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Quantitative decision-making model to analyze the post-disaster consumer behavior

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ABSTRACT

Consumer behavior is a key factor that affects the profitability of a business. It is altered significantly in disaster times, which affects the businesses and their supply chains. The media reports during the recent COVID19 pandemic has provided adequate proof of consumer stockpiling and its consequential effects on the supply chain, also in fuelling additional stockpiling. We have developed an agent-based tool to understand consumer purchase behavioral changes in a disaster scenario. The quantitative consumer decision-making model is based on a logistic transformation model using a regression analysis of a questionnaire survey. The significant factors in the scenario have been assessed and employed in the model. The agent-based model evaluates the purchase intention probability, given the personal and situational factors. Such tools give a quantitative perspective to evaluate consumer behavior for future disaster mitigation and management to help the government and the industries.

1. Introduction

Disasters have lasting effects on all sectors, from people to economic growth. Disaster mitigation and management have risen to a priority with the increasing number of large-scale disasters in the past few decades [1]. Crises such as the Great East Japan earthquake, the Christchurch earthquake, hurricane Katrina, and more recently the COVID-19 pandemic had a severe impact on global economies and also on the lives of millions of people, with drastic changes in their lifestyles. The occurrence of such events has shown the importance of mitigation measures in order to alleviate the resulting human and economic loss. People have been tirelessly trying to reduce the impact and damage by developing mitigation measures and methods which enable a speedy post-disaster recovery.

Disaster mitigation is very important in the industrial sector too. Globalization has turned the world into one global market, increasing the risks posed to the businesses and supply chains. The supply chains are often susceptible to many disruptions due to various reasons such as disasters, terrorist attacks, or even transportation issues [2–4]. As supply chain performance is vital to any business, there has been much work to improve efficiency, optimize the involved processes such as just-in-time techniques. There is a lot of literature in the field of supply chain risk management, which works towards the reduction of these disruptions. But, one major reason for the disruption, which is often ignored, is the change in consumer behavior in uncertain situations such as large-scale natural disasters or emergencies.

In uncertain situations, people are surrounded by a sense of fear and anxiety. Researchers have highlighted that human nature is oriented to take some protective action to overcome or in response to a heightened emotion [5–7]. One such reaction to the fear induced by disaster is the stockpiling of essential commodities to mitigate the risk of a possible stockout. Fig. 1 shows the mechanism of actions leading to stockpiling. Disasters or emergencies create uncertainty about the developing consequences. This increases anxiety in the person. Anxiety leads to fear. The stockpiling of necessary goods is a reaction that gives the person a feeling of control or protection over the situation. Seeking protection can be seen as the most rational action in case of an unforeseen incident. Hence, stockpiling is a natural response when one gets information about a possible shortage or stockout. It can be seen regularly before or after natural disasters such as hurricanes, earthquakes, etc. But, the COVID19 pandemic has shown that such a behavior can be seen in all uncertain situations and has established sufficient proof of stockpiling behavior among the consumers. Media has reported several cases of stockpiling and stores stocking out of essential commodities. Masks, sanitizers are products that were difficult to be obtained even by some governments. But, low priority goods, during a pandemic such as toilet

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paper, groceries, etc., were also flying off the shelves, which resulted in stores implementing sales restrictions. Owing to the lockdowns and movement restrictions in place in most countries, we have witnessed similar scenarios from all over the world. The purchasing behavior of the people during the pandemic can be better understood using product and sales data of stores, but such is yet to be studied comprehensively.

Consumer decision-making follows a rational path, guided by requirements, emotions and preferences. Similar to evacuating to a safer location following an earthquake or fire, the increase in purchase quantity of essential commodities is a most sensible action in case of an indefinite crisis. However, even though the increase in demand by an individual is small, the cumulative increase leads to a surge in demand in a very short duration. This creates mayhem along the supply chains of retail industries, which mostly work in just-in-time techniques [8]. This disruption leads to more consumers resorting to stockpiling forming a vicious circle. While consumer behavior is a widely studied field, stockpiling in disasters or crises is still relatively new with not much work in understanding the causes and response of the actions which lead the consumer to indulge in stockpiling. The limited research available on consumer panic buying or stockpiling has been conducted by sociologists or psychologists but is mostly confined to statistical analysis. Consumer stockpiling was largely studied under promotions and price fluctuations. Mela et al. [9] studied the panel data for frequently purchased, non-food, consumer packaged-goods and suggested that long term promotions have reduced the likelihood of category purchases with an increasing tendency of waiting for good promotions to purchase in bulk. Helsen and Schmittlein [10] showed that consumers tend to stockpile when there is an uncertainty of deal opportunities or regular price. A few researchers studied excessive buying in disastrous situations. Strahle and Bonfield [6] conducted a preliminary study of a model of individual decision-making in panic situations using eight structural factors, listed from previous literature, in an effort to understand collective consumer actions in panic. Hui, Bradlow, and Fader [11] tested the impact of three factors (time pressure, the composition of the shopping basket, and the presence of other shoppers) that were found to influence consumer decision-making in laboratory experiments. Kurihara and Maruyama [12] had attempted to investigate the causes and factors of consumer behavior from an analysis of a survey conducted after the Great East Japan earthquake and found that unpreparedness of disaster and excessive media coverage caused excessive buying of essential goods. Forbes [13] conducted a study to understand the post-disaster consumption trends after the Christchurch earthquake from scanner data of purchases and found consumers purchase increased levels of utilitarian products necessary for survival. Liren et al. [14] have put forward the evolution mechanism and development tendency of panic purchase and suggested that the government involvement controls panic purchase.

