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An Multi-agent-based Model for Consumer Panic Buying Behavior

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Abstract: With the increase of natural disasters and man-made threats, panic buying phenomenon is also on the rise, causing serious impacts on social stability, economic order, business management and consumer psychology. In this study, multi-agent-based simulation (MABS) approach is used to construct a consumer panic buying behavior model to capture the dynamics of consumer behavior and demand volatility, and to quantitatively analyze the characteristics of consumer panic buying behavior in different supply level.

Keywords: Consumer panic buying, Agent-based model, Simulation.

1. Introduction

As an important stakeholder in business, the study of consumer behavior is a very popular area, as it forms the basis of the future of any business. With the increase in natural disasters and man-made threats, panic buying behavior has grown and become the focus of media coverage and ethical commentary. For example, in the aftermath of COVID-19, scholars have generally observed the impact of COVID-19 on the supply and demand for commodities and public mental health and have found a surge in panic buying events around the world [1], with supermarkets snapping up essential goods such as groceries, fast food, drinking water, and toilet paper. Increasing the quantity of essential goods purchased may seem to be a sensible action, however, even if the increase in individual demand is small, the cumulative increase leads to a surge in demand in a very short period of time, turning the basic balance of supply and demand into a huge contradiction between supply and demand, and disrupting the market order [2]. At the same time, in the context of biological viruses, large crowds gathered in supermarkets and grocery stores can increase the risk of infection. Empty supermarket shelves can increase public anxiety, amplify the suffering associated with the outbreak, and weaken the credibility of the government. It can be said that panic buying behavior has serious effects on social stability, economic order, business management, and consumer psychology [3]. Therefore, the study of panic buying has a wide range of practical application values, which has drawn the attention of academic researchers to consumer panic buying behavior [4].

The purpose of this study is to construct a model of consumer panic buying behavior using an Agent-based modeling approach to capture the dynamics of consumer behavior and demand volatility, and to quantitatively analyze the characteristics of the spread of consumer panic buying behavior in different supply contexts.

The rest of the paper is divided into four parts. First, we overview reviews the definition of consumer panic buying and the research methodology. Then, the model section describes the constructs of the model. The results of the numerical experiment would be explained in the fourth section. Finally, the conclusion and the future work would be dealt with.

2. Literature Review

According to Arafat et al [5], panic buying is a phenomenon in which the business of one or more essential goods exceeds the normal demand, usually after a disaster or epidemic, driven by media coverage, thus leading to an imbalance between supply and demand. In this study, consumer panic buying is defined as the behavior of a large number of consumers who purchase more than the normal demand for the same commodity at the same time due to the fear of shortage of the commodity in the context of a natural disaster or social event with uncertainty and contingency, which is infected with panic through the media or crowd communication.

Consumer panic buying has been mainly studied by economists, psychologists and sociologists, who usually using questionnaire surveys to collect empirical data [6], and then using structural equation modeling[7,8] to understand the relationship between factors influencing consumer panic buying and behavior, and proposing recommendations to mitigate consumer panic buying behavior [9]. Although these studies can theoretically explain the causes of consumer panic buying phenomenon, they cannot restore the overall change process of panic buying phenomenon from brewing to development and then back to normal level. The extant paper also lacks intuitive presentation and supporting materials. In contrast, the agent-based simulation modeling approach is good at capturing the complex system behavior arising from the interaction between individuals and with the environment [10]. Therefore, the paper adopts the Agent-based simulation modeling approach to simulate the panic buying behavior of consumers.

3. Model

The Agent-based market model constructed in this study consists of a group of consumers, where the consumer agents are able to perceive the environment, make decisions and execute actions, and have capabilities such as perception, reasoning, decision making and execution. The consumer state is the result of the consumer agents' perception of the environment, while the consumer action is the response of the consumer intelligence to execute actions to influence the

environment. We assume that the consumer group has four states and denote the consumer states at moment t by i, which are (1) rational buyer ($i = 1$), (2) susceptible panic buyer ($i = 2$), (3) hoarder ($i = 3$), and (4) panic buyer ($i = 4$), with the panic level deepening in order. The actual daily usage of each consumer obeys a normal distribution with mean DD_i and variance σ^2.

