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Customer Trust Versus Retailer Profit: A Case Study on Optimising Base Stock Level Using Multi-Agent-Based Simulation*

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Abstract

Trust plays an important role in supply chains as a binder between business partners as well as between a customer and a retailer. Customer's trust in a retailer depends, among others, on the retailer's ability to meet the customer's demand. Insufficient product availability leads to customer churn and lost revenue, while overstocking increases the retailer's operating costs. The retailer has to find the right balance between the costs of customer churn and the storage costs, but it is a demanding task due to the diversity of customers. This diversity can be modelled using a multi-agent approach. However, scientific literature contains too little research on overcoming the problem of finding the abovementioned balance using multi-agent technologies. In this paper, we examine customer's trust in a retailer and we show how replenishing warehouse stock (reorder point) affects the retailer's profits and customer's trust. A multi-agent software tool in NetLogo environment was developed to study the relationship between product availability, reorder point, a retailer's profit, and trust in a customer population. The tool allows its users to observe non-linear relationships between reorder point, profit, and trust, as well as determine the appropriate replenishment policy of the warehouse what is important for researchers dealing with customer-retailer relationships and the human factor in supply chains. It is also crucial for decision-makers responsible for inventory policy. The case study described shows how to use the tool to maximise a retailer's profit or maximise the number of products sold.

Keywords: multi-agent simulation, supply chain modelling, reorder point determination, stock level.

Introduction

The relationship between a customer (product recipient) and a retailer (product supplier) has a key impact on the functioning of the supply chain. Understanding this relationship is important for effective supply chain management (SCM). According to Sahay (2003), the relationship in a supply chain is significantly influenced by the recipient's trust in the supplier. Additionally, the paper by Ian Stuart et al. (2012) shows that one of the factors influencing trust is the ability to meet customer's demand for a product. Salam et al. (2016) underline that the ability to buy the right product, in the right quantity and at the right time affects not only the customer's trust and satisfaction, but also the retailer's profits. Customer trust in a retailer results in customer loyalty which, can translate into more purchases and greater profits for the retailer.

The research by Wang et al. (2020) shows that the most important tasks of SCM include choosing the right strategy for managing product inventory. Maintaining too high inventory levels will generate too high storage costs. On the other hand, too low inventory levels may not be sufficient to meet customer demand. This reduces the retailer's

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potential income and causes the customer's trust in the retailer to decrease. The situation described above is a problem of establishing the optimal balance between the cost of storing products and the cost resulting from the loss of potential sales revenues (cost-balance trade-off). The loss of potential revenue in this case is caused by two factors: (1) failure to serve customers due to the lack of products in stock (lost sales); (2) customers resigning from purchasing products, which is caused by the loss of trust in the retailer due to unsuccessful purchase attempts because of the lack of products in stock (customer churn).

In the above-defined cost-balance trade-off, the reorder point value is important. In the book by Axsäter (2015) the reorder point is defined as follows: when the amount of product in the warehouse is lower than or equal to the reorder point, then it is a signal to replenish the product inventory by ordering the product from the supplier. A relatively high reorder point will result in a large amount of products in the warehouse and, as a result, increased storage costs. In turn, a relatively low reorder point means smaller stocks of products in the warehouse and a higher probability of lost sales and customer churn. Therefore, the solution to the posed cost-balance trade-off problem comes down to determining the optimal inventory policy, the key element of which is the reorder point.

According to Takeda Berger et al. (2018), one of the techniques used to determine the optimal inventory policy is simulation. Simulation models can consider many factors related to the supply chain and product storage, such as reorder point, budget constraints, and warehouse capacity. Moreover, the reliability of suppliers and the randomness in their delivery capacities can be modelled. Wang et al. (2022) describe a special type of simulation called multi-agent simulation, where agents play the role of customers (recipients of products) in the supply chain. This allows the model to include customer characteristics, such as stochastic demand or customer trust in a retailer. Therefore, multi-agent models make it possible to study, among others, the impact of product availability on customer trust and their purchasing decisions.

The aim of the conducted research, the results of which are described in this paper, is to develop a tool that allows selecting the appropriate reorder point in order to obtain the optimal cost-balance trade-off. In connection with the research aim, two research questions were formulated: (RQ1) What is the impact of the reorder point in the logistics partner's warehouse on the retailer's net profits and on the level of customer trust in the retailer? (RQ2) How to use modelling and simulation techniques to determine the appropriate reorder point in order to obtain the optimal cost-balance trade-off between storage costs and costs due to lost sales and customer churn?

In summary, the conducted research consisted of developing and implementing a simulation model to select the optimal value of the reorder point, in order to maximise the retailer's net profit while ensuring an appropriately high level of customer trust. The answers to the research questions, which were obtained thanks to multi-agent modelling and simulation, are important primarily for researchers dealing with customer-retailer relations and the human factor in supply chains and production economics. The research results are also addressed to business professionals, whose task is to take care of customer relations and manage the warehouse policy of enterprises.