While the above were a few works until recent, the year 2020 has witnessed an unprecedented amount of stockpiling all over the world, given the uncertainty of the lockdown durations, which caught the researcher's attention to study the causes, effects, and managing strategies of consumer stockpiling. Yuen et al. [7] have conducted a thorough literature review of the existing academic papers regarding panic buying and identified its causes to be 1) individual's perception of threat or scarcity, 2) fear of unknown, 3) coping behavior, 4) social psychological factors. Loxton et al. [15] established that the consumer behavior during the COVID19 crisis is highly comparable to the experiences during previous crises and shock events by analyzing and comparing the volume and timing of consumer spending patterns. Balacco et al. [16] investigated how the changes in water consumption are related to the new lifestyle of people in Italy and have noticed considerable changes in consumption patterns attributed majorly to the restrictions imposed by the government. Keane and Neal [17] developed an econometric model to measure consumer panic based on google search data as a function of government policy announcements and COVID19 cases. Government policies on movement restrictions have a substantial impact on consumer panic as revealed by the panic-index at the time of announcements when compared to travel restrictions or stimulus announcements. Most of these studies used a questionnaire survey, available retailer data, or data analysis for understanding the causes of stockpiling and gave suggestions based on the results as methods for mitigation. The dearth of predictive or simulation models, which can help in forecasting the future behaviors of consumers, is quite evident [7]. The lack of research and understanding on consumer stockpiling phenomenon, with respect to the supply chain, was apparent as the industries were at a loss to cope with the pandemic situation. This has brought forward the importance of understanding how consumer behavior changes in uncertain situations, which would help a great deal in working towards controlling the demand in challenging times.

In view of the above, the objective of the current work is to develop a consumer model that will quantitatively analyze the transformation of consumer purchase behavior during disasters or emergencies using an agent-based tool and evaluate the consumer purchase intention during disasters to help industries estimate the post-disaster scenario. The simulation model is developed based on the agent-based modeling methodology. The agent-based approach is quite appropriate in modeling human behavior as it can elevate the individual characteristics of each agent. This methodology has the ability to represent the complexity of human cognition aptly. The current research is part of a novel effort to develop a simulation tool that analyses the impact of consumer stockpiling on the supply chain and tests the mitigation measures to reduce the impact using an agent-based model of consumer behavior and supply chain together during disasters [18]. We have based the model on the consequences of the Great East Japan Earthquake, which was one of the large-scale disasters in recent times. There was a severe shortage of bottled water due to radiation contamination of city water. People were stockpiling bottled water in huge quantities in Tokyo and surrounding prefectures. Hence, the product considered in the model is bottled water, which is generally the most sought item in every disaster situation. Nevertheless, the model can be applied to any product with regular consumption requirements.

The rest of the paper is divided into four parts, where the second part deals with the explanation of the consumer model, including the model development, analysis methodology, and consumer agent. The third part deals with the output of the regression analysis. The preliminary results would be explained in the fourth section, along with the discussion. Finally, the last part would deal with the conclusions.

2. Consumer model

Consumer behavior refers to the acquisition, consumption, and disposal of products, services, time, and ideas by decision-making units [19]. The decision-making process is a key to consumer behavior which studies how individuals make decisions to spend their available resources such as time, money, effort on choosing, consuming, and disposing of products, which is influenced by the consumer's emotional, mental, and behavioral states. In general, consumer decision-making is influenced by factors, such as lifestyle, family, motivation, price, brand,

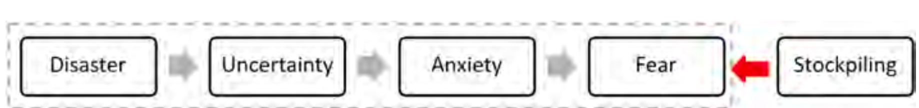

Fig. 1. The mechanism leading to stockpiling.

etc. In a disaster scenario, the products sought out are mostly essential commodities, and hence, the key factors to affect are family, motivations, psychological factors over other factors such as price and marketing. These factors are segregated into different categories – Personal, Social, Psychological, Individual, and Situational, as shown in Fig. 2.

Personal factors: Personal factors are the characteristics that are basic and unique to a person such as age, gender, weight. Their need, consumption, etc., are dependent on these factors.

Social factors: Factors such as the presence of a family, characteristics of family members, reference groups such as friends, relatives affect the purchase decision significantly.

Psychological factors: The psychological factors include the beliefs, motivation, perceptions the individual possesses, such as anxiety, risk-taking nature, satisfaction, etc. These factors accelerate or decelerate the decision-making process.

Individual factors: Individual factors indicate a person's habits, such as their preferences, lifestyle, past experience, etc. Their desires and choices are highly dependent on these factors.

Situational factors: The decision making of a consumer is significantly influenced by the circumstances surrounding the individual. For example, even if an individual has no intention to buy, he tends to change his mind when he learns that there would be a possible shortage of the product.

The factors shown in Fig. 2 are the result of the research available based on the 2011 triple disaster [12]. The articles published during the time provided key inputs which serve as the basis for the selection of these factors. The radioactive iodine levels in city water exceeded the permissible level for infants. Hence, families with children were most concerned about the shortage of bottled water. Similarly, households with more members expressed a desire for stockpiling [12]. Several stores implemented restrictions on the quantity of purchase of bottled water. Media reports aggravated consumer stockpiling. Rumors regarding the shortage of essential goods, radioactive contamination etc, were increasing anxiety among the public. Human actions are greatly influenced by their observation such as long queues in front of stores, consumers purchasing in excess quantities; neighbor's behavior is also a key influencing factor. Hence, the factors included in the present study, based on previous literature, represented the possible elements driving the decision-making to stockpile or not. However, when using the model for a different crisis, other factors might be driving the decision-making, for example, during the recent pandemic, restrictions on movements, presence of lockdown etc., would be the forerunners in making the purchase decision.