In the initial normal state, the population of consumers can be divided into two categories. One is the rational buyer ($i = 1$), whose behavioral preference is to purchase only the amount needed for the day on an daily basis and its purchase amount is WTB_{1t}. Meanwhile, rational buyer is calmer in the face of panic and less susceptible to external influence. The other is susceptible panic buyer ($i = 2$), who prefers to stock up one stocking cycle QS_2 of daily use according to their personal inventory level and is very susceptible to the influence of other consumers. Of course, the states of these two groups of people can also be transformed into each other. Susceptible panic buyer will become more rational when all of its needs is satisfied over time.

When a disruption occurs and panic about supply shortages begins to spread through and the crowd, it is necessary to distinguish whether consumers' purchases in a disaster are rational preparedness or panic purchases caused by scarcity phobia or instigated by people around them. Consumer behavior will change and successively transformed from two normal states into hoarder and panic-buyer states, respectively. The hoarder ($i = 3$) from the rational state will prepare rationally based on the product life cycle PP_i, the actual daily demand DD_i and the existing inventory CI_{3t}. The panic buyer ($i = 4$) will irrationally hoard large quantities of products regardless of whether they can be used up within the product life cycle. Therefore, the buying behavior of the four states is characterized as shown in Equation (1):

$$WTB_{it} = \begin{cases} normal(DD_i, 1) & i = 1 \\ QS_i \times DD_i - CI_{it} & i = 2,4 \\ PP_i \times DD_i - CI_{it} & i = 3 \end{cases} \quad (1)$$

The retailer's inventory level RS_{it} directly affects the actual quantity BUY_{it} that consumers can purchase. if the inventory is insufficient, consumers will not be able to purchase the required goods, and if the inventory is sufficient, consumers will have more choices and purchase more goods, as in Equation (2).

$$BUY_{it} = min(WTB_{it}, RS_{it}) \quad i = 1,2,3,4 \quad (2)$$

The inventory of the individual consumer depends on the existing inventory, the actual quantity purchased, the actual daily usage, as in equation (4)

$$CI_{i(t+1)} = CI_{it} + BUY_{it} - normal(_{DD_i, \sigma^2}) \quad i = 2,3,4 \quad (4)$$

Stockout occurs when consumer demand is less than actual purchase, i.e., when the retailer fails to fully satisfy all consumer demand, as in equation (4).

$$SO_{it} = SO_{i(t-1)} + (WTB_{it} - BUY_{it}) \quad i = 1,2,3,4 \quad (4)$$

A retailer's out-of-stock rate SOR_{it} is the percentage of a retailer's inventory of a product or products that is insufficient to meet customer demand in a given time period, resulting in the inability to meet customer purchase demand, as in Equation (5). High SOR_{it} can have an impact on consumers' panic buying behavior. When consumers find out that a product they need is out of stock at a retailer, they may experience panic that the product will soon be sold out and take actions to ensure that they can obtain the product, for example, they may increase the number of purchases to ensure that they have enough product in stock; or they may purchase the product in advance, even though they do not need the products, but simply to prevent being unable to purchase them in the future when they are out of stock. These panic buying behaviors can lead to additional spending and waste by consumers, as well as impact the purchasing power and experience of other consumers.

$$SOR_{it} = 1 - \frac{BUY_{it}}{WTB_{it}} \quad i = 1,2,3,4 \quad (5)$$

The behavior of consumer agents is usually influenced by the external environment and internal state. We assume that the type of initial state of the consumer depends on the endogenous factor of personal traits, while the shift in state is mainly influenced by the initial state of the consumer, supply chain disruption events, supply levels, and actions of other consumers.

(1) Supply chain disruption events

Since panic buying usually occurs in the context of a specific event, such as a natural disaster or social event, it is assumed that consumer states and behavioral preferences change when a supply chain disruption event occurs (state= 1). It is assumed that the rationalist state ($i = 1$) will switch to the hoarder state ($i = 3$) at a rate of γ_1 and the vulnerable panic buyer state ($i = 2$) will switch to the panic buyer state ($i = 4$) at a higher rate of γ_2 ($\gamma_2 > \gamma_1$).

$$ER_i = \begin{cases} randomTrue(\gamma_1) & state = 1, i = 3 \\ randomTrue(\gamma_2) & state = 1, i = 4 \\ 0 & O.W. \end{cases} \quad (6)$$