Literature Review

The literature review first attempts to answer the question of how trust is defined in the context of supply chains, what influences trust in supply chains, and how it can be modelled. The research described in this paper analyses the impact of the inventory level on the customer's trust in a retailer; therefore, the literature review finds factors influencing the inventory level and methods used to determine the appropriate inventory level. Particular attention was paid to how simulation methods are used for this purpose, because simulation was used in our research.

Trust in supply chains

The term 'trust' in the context of the relationship between a customer and a retailer has been present in the literature for many years (Doney and Cannon, 1997). Authors define trust in different ways (Paluri and Mishal, 2020). One of the definitions is as follows: 'the extent to which one party is willing to participate in a given action with a given partner, considering the risks and incentives involved' (Ruohomaa and Kutvonen, 2005).

Factors affecting trust in supply chains

Trust in a supply chain can be influenced by many factors. Therefore, measuring trust may not be feasible using a simple measure or a single criterion (Msanjila and Afsarmanesh, 2008). Trust can be expressed using numerical values or labels Consequently, the domain of trust values can be binary ('trusted', 'untrusted'), discrete (e.g., on a scale of several natural numbers from 'very untrusted' to 'very trusted') as well as continuous (Ries et al., 2006). Mathew et al. (2020), after reviewing the literature on various perspectives on trust assessment, identified several key trust factors considered by researchers: benevolence, credibility, ability, integrity, goodwill, and openness.

The degree and quality of information shared between supply chain partners also affect trust (Kwon and Suh, 2004). Effective information sharing reduces uncertainty and therefore increases mutual trust in a supply chain (Ayadi et al., 2013). Information that can significantly affect trust are inventory levels, sales data, order status and tracking, delivery schedule, and sales forecasts (Lee and Whang, 2000).

Another key factor in building trust is a supplier's reputation, which can be considered in many dimensions (Stravinskienė et al., 2021). Reputation depends especially on the reliability of delivery and the quality of the product (Ian Stuart et al., 2012), as well as on sales services quality (Paparoidamis et al., 2019).

Trust is also affected by the social characteristics and behaviour of supply chain partners, e.g. opportunism and selfish behaviour minimise trust, while benevolent behaviour can foster trust (Daudi et al., 2016).

Methods for research and modelling trust in supply chains

In summary, two approaches are most often used for research on trust: survey based and mathematical model based (Mathew et al., 2020). Questionnaire surveys are usually used to gather data for trust research between retailers and customers. Researchers are able to analyse trust in supply chains based on the data from the surveys thanks to, e.g., statistical data analysis (Ian Stuart et al., 2012), factor analysis and structural equation modelling (Kiwala et al., 2023), multiple regression and ANOVA (Chen et al., 2011), as well as use survey results to create fuzzy decision support systems (Ayadi et al., 2013). Moreover, semi-structured interviews carried out to empirically examine trust definition, as well as its factors and outcomes (Ghondaghsaz and Engesser, 2021).

Researchers uses also multi-agent technologies. They help to show how trust evolves in supply chains (Hossain and Ouzrout, 2012) or validate the performance of a multi-criteria decision-making approach that consider trust and reputation in supply chains (Chang et al., 2014). Other ways to measure, model, and evaluate trust in supply chains include: directed weighted trust evolution network models based on complex network theory (Zhang et al., 2022), a system dynamics approach (Yin et al., 2012), a behavioural experiment with gamification (de Siqueira Braga et al., 2017), a conceptual framework that can be used as a generalized trust measurement tool (Msanjila and Afsarmanesh, 2008), or a quantitative model of trust used to support decision making and risk analysis (Collier et al., 2021).

Inventory level and its impact on the cost-balance trade-off

The cost-balance trade-off, which is defined in this paper as a balance between inventory cost and costs due to lost sales and customer churn, can significantly impact retailer's profit. The balance is directly influenced by the size of the inventory stock (inventory level). Determining the optimal inventory level is crucial to ensure customer trust and satisfaction while minimising unserved customers and customer retention, as well as avoiding stockouts (Salam et al., 2016).

Finding the appropriate cost-balance trade-off is difficult due to the many factors that influence the total inventory cost. The total cost includes, in particular, holding cost, ordering cost, and costs resulting from ordering too few products (shortage cost). An additional cost-generating issue is over-ordering. It results in costs of renting additional space or returning goods to a manufacturer, which often generate penalty costs (Wang et al., 2020).

The amount of inventory held by a supply chain partner may depend on many factors, such as demand variability, lead times, replenishment level, order quantity, inventory holding costs, variety of products, number of dealerships, or size of the company (Casalin et al., 2017).

To determine the size of inventory levels, two approaches are used: continuous review and periodic review (Axsäter, 2015). Multiple research studies describe how to effectively achieve the cost-balance trade-off by establishing an adequate inventory level. Researchers use, among others:

- response surface methodology (Wang et al., 2020),
- a combination of genetic algorithms and simulated annealing (Diabat, 2014),
- a Markov decision process (Gayon et al., 2009),
- dynamic programming (Chen et al., 2016),
- reinforcement learning algorithms (Giannoccaro and Pontrandolfo, 2002),
- a mixed integer nonlinear programming (Guo and Li, 2014),
- heuristic approaches (Abdul-Jalbar et al., 2010).