2.1. Consumer agent

The consumer agent in the current model is a household. A household is formed with its members. Every household in the model is assumed with a size between 1 and 4 members, as an average household size in Japan is around 2.4 [20]. The household is modeled such that every household has a minimum of two adults if it is not a single person household. The age of a member is considered to be between 0 and 80 years. A member above 18 years is considered as an adult, while 6–18 years are considered children, and 0–6 years are considered infants or toddlers. The decision-maker and the buyer of the household is the 'head', while the other members are considered to be the influencers. The characteristics of each agent are established, specifically according to actual data, such as the Japanese demographic data and survey data, or the questionnaire survey we conducted. The household has a knowledge of the environment to a certain radius from its location, defined as the vicinity of the consumer. The consumer knowledge is limited to the stores and other consumers (neighbors) in this area.

The main model of the consumer is the decision-making model. There are other sub-models that are essential to complete the agent action. The agents calculate the average consumption of each member and the per interval consumption of the household using the product consumption model based on the weight of each member [21,22]. The store selection model uses the environment and consumer preferences to search the vicinity and select a store for the purchase of the product. Using the agent's consumption habits and available household inventory, the purchase quantity is calculated in the purchase quantity model. The consumer satisfaction model evaluates the satisfaction as a function of inventory availability and purchase action outcome.

2.2. Phased simulation scenario

The time interval of the model is fixed, and one interval is considered as one day. The first few intervals of the simulation are in normal condition, after which a disaster is introduced into the model. The flow of the simulation is divided into three time phases. Phase 1 is a pre-disaster phase. Phase 2 is the post-disaster phase, which starts at the onset of the disaster. Phase 3 is the strategy phase. Consumers modify their actions according to the phase.

Phase 1: The pre-disaster phase is a regular sale time, where all the

Fig. 2. Factors influencing the consumer decision-making process.

agents try to maximize their utility. The consumer's purchase is solely dependent on their requirement and available inventory. The supply meets the demand in all the intervals of Phase 1.

Phase 2: This phase starts when the disaster is triggered. People get anxious from the information of disaster. Some households, based on their situational and personal factors, resort to stockpiling. Hence, the demand for the product increases exponentially, causing a shortage of the product leading to a supply chain disruption.

Phase 3: This phase begins when a strategy is employed to restrain consumer stockpiling. In this model, we have used quota policy and rationing as the mitigation measures employed to control the consumer demand by limiting sale quantity per person. Quota policy is a very popular strategy implemented to control the increased demand. It was employed at large by most stores during the aftermath of the triple disaster. This model also evaluates the consumer reaction to these strategies.

2.3. Consumer decision-making process

The consumer decision-making process is based on the traditional decision-making process involving six stages, viz., need recognition, information search and processing, factor valuation, purchase decision, purchase, and purchase evaluation, as shown in Fig. 3.

Need recognition: The consumer collects all the necessary information of each factor that would play a role in decision-making, such as the amount of inventory available, psychological factors, situational factors.

Information search and processing: The consumer searches for additional information such as past experiences, current situations, social circumstances, reference group behavior, and processes the data for evaluation.

Factor valuation: The purchase intention (PI) is calculated based on the evaluated factors and decision criteria. The decision criteria are different for different phases, as explained in the following section.

Decision: The purchase decision is based on the calculated PI. If the value of PI is greater than a threshold, here 0.5, the household makes a purchase, and if it is lower than or equal to the threshold, the household does not make a purchase.

Purchase: The household proceeds to calculate the required purchase quantity based on the household inventory and future consumption habits of the household. After this, the consumer moves to the store to make the purchase.

Purchase evaluation: The consumer evaluates the satisfaction level based on the purchase. If the required quantity is purchased, the satisfaction level is high. Similarly, if the purchase is unsuccessful, the satisfaction is low. The overview of the consumer agent action algorithm in an interval is shown in Fig. 4.

Fig. 3. The six stages of the consumer decision-making process.

2.3.1. Pre-disaster decision-making model

In this phase, the decision-making model is based on the inventory of product available with the household and the amount required, as shown in Equation. 1. The household head checks the inventory and the quantity required for the consumption of the household. If it is sufficient, there is no action required for the interval. If it is insufficient, the head decides to make the purchase.

$$if\ (I_{hi} < I_{d\ Low} * C_{ha}) \rightarrow Purchase \tag{1}$$

here, I_{hi} is current household inventory.

$I_{d\ Low}$ is minimum number of days of stock held before the purchase decision.
C_{ha} is average water consumption of the household.

2.3.2. Post-disaster decision-making model

Disaster induces anxiety among the people, changing their attitudes and behavior. However, the consumer in the model follows a rational post-disaster decision-making process based on their needs, preferences, emotions and circumstances. The post-disaster phase is initiated at the onset of the disaster. As water contamination or unavailability of city water is one of a highly possible consequence of a large-scale natural disaster, all the consumer agents who consume tap water, discontinue the usage. The decision-making model in the disaster phase is based on a logistic transformation model using the regression analysis of a questionnaire survey.

2.3.2.1. Logistic model. The goal of the model is to judge whether a consumer has decided to purchase in excess or not. A logistic function is apt for a model with a binary outcome variable. The probability is expressed as Equation. (2).

$$p = \frac{1}{1 + e^{-Y}} \tag{2}$$

here, p is probability of stockpiling.

Y is response variable..

The logistic transformation or the logit is shown in Equation. (3).

$$Y = \ln\left(\frac{p}{1-p}\right) = \sum_{i=1}^{4} \alpha_i x_i + \varepsilon \tag{3}$$

here, x_i is situational vector element for i^{th} situational factor.