(2) Supply Level

The level of supply is the degree to which the supply of a good in the market at a given point in time is in balance with the amount of consumer demand. When the level of supply does not meet consumer demand, consumers tend to feel uneasy because they fear that they will not be able to obtain the desired good or service in the future. According to the theory related to consumer panic buying behavior, perceived scarcity is a very important factor among the psychological factors that influence consumer panic buying behavior. When consumers' perception of scarcity increases, they may perceive that the availability of these essential goods will decrease, resulting in panic buying behavior. Therefore, when the retailer's level of scarcity is higher, consumers are more likely to shift from a normal state to a state of emergency buying under extraordinary conditions. Since rational buyers are less sensitive to scarcity than susceptible panic buyers, the shift to hoarders and panic buyers is accelerated at rates corresponding to the original states θ_1 and θ_2 ($\theta_2 > \theta_1$), respectively.

$$SR_{it} = \begin{cases} \theta_1 \times SOR_{(i-2)t} & i = 3 \\ \theta_2 \times SOR_{(i-2)t} & i = 4 \end{cases} \quad (7)$$

(3) The actions of other consumers

It suggests that social factors that influence panic buying behavior include social influence, observational learning, and social trust [11]. Influenced by social learning, when a person feels that others are panic buying a good or service, he is likely to perceive it as a social identity and start to follow others in panic buying, which may lead to more people joining panic buying behavior, thus further aggravating the imbalance between supply and demand and price increase, further intensifying people's panic and having a great impact on individual consumption decision behavior. The impact rate depends on the number of people exposed CR_i and the transmission rate IF_i, i.e., the more people are exposed and the higher the transmission rate, the higher the degree of people's panic.

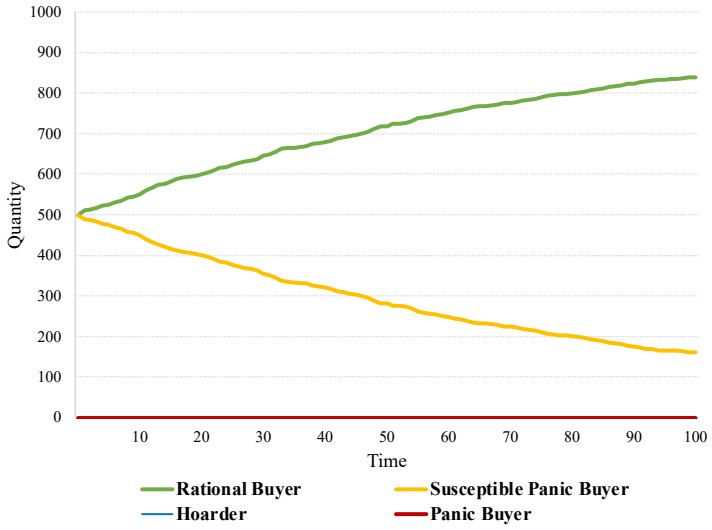
$$IR_{it} = CR_i \times IF_i \tag{8}$$

4. Numerical Experience

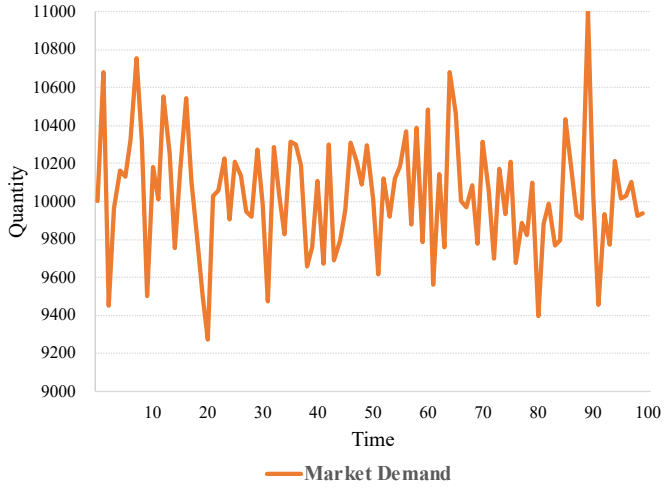
The overall size of consumers is assumed to be 1000 and the market behavior is simulated for 100 days. When the disruption starts, the rational and susceptible panic buyers in the normal state enter the two non-contingent buying states successively at a rate of $\gamma_1 = 0.3$ and $\gamma_2 = 0.6$, respectively. state. The impact of supply level on the rational and susceptible panic buyers is 0.4 for θ_1 and 0.8 for θ_2. The number of consumers in contact with other consumers CR_i and the transmission rate IF_i are 5 and 0.01, respectively. The actual consumption per person per day is assumed to satisfy a normal distribution with a mean of 10 and a variance of 1. The rational person buys according to the actual daily demand, the hoarding cycle QS_2 of panic buyer is 1.2, the hoarder stocks according to the product life cycle PP_3 (its value is 5), and the hoarding cycle QS_4 of panic buyer is 9.

