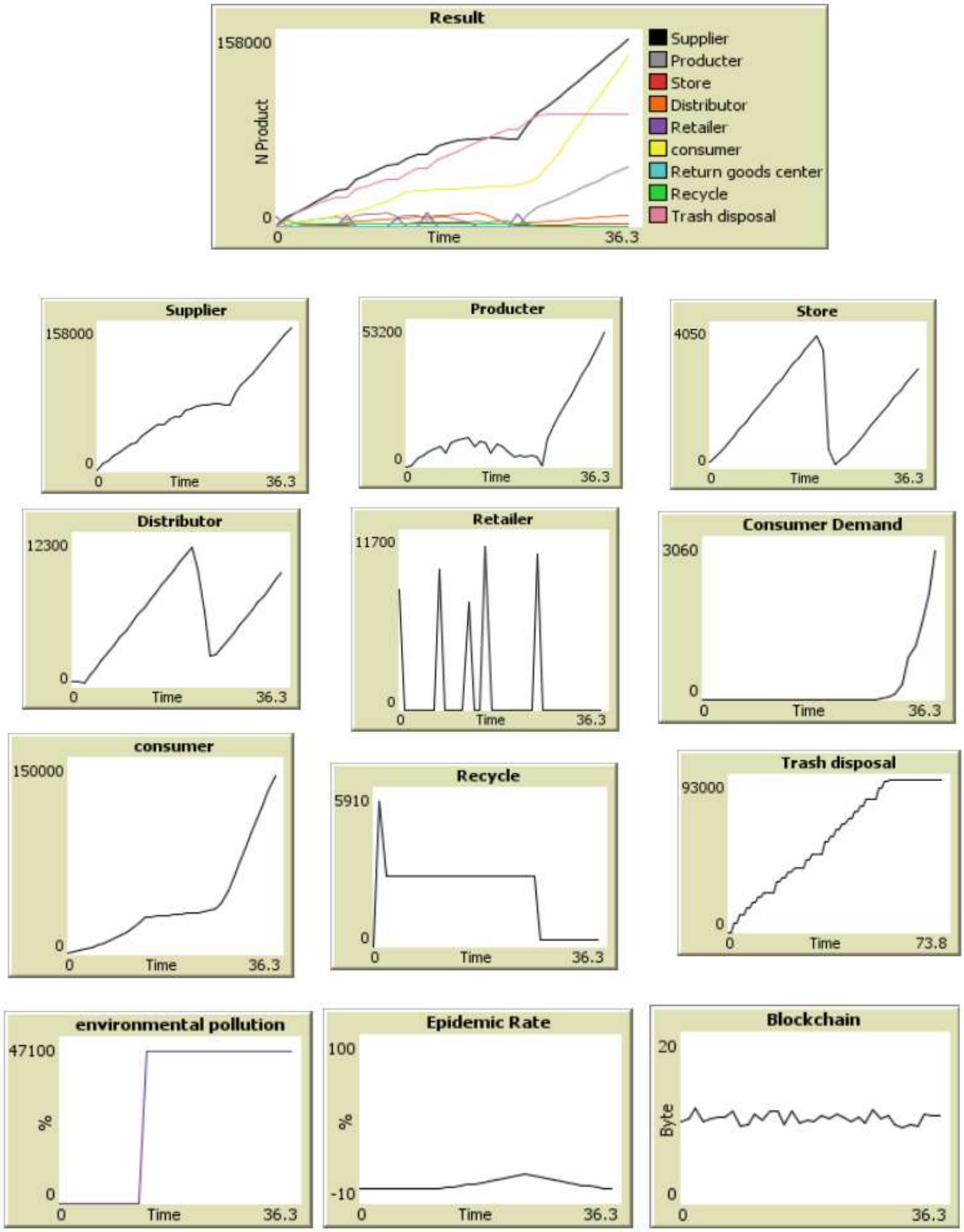

Figure 5. A view of the outputs of the simulation model of perishable goods in Netlogo software