α_i is linear model parameters for i^{th} situational response variable.
ε is a constant.

The model parameters α_i, required for the calculation of the response variable has to be dependent on the consumer attributes, which influence the decision-making model. Several factors could influence the decision, but, we need to identify the factors which could affect the decision-making process in a post-disaster scenario. Hence, to identify those factors and their effect, a regression model was built based on a questionnaire survey.

2.3.2.2. Questionnaire survey. A survey was conducted in April 2020, to identify the factors which influence the decision-making of the purchase of essential commodities, specifically bottled water, during disasters. The method of the survey was a web survey, with the target respondents being people who manage the purchase of their household commodities. The survey was conducted with 300 participants in the Tokyo metropolitan area, between the age groups of 19–70 years. The questionnaire was framed such that the survey can provide an insight into all the influencing factors collected from the past literature. The questions were

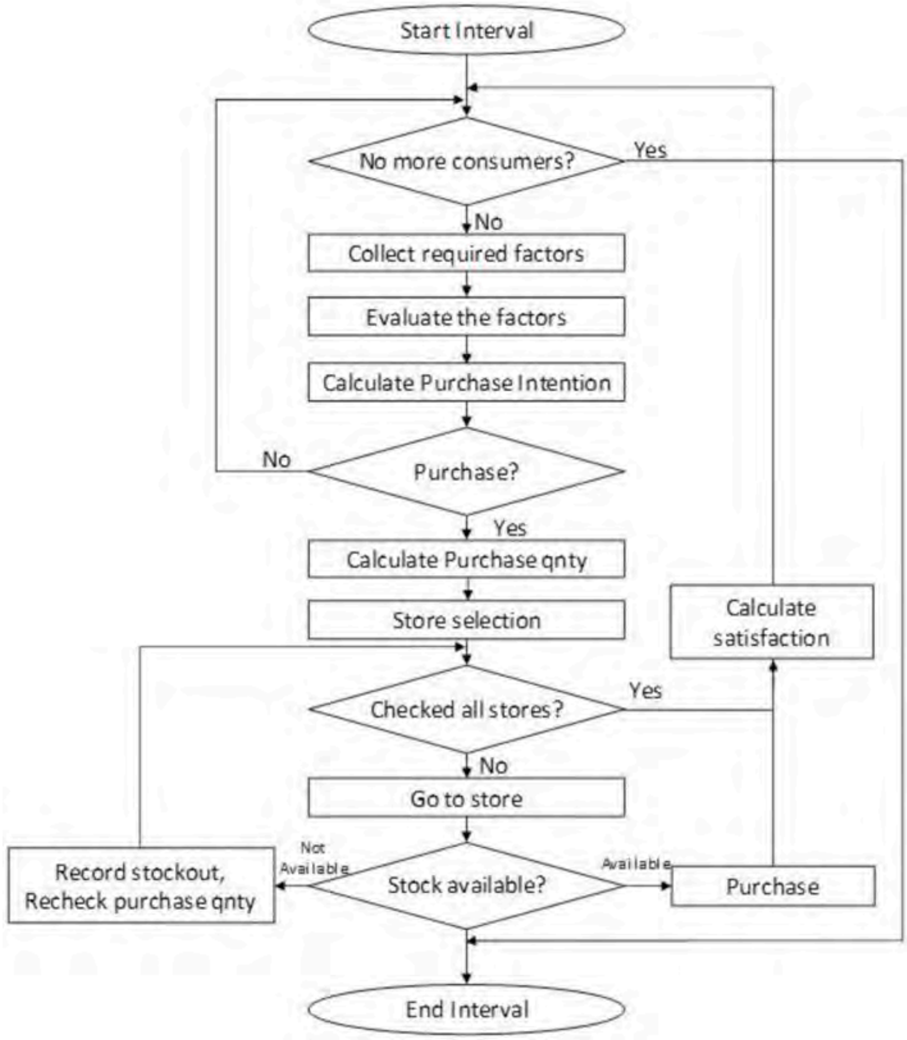

Fig. 4. Flowchart of the consumer decision-making model.

Psychological						
1	Do you think you are a risk taker?	I strongly think so	I probably think so	I cannot say either	I probably do not think so	I strongly do not think so
2	Do you think you get anxious easily?	I strongly think so	I probably think so	I cannot say either	I probably do not think so	I strongly do not think so
Past experience						
1	Have you experienced difficulty of purchasing during previous disasters?	Yes	No			
2	How did your purchase behavior change, in terms of quantity?	As usual	1.5 times	Double	Triple	4 times or more
3	When did you stop panic buying?	After the emergency has passed	After seeing lot of stock at stores	After restrictions were removed	After stocking sufficient at home	Did not panic buy
4	How much do you think you would purchase in future?	As usual	1.5 times	Double	Triple	4 times or more
Media reports						
1	Were shortage reports published in the media?	A lot	Quite a few		A few	None
2	If there were media reports about panic buying or shortage reports, would you make a purchase?	Definitely stock up	Probably stock up	Probably not	Definietly not	Do not know

Fig. 5. Sample of the questionnaire.

regarding the personal characteristics, such as age, gender; psychological attributes, such as risk temperament, anxious temperament; individual and household consumption habits of bottled and tap water; purchase habits such as frequency and quantity of purchase; previous experience; and effect of situational factors on their future purchase behavior, a sample is shown in Fig. 5.