4.1. Analysis of Simulation Results In The Absence Of Panic Buying Scenarios

It is assumed that no supply chain disruptions occur during the 100 days of the model simulation and that supply is sufficient. The simulation results show that consumers do not engage in panic buying behavior in the absence of disruptions, and that anxious panic buyers become more rational when all of their needs are met over time (Figure 1a), with total consumer demand fluctuating around 100,000 units (Figure 1b).



(a) Consumer States

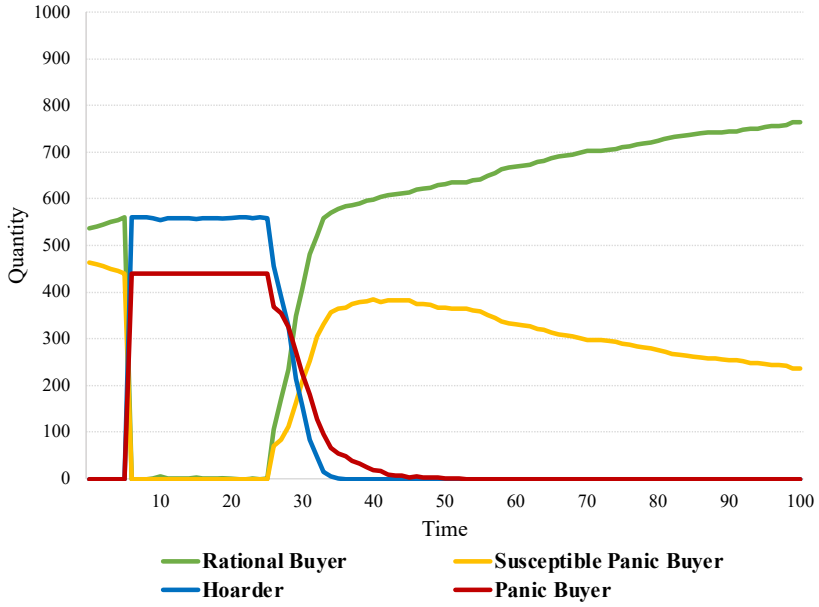


(b) Market Demand

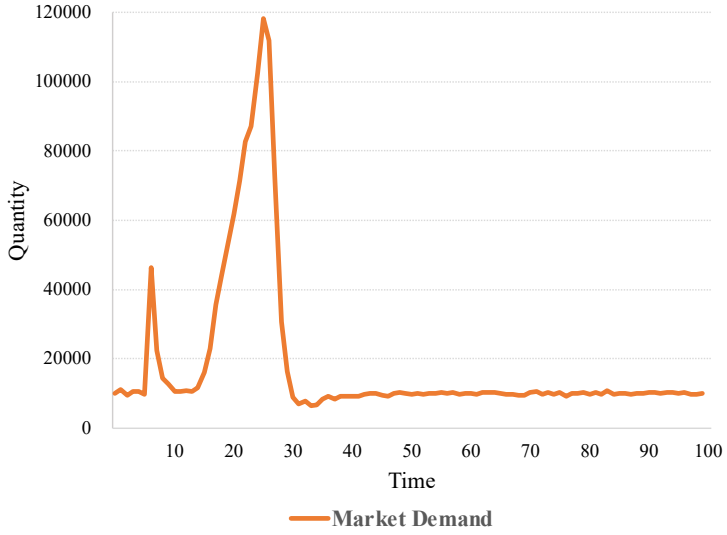
Figure 1. Consumer States

4.2. Analysis of Simulation Results Of Panic Buying Scenarios

Assuming that a supply chain disruption occurs on days 5-25, i.e., the daily supply level drops to 0 during this period due to the occurrence of a supply chain disruption, the experimental results show that hoarders and panic buyers drop to 0 on days 34 and 45, respectively, i.e., panic buying behavior completely recover. In contrast, total consumer demand experiences two demand surges, on days 7-9 and days 16-30, up to over 110,000 (Figure 2b). The first surge is primarily influenced by the supply chain disruption event itself, while the second surge is primarily influenced by out-of-stock rates and other panicked consumers. Retailers had higher out-of-stock rates on days 14-27 and lower service levels on days 14-30, thus showing that even when the supply chain disruption resumed supply, retailers still had higher out-of-stock rates and lower supply levels, indicating that abnormally high demand leads to large out-of-stocks, which induces more panic buying, creating a vicious cycle and "snowball effect".