After the completion of the simulation operation, as seen in the simulation output in Figure (5), the model outputs remain unchanged after 36 ticks. First, the simulation starts, and after 12 ticks, the virus enters the model, and after 24 ticks, vaccination begins. The COVID-19 virus has caused a change in the demand pattern, primarily for retail sales of perishable goods (necessary/unnecessary). Hence, it is difficult to predict and requires adaptive measures in retailers. In the studied model, the COVID-19 virus with a rate of 90% has led to a severe stagnation in the purchase of unnecessary perishable goods in retailers (stores, supermarkets, etc.).However, as the virus enters, in-person purchase methods, the type of cash payment, the type of non-green packaging, subsidy (5,000,000 Rials), the rate of using robotics in the production line (15 percent), the shelf life of products (90 percent equals to 27 days), health and safety of employees (15 percent), and awareness of the safety of perishable goods (15 percent) should be applied. We face a sharper decline in demand and an increase in expired goods in retailers (increase in accumulation of goods). Due to an increase in expired goods, landfilling of unnecessary perishable goods has increased and recycling has decreased, resulting in an increase in environmental pollution by 47%. We used different strategies to reduce the impacts of certain disruptions on the perishable goods supply chain. For this purpose, 24 ticks of vaccination were started. With the start of vaccination and applying blockchain and changing online purchase methods, non-cash payment type, green packaging type, subsidy (10,000,000 Rials), discount (20%), the rate of using robotics in the production line (35%), health and safety of employees (35 percent), and awareness of the safety of perishable goods (35 percent), the demand for unnecessary perishable goods increased and the expired goods decreased on the side of retailers (reducing the accumulation of goods). Thus, by using different strategies, relative stability of landfills, and thus, environmental pollution is observed. Generally, due to the unknown nature of certain disruptions such as the coronavirus pandemic, the behavior of the actors caused a sharp decrease in the demand of consumers of unnecessary goods. Then, using different strategies (vaccination, blockchain, using robotics, discounts, online shopping, non-cash payment type, green packaging, subsidy, etc.) caused an exponential growth in consumer demand for unnecessary goods. The increase in consumer demand for unnecessary perishable goods has caused a reduction in expired goods on the part of retailers, and a reduction in the accumulation of expired perishable goods has caused a relative stability in landfills and environmental pollution.

4.3. Model validation

The method proposed by Rand and Rust (2011) was used to validate the agent-based model. Based on this method, the coded model in the software was first compared with the documentation and the conceptual model of this study. Then, the coding errors and mistakes were corrected and the components of the program were checked and the errors were resolved. In NetLogo software, the model is coded in a way that when an error occurs in the input data, the model announces an error message to the observer (user). To examine the general behavior of the simulation model, different data were assigned to the input variables. Then, the outputs of the simulated model were compared with the concepts and behavioral rules of the model (Reference mode). For example, based on the theoretical foundations and experts' views and views, the demand for unnecessary perishable goods increases at the end of the simulation process, and expired goods in retailers reduce with increasing the rate of discount. This scenario was executed in the model and the simulation outputs confirmed the mentioned claim.

5. Conclusion

Since perishable goods make up a significant portion of any country's GDP, the GDP of many countries has faced a serious decline during the COVID-19 pandemic, statistical evidence shows that COVID-19 has negatively affected the GDP of Iran, India, France, China, Singapore, and other countries. These problems have made researchers worldwide study more closely the disruptions in perishable goods supply chains caused by the COVID-19 pandemic and develop strategies in this regard. This present study designed an agent-based model of the supply chain for perishable goods during the occurrence of specific disruptions. Also, this research is the first attempt to manage specific disruptions in the supply chain of unnecessary perishable goods. In previous studies, only one or several specific disruptions in the supply chain of necessary goods have been investigated. For example, Bø et al. (2023), Abdolazimi et al. (2023), Shafiei et al. (2022), and Karwasra et al. (2021) investigated disruptions in the supply and demand side for necessary goods. In this research, all specific disruptions are considered in the modeling. These disruptions include disruptions at the macro level (change in consumer behavior), demand, production, supply, transportation, information, and financial. In addition, in this research, for the first time, a mitigation strategy has been considered according to each disruption, for example, to reduce the disruption on the demand side, mitigation strategies and customer awareness of the safety of perishable non-necessary goods have been considered.

Based on real data, the results of agent-based modeling show that vaccination along with the application of other strategies such as use of blockchain, robotics, discount, subsidy, changing in-person shopping to online shopping method, changing the cash to non-cash payment method, changing non-green to green packaging method, awareness of product safety, and employee safety and health caused a significant reduction in the effects of specific disruptions on the perishable goods supply chain. Other results of this research showed that, among the different strategies, the discount has played the greatest role in reducing the effects of specific disruptions on the perishable non-necessary goods supply chain. Therefore, according to the research results, it is recommended that managers of the perishable goods supply chain persuade retail stores to increase their online ordering and payment capabilities in addition to seriously pursuing the issue of vaccination of employees in the production sector and other parts of the perishable goods supply chain. Also, consumers of unnecessary perishable goods are faced with job loss and reduced income, change in consumption habits, and thus, reduced purchase of unnecessary perishable goods during special disruptions such as COVID-19. Perishable goods supply chain managers are recommended to encourage consumers to buy unnecessary goods by applying a variety of discounts. Also, according to the results of the simulation, governments should take measures to make subsidies purposeful so companies in their supply chains can use blockchain and robotics more (due to high costs) and consumers of unnecessary perishable goods can buy more by receiving subsidies. Moreover, to increase the safety and health of employees in the perishable goods supply chain, it is recommended that the perishable goods supply chain managers provide disinfectants and personal protective equipment (such as latex gloves, face shields, and appropriate respiratory aids (such as N95 masks) for employees and put the insurance coverage for all employees on their agenda. Also, to increase consumer awareness of product safety, perishable goods supply chain managers are recommended to provide clear information related to the safety and health of perishable goods during COVID-19 through websites, applications, and virtual networks to consumers.

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