The survey also focuses on the situational occurrences after a disaster, such as sales restrictions in stores, media reports regarding stockouts or stockpiling, rumors about the shortages of products and the stockpiling behavior of their reference groups and how the above situations would influence their purchase behaviors. The above four situations have been chosen as they could be the prime consequences of a disaster, which could lead to a possible stockpiling. We were able to understand the respondent's attitude towards anxiety and risk friendliness also. The data obtained in the survey is used to conduct the multiple regression analysis as explained below.

2.3.2.3. Multiple regression model. A regression model was developed based on the survey. The methodology for the development of the model is mentioned in Fig. 6. The data obtained from the survey is investigated to select the candidate variables which could be used to predict the response variable. We have categorized the explanatory variables into personal and situational variables, obtained from the survey, which could have an effect on decision-making during an uncertain situation as mentioned earlier. Personal variables are the individual's characteristics – age, gender (Binary); Household features – household size, number of children; Psychological elements – risk temperament (Likert scale), anxious temperament (Likert scale), presence of children (Likert scale), perception of tap water quality (Likert scale); Past experience – difficulty of obtaining the product (Binary), past stockpiling behavior (Nominal, increase in quantity). The four situational explanatory variables are restrictions on sales in stores (Likert scale), the number of media reports (Likert scale), rumors (Likert scale), neighbor's stockpiling behavior (Likert scale). The response variables are the effect of sales restrictions (Likert scale), effect of reports (Likert scale), effect of rumors (Likert scale), and effect of neighbor's stockpiling behavior (Likert scale). As the obtained survey data is a combination of different type of variables, all the variables have been converted into continuous variables on a scale of 0–1, to implement the regression analysis. For example, a 5 point Likert scale is converted as 0.05, 0.25, 0.5, 0.75, 0.95.

In order to avoid overfitting of the model, an appropriate model is required. Correlation coefficients are insufficient for a mixed model. Hence, p-values have been used to judge the association and significance of the explanatory variables. Each explanatory variable has been fit against each response variable, and the p-values have been obtained. A p-value of less than 0.05 is considered to be statistically significant.

Before conducting the regression analysis, we calculated the preliminary model parameters. The stockpiling probability of each option for the questions in the survey is converted on a scale of 0–1. The situational variables either take a value of 0 or 1 depending on their absence or presence. The above values when inputted into Eqs. (2) and (3), the model parameters for each situational variable are obtained, as shown in Table 1.

Multiple linear regression analysis has then been conducted on the selected model with the selected personal explanatory variables, *pv*, and each of the situational response variables viz., the effect of sales restrictions, reports, rumors, and neighbor's behavior. The Likert scale options of the response variables in the survey data have been

Table 1
Model parameter values obtained from the logistic transformation model.

Situation	x_i	Option	p	Y	α_i	ε
Normal	0		0.05	−2.945		−2.944
Sales	1	Strongly yes	0.95	2.945	5.889	
Restrictions,		Probably yes	0.75	1.099	4.043	
Media		Not sure	0.5	0	2.944	
Reports,		Probably no	0.25	−1.099	1.846	
Rumors,		Strongly no	0.05	−2.945	0	
Neighbors						
behavior						

substituted with the corresponding model parameter values, α_i obtained from Table 1. Multiple linear regression analysis has been conducted individually to obtain the four regression equations, as shown in Equation. (4).

$$\alpha_i = \sum_{i=1,j=1}^{4,\,6} \beta_{ij}\, pv_j + \gamma_i \tag{4}$$

here, α_i is linear model parameters for i^{th} situational response variable.

pv_j is j^{th} personal variable.
β_{ij} is regression coefficient corresponding to j^{th} personal variable for α_i.
γ_i is constant for i^{th} regression equation.

Hence, the effect of each situational factor $\alpha_{1\sim4}$ can be obtained for a consumer agent from the above equation given the household's static personal attributes *pv*. Fig. 7 shows an overview of the process for post-disaster decision-making. The process in the dashed box is conducted for every interval once the disaster occurs. Using α and the situational vector x, we can obtain the response variable Y, from Equation. (3), and finally, the purchase intention probability p, from Equation. (2).

The situational vector x, is calculated for each consumer agent according to its corresponding circumstances in each interval. The four elements of the situational vector are the number of restrictions, the number of media reports, the number of rumors, and the number of stockpiling neighbors. The values of these elements are between 0 and 1, where 0 indicates low or no presence and, 1 indicates a high presence of the situational element.

$$x = \left(N_{Res}, N_{Rep}, N_{Rum}, N_{PBN}\right) \tag{5}$$

N_{Res} is the fraction of stores that have implemented the strategy among the stores the consumer has visited. Similarly, N_{PBN} is the fraction of stockpiling neighbors among all neighbors. N_{Rep} and N_{Rum}, which indicate the intensity of the reports and rumors respectively, are assumed to possess a log-normal distribution, which replicates a life cycle of a news article. The probability density function of log-normal distribution with respect to time, t is as shown in Eq. (6), where μ and σ are the parameters.

$$f(t) = \frac{1}{t\sigma\sqrt{2\pi}} exp\left(\frac{-(\ln t-\mu)^2}{2\sigma^2}\right) \tag{6}$$

The presence of reports and rumors, for the current simulation, are calculated with μ being 2 and 2.5 and a σ of 0.5 and 0.25 for reports and rumors, respectively. Henceforth, the purchase intention of the consumer agent is calculated with the model parameters and situational

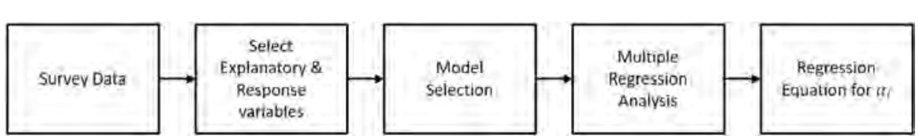

Fig. 6. Methodology for the development of the regression model.