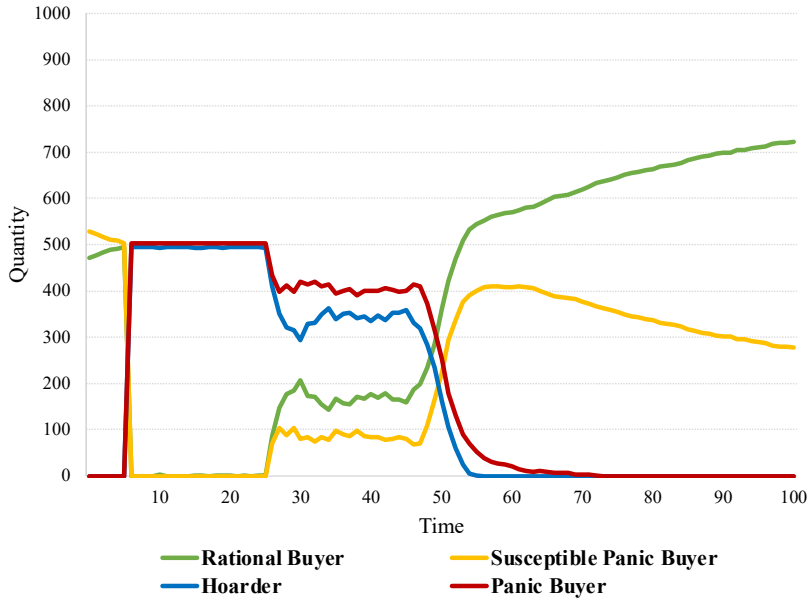
(a) Consumer States



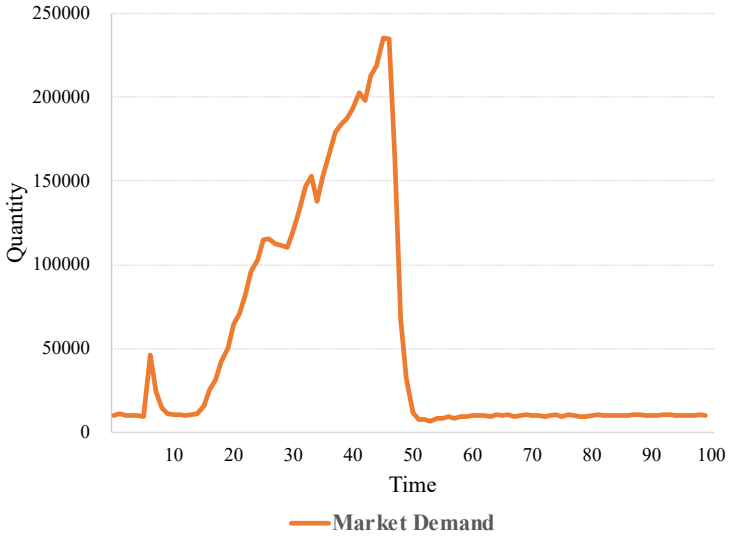
(b) Market Demand

Figure 2. Consumer States

Supply chain disruptions are assumed to occur on days 5-25, but daily supply levels are zero on days 5-40, with all other parameters held unchanged. The simulation results in Figure 3 show that hoarders and panic buyers drop to 0 on days 50 and 70, respectively, and demand surges to a maximum of over 190,000 on days 7-9 and 16-46, and decreases slightly on days 47-51. Retailers have higher out-of-stock rates on days 14-41 and lower service levels on days 14-51. Comparing the experimental results in Figure 3 shows that the lower the level of supply and the longer it takes to recover, the harder it is for consumer panic buying behavior to subside and the more complex and dramatic the change in demand.



(a) Consumer States



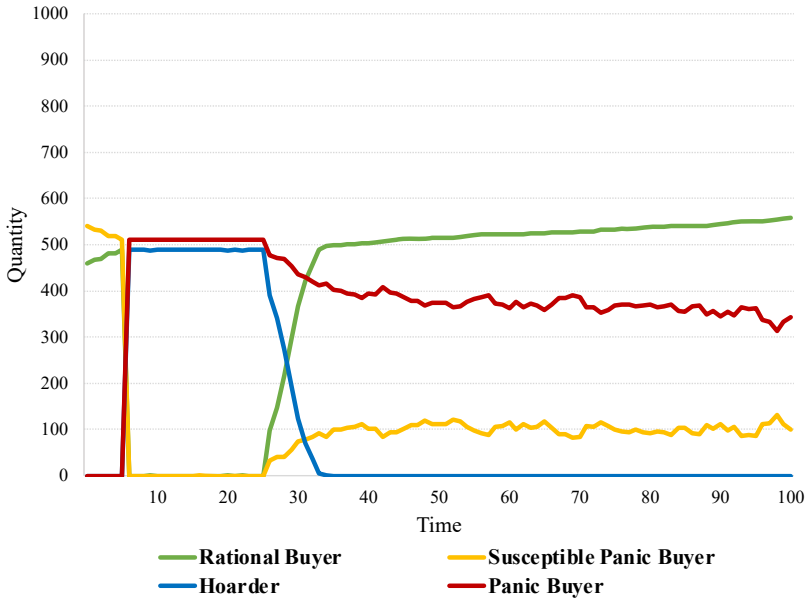
(b) Market Demand

Figure 3. Consumer States

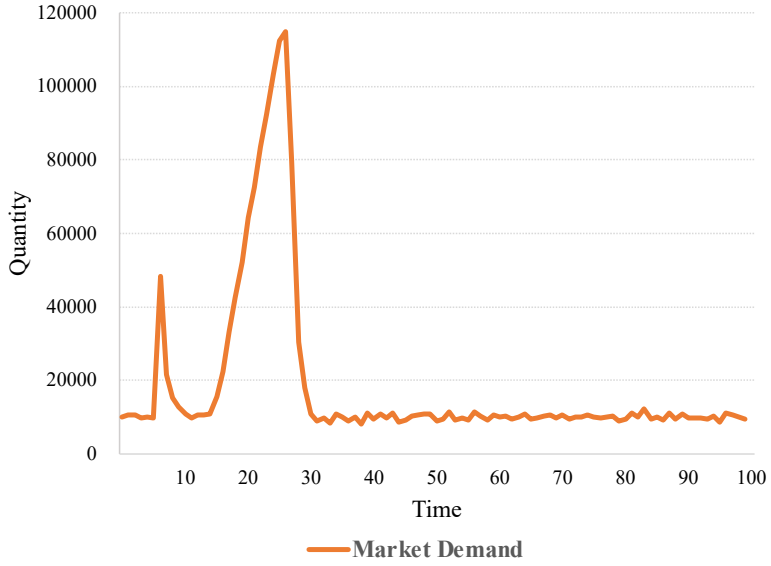
4.3. Sensitivity Analysis of Important Parameters

(1) Number Of Contacts

Suppose the number of contacts CR_i increases from 5 to 50, and other parameters remain unchanged. The experimental results in Figure 4 show that an increase in the number of contacts will keep the number of panic buyers at a high level, which undoubtedly has a negative impact on the socio-economic stability. The main reason for this phenomenon is that the higher the number of contacts, the more likely it is to be influenced by others and to be exposed to more risk information. If the more social pressure consumers feel from those around them, the higher the perceived risk, the more likely they are to make panic purchases. Based on the results of this experiment, retailers could offer appointment-based services that allow customers to purchase products in a physical store at a specified time, which would help reduce customer wait times and reduce customer-to-customer contact. Or customer support could be added, providing support via phone, email or online chat, which would help reduce the need for customers to visit a physical store and provide shopping advice and support without contacting others. All of these measures can be effective in reducing consumer contact with other panic shoppers, thereby reducing the occurrence of panic buying behavior.