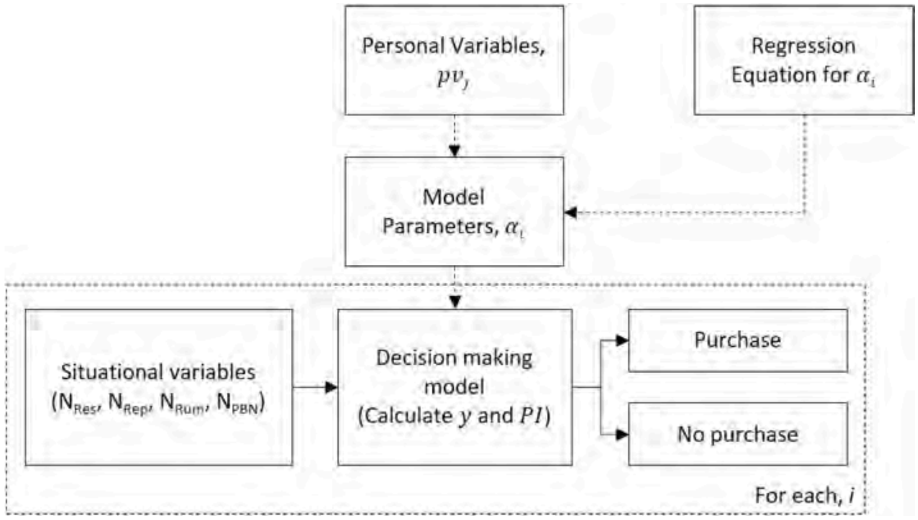

Fig. 7. The framework of the logistic decision-making model.

vector.

During the strategy phase, the consumers try to adjust their behavior according to the changes in the environment. While the decision-making process and calculations remain the same as in Phase 2, the purchase action differs slightly. Once the strategy of sales restrictions is imposed by the retail stores, the information about the presence of the strategy is given to the consumers. However, the consumers are ignorant of which stores have restrictions unless the consumer visits the store. Hence, as a reaction to per-person sales restrictions, all the household members move to the store to make a purchase, which was initially made only by the head of the household. The purchase quantity is also based on average household consumption and inventory days. Inventory days (I_d) is the average number of days the consumer wants to store the product for a periodical purchase. Hence, the consumer buys the stock such that it would be sufficient for the predefined inventory days and is normally expected to make the next purchase after those many days. The purchase interval is decided based on the exhaustion of the stock.

3. Regression analysis outputs

The simulation model is based on the data analysis output as mentioned in the previous section. The data analysis was conducted using JMP statistical tool. We have considered 14 explanatory variables, and four response variables from the questionnaire survey. The corresponding p-values have been shown in Table 2. However, as mentioned in the previous section, only significant variables are used to build the model. Variables with a p-value of less than 5% are considered to be statistically significant. The statistically significant explanatory variables are shown in light grey, with the least significance frequency shown in dark grey.

Hence, based on the above, from the 10 personal variables, six significant variables viz., household size, presence of children, past purchase difficulty, past stockpiling behavior, risk temperament, anxious temperament have been used to build the regression model for the analysis.

The parameter estimates of the multiple regression analysis conducted with these six personal variables and each of the situational response variables are shown in Table 3. Hence, the regression equations for the model parameters of the effects due to sales restriction (α_1),

Table 3
The coefficients of the regression analysis for the effect of the four situational response variables.

Explanatory Variables	Response Variables			
	Effect of Sales Restrictions	Effect of Reports	Effect of Rumors	Effect of Neighbors behavior
Intercept	1.444	3.083	3.040	2.297
Household size	0.129	0.035	0.062	−0.010
Presence of children	1.770	0.174	0.889	0.077
Past purchase difficulty	0.386	0.202	0.183	−0.003
Past stockpiling behavior	−0.144	0.093	−0.210	0.561
Risk temperament	0.644	−0.751	−0.534	−1.342
Anxious temperament	0.254	−0.815	−1.106	0.449

Table 2
The explanatory and the response variables along with the p-values and the statistically significant variables.

Explanatory Variables	Response Variables				
	Effect of Sales Restrictions	Effect of Reports	Effect of Rumors	Effect of Neighbors behavior	Significance Frequency
Age	0.3287	0.4523	0.0858	0.4081	0
Gender	0.9736	0.7612	0.97	0.918	0
Number of children	0.0009	0.0016	0.0008	0.0115	4
Presence of children	<0.0001	<0.0001	<0.0001	0.0078	4
Household size	0.0047	0.02	0.0276	0.0269	4
Quality of tap water	0.9368	0.5469	0.7901	0.5605	0
Past purchase difficulty	<0.0001	0.0111	0.0214	0.2419	3
Past stockpiling behavior	0.0031	0.0005	0.0001	0.0085	4
Risk temperament	0.0092	0.0138	0.0003	0.0101	4
Anxious temperament	<0.0001	<0.0001	<0.0001	<0.0001	4

reports (α_2), rumors (α_3), and neighbor's behavior (α_4) can be obtained.

4. Preliminary simulation results

The consumers in the simulation are generated randomly with the characteristics mentioned in Section 2.1. The simulation was conducted with 2000 households with 4 stores for the consumers to purchase the product, as shown in Fig. 8. It was found in the METI Japan statistical data that, based on the store density of Tokyo, there are approximately 2 retail stores per 1000 households [23]. The stores are restocked at the end of every interval. The simulation runs for 60 intervals, where the disaster occurs in the 30th interval. All simulations are conducted using the same agent set. The simulations were conducted in four scenarios to understand the behavioral changes depending on the various situations; Normal case without disaster, Disaster case without strategy, Disaster case with sales restrictions, Disaster case with rationing. The difference between the two strategies is that in the sales restrictions case the consumers can make multiple purchases by visiting several stores until their requirement is met while the consumer's purchase is limited to one purchase per interval in the rationing case.

4.1. Validation

The validation of agent-based models is a difficult task. A possible method is to compare the simulation outputs with the real phenomenon. But, access to such data is difficult. As a preliminary validation method of the model, the consumption and demand have been compared in a normal scenario, as shown in Fig. 9. The cumulative bottled water consumption of all the agents in each interval can be seen in the blue line, while the grey line indicates the variation in daily demand.

The average daily bottled water consumption is 4.17×10^3 units per interval while the average daily demand is 4.36×10^3 units per interval. It can be observed that the consumption and demand are similar in nature, which shows that the consumer model works well.

4.2. Consumer behavioral transformation

The consumer behavioral change can be better understood from the household inventory the consumer holds rather than from the purchase intention plot. For the simulation of the below results, all the stores have implemented sales restrictions. To depict the different types of purchase pattern of the consumer, three randomly chosen agent's purchase behavior is shown here. Fig. 10 shows the household inventory against time for those three agents. The static personal variables of the agents are shown in Table 4. The peaks in the graphs show the replenishment of

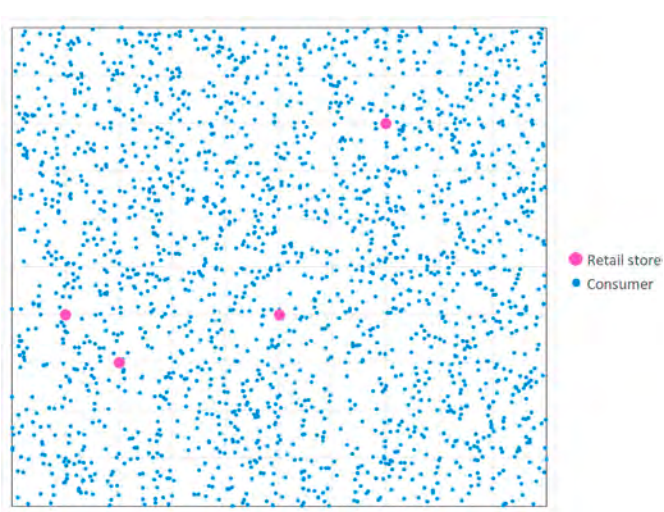

Fig. 8. Agent spatial distribution in the environment.

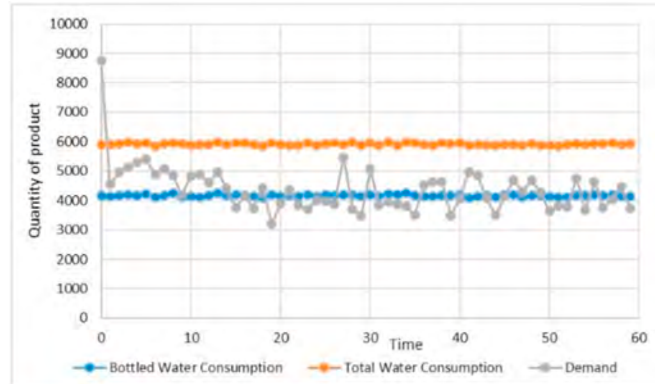

Fig. 9. Cumulative consumption and demand for the product in a normal scenario.

inventory, while the vertical drops indicate the consumption. The purchase behavior of the agents in the normal case is clearly based on the available inventory and regular consumption of the product represented by the drops and peaks. However, in other cases, we can see the changes in the purchase behavior of the agents.

Household 1 has a stockpiling factor of 1; hence, there has not been a rise in the purchased quantity. However, when the disaster occurred, the agent has bought his required quantity and has tried to maintain its inventory level by making daily purchases in the intervals around 35 to 45, which can be attributed to situational factors and the high psychological factors. In the case where restrictions were implemented by the stores, the household could reach its required quantity in just a couple of intervals as the household has four members, who visit the store for the purchases. But, when the rationing system is in place, the household required around ten intervals to reach its regular inventory level. In both the strategy cases, the household has tried to maintain its inventory level by making daily purchases given the high situational factors.

Household 2, with a stockpiling factor of 2.17, has started to purchase even before it has reached its low inventory level owing to the situational factors, which had persuaded the consumer to purchase in that interval. However, the household has not made a purchase in the following intervals given that the agent has reached its maximum inventory level. In case 3, the household adjusted its behavior to the situation and had made a purchase in every interval until the required quantity was purchased. However, in case 4, when rationing was in place, the household took a considerable number of intervals to gradually improve its inventory. It can be observed that restrictions and rationing have increased the time taken for stockpiling, and rationing has controlled this household's stockpiling behavior.

Household 3 could not procure the product for around ten intervals in the cases of disaster without or with restrictions. However, the number of intervals had reduced when the restrictions were imposed by the stores. The rationing strategy seems to have helped this household as it could maintain a minimum inventory level in all the intervals following the disaster and has gradually tried to improve the inventory level by making daily purchases.