(a) Consumer States

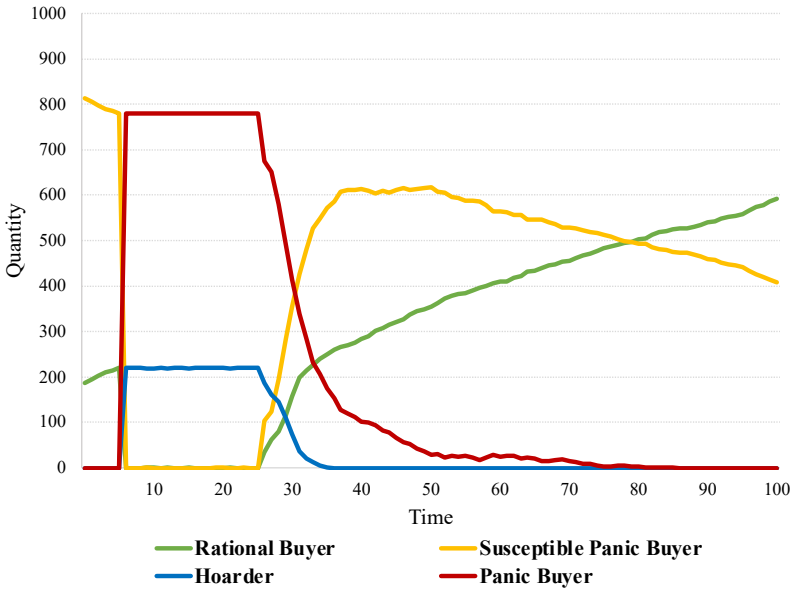


(b) Market Demand

Figure 4. Consumer States

(2) Initial State Ratio

Suppose the initial ratio β between rational buyers and susceptible panic buyers in the normal state changes from 0.5 to 0.2, i.e., the initial ratio of susceptible panic buyers becomes higher, and other parameters remain unchanged. The experimental results in Figure 5 show that the higher the initial proportion of susceptible panic buyers, the longer it takes for consumers to recover from the disruption to normal buying behavior. It can be seen that it takes 59 days for the panic buyers population to return to the normal state. Retailers can provide consumers with sufficient information and transparency, including inventory status, supply chain stability and product prices, so that consumers can make informed purchasing decisions, and educate consumers through various channels to provide them with information and advice about panic buying to promote more rational shopping and reduce the occurrence of panic buying behavior.



(a) Consumer States

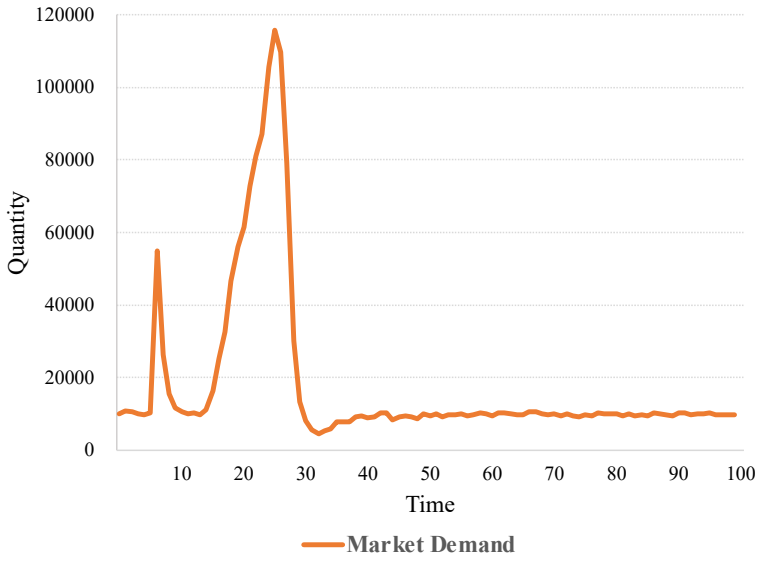


Figure 5. Consumer States

5. Conclusions

This study constructs a model of consumer panic buying behavior based on consumer behavior theory and multi-agent-based simulation (MABS) modeling approach. The study shows that the lower the supply level and the longer the recovery time, the more difficult it is for consumer panic buying behavior to recover and the more complex and dramatic the demand changes. At the same time, both a high percentage of susceptible panic buyer and a high contact rate will slow down the recovery of consumer panic buying behavior. Therefore, first, supply issues are the most important factor in consumer panic buying behavior, and retailers should ensure that shelves are replenished to ensure that consumers have access to the essentials. Second, from a media perspective, policymakers should discourage the media from portraying visual images of out-of-stock situations and from spreading false news that could cause consumer panic resulting in more and more exposure to panic news or events.

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