5. Discussion

The objective of the research is to develop a consumer behavior model in a disaster that can calculate the purchase intention taking into consideration the personal as well as situational factors. The model can guide us in identifying the most influential parameters with severe impact on the consumers. It can help identify the number of vulnerable people in need of the product. The results demonstrate the usage of the model. In the outcome of the trial setting, the purchase behavior of the agents in the pre-disaster phase is clearly based on the available inventory. However, in the disaster phase, we can see the changes in the

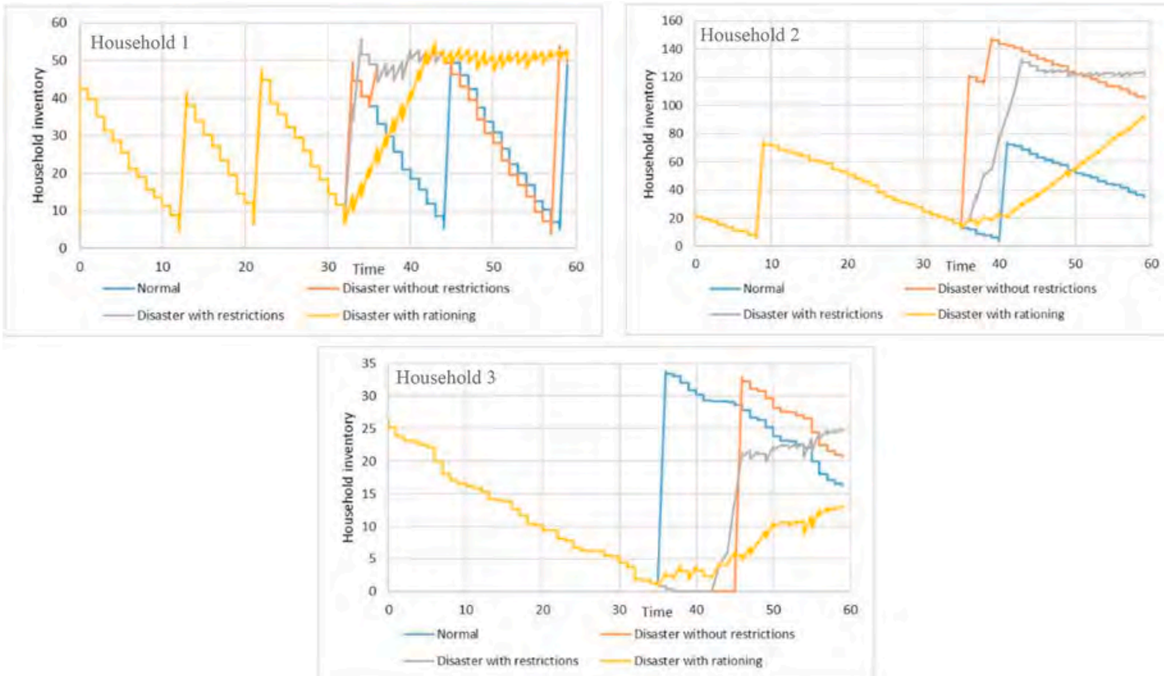

Fig. 10. The changes in consumer purchase pattern of the three households in different cases.

Table 4
Personal explanatory variables of the three agents.

Agent	Household size	Presence of children	Past purchase difficulty	Past stockpiling behavior	Risk friendliness	Anxiety level	Future stockpiling factor
1	4	0.78	2	1.17	0.5	0.74	1
2	3	0.61	1	1.68	0.57	0.35	2.17
3	1	0.89	2	1	0.71	0.49	1.2

purchase behavior of each agent. The effect of these situational factors is greater in the case of households 1 and 2. Even with sufficient inventory available for the next few days, the situational factors prompted the consumer to make a purchase. The supply, which was quite sufficient for the consumers fell back in satisfying the consumer requirement due to the stockpiling of such consumers. This impacted consumer such as household 3, who could not find the product in any of the stores in its vicinity even with a low stockpiling factor. Such behavior also leads to an increase in the number of people deprived of the product. As the current product is water, it is very difficult, especially when there is possible contamination, for people to manage without it for several days, as seen in the case of household 3. This situation elevates the importance of strategies. Any strategy which can allow providing to the consumers in need is necessary. The most popular is the sales restrictions with an easy implementation procedure. Implementing sales restrictions in 100% of the stores has helped in reducing the number of intervals, but still, household 3 had to survive several intervals without the product. The strategy of rationing has allowed providing this household in all the intervals, even though if it is a minimum quantity. Similar to the behavioral analysis of the three agents, the changes in the purchase pattern of each consumer can be analyzed, and the causes which provoked stockpiling can be identified, which will help a great deal in understanding consumer behavior in crises. This tool can further help in understanding herd behavior on a societal level, which is quite prevalent in crises.

We can conduct a survey in a community and use this methodology to study their behaviors. This casual analysis will lead to measures that can help reduce anxiety and stockpiling by identifying the most influential situational factor in the community and develop methods to control those elements in future disasters. The expected demand from the community can also be estimated in case of future disasters. Other control measures can also be tested which can build a resilient community for future disasters.

6. Conclusions

An agent-based simulation model has been developed to understand the changes in the purchase behavior of a consumer when a disaster occurs. A quantitative decision-making model has been implemented to calculate the stockpiling probability of the consumers, given the personal and situational factors, using a logistic transformation model based on a multiple regression analysis of a questionnaire survey. The changes in consumer behavior during a disaster can be observed, using this model, by setting various situations, such as a few stores employing restrictions, a lot of shortage reports, etc. This model can be implemented in the supply chain simulation model to calculate the response and effects of consumer stockpiling on the supply chain and test various mitigation methods to reduce or avoid disruptions.

We can study the behavior of people by conducting a survey in a certain area and using this model understand the community response in case of a disaster. The obtained outputs can lead the policymakers to restrict elements that could cause unsettlement among the public. Consumer behavior can be understood when measures such as quota policy are implemented and their reactions can be analyzed. The supply chain managers can take a cue from the output in building their disaster response plan with minimum impact on its productivity. There is an increasing need for more researchers to work on consumer stockpiling behavior to understand better and improve the situations in the future. Such tools are quite essential for the industrial sector and governments to mitigate future disaster scenarios.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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