Simulation research for determining inventory level

Simulation is often used in the context of supply chains because it offers many possibilities, such as establishing desired inventory levels even in the presence of uncertainty, comparing alternative supply chain models and predicting their performance (Takeda Berger et al., 2018). Simulation can also assess the validity of the selected inventory policy prior to its implementation. In a relatively short time (e.g. a few seconds) it is possible to examine certain phenomena that occur over long periods of time (e.g. several years) (Axsäter, 2015).

Discrete event simulation can be used to analyse different inventory management strategies taking into account stochastic behaviour on both the supplier and the customer sides (Takeda Berger et al., 2018). However, the system dynamics approach may in some respects be better than discrete event simulation in supply chains, and even both approaches can be combined (Al-Hawari et al., 2022).

Also, a multi-agent simulation is used in the context of supply chains to, e.g., maximise supply chain performance and efficiency (Wang et al., 2022), or describe the adaptability and dynamic behaviour of supply chain networks with an agent considers as a partner in a supply chain who selects suppliers and makes orders decisions based on trust (Hou et al., 2018). Multi-agent simulations are also used to verify supply chain models (Chang et al., 2014) and observe changes in trust between partners in the supply chain (Hossain and Ouzrout, 2012).

The use of multi-agent models and agent-based simulation for research related to SCM is justified due to the features of multi-agent systems, such as autonomy, distributed collaboration, and intelligence. These features naturally correspond to the characteristics of supply chains (Hossain and Ouzrout, 2012). However, after the literature review, the impression remains that the use of multi-agent simulation in the context of trust, supply chains, and setting an appropriate inventory policy is relatively rare.

In order to check how large the potential research gap is in the abovementioned area, a keyword analysis was conducted in publications from three scientific publication databases: Scopus, Web of Science, IEEE Xplore. 385 publications were found related to the topic of customer trust or satisfaction, as well as inventory levels in supply chains. Of these, only 7 publications concerned simulation and multi-agent technologies.

Applied methodology and model's characteristics

Based on the literature review, it can be concluded that most inventory management models only consider independently varying demand patterns, volume discounts, inventory costs, or lead time changes, but few models focus on customer relationships (Lam and Ip, 2011). To fill this gap, in our research we consider trust as a key factor influencing the supplier-customer relationship. We applied a periodic review approach with an interval of one day (one simulation cycle). Considering the advantages of multi-agent technology, and the desire to fill another gap related to the use of multi-agent simulation in the research on trust in the context of inventory policy, we assumed that in the conducted research will use a multi-agent model.

Introduction to the case study

In the case study, the retailer is considered, who sells products to the final customers. The analysis of the company's sales data shows that average sales per day is 7.5 pcs and the average customer makes one additional attempt to purchase the product at the retailer if his earlier purchase was not successful because of an out-of-stock event. The number of customers served per month varies from 50 to 110 clients. Customer satisfaction's surveys show that a successful purchase increases the customer's trust in the retailer by 2.5 points on a 10-point scale. Because of the retailer's location, the company does not have its own product's warehouse, but the products are delivered to customers directly from a logistics partner's warehouse and the storage costs include the following elements:

- fixed costs – related to renting warehouse space from the logistics partner – are equal to $8.31 / 1 ft2 / year; 1pcs of the product requires 10.5 ft2,
- variable costs – related to handling the products in the logistics partner's warehouse – are equal to $3.18 per day / 1 product.

The initial stock of products at the logistics partner is equal to 30 pieces. Sales price of 1 pc. of product is equal to $150, total costs of producing and transporting 1 pc. of product to the logistic partner's warehouse are estimated at 70% of the final sales price.

The retailer wants to know: how to choose the optimal level of base stock at a logistics partner's warehouse, that will enable the maximisation of profit achieved by the retailer. The optimal level should be set to the value, which, on the other hand, ensures that the average level of customer trust to the retailer will be high enough (above 95%). The retailer wants to test the following set of various base stock levels: 1, 2, 3, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18 and 20 pcs.

Research problems solving process

The research work consisted of three main groups of activities:

1. Preparation of a simulation model: analysis of the case study, developing a conceptual model and a graphical user interface (GUI), developing a simulation model by translating the conceptual model into appropriate structures of the NetLogo programming language, verification and validation of the developed simulation model;
2. Using the simulation model prepared as a software tool for simulation experiments: setting the simulation parameters according to the case study, conducting simulation process, recording values of selected metrics;
3. Analysing and visualizing recorded values according to the research problem.

During examination of the research problem, as well as description of the case study, a set of model assumptions was formulated.

<u>Model assumptions</u>

The model assumptions are as follows:

1. Each simulation cycle represents one business day.
2. There are two types of agents in the model: customers and one retailer.
3. Customer characteristics:
    a. The customer's task is to purchase the product from the retailer with a specific frequency. Depending on whether the purchase was successful or not, the customer's current level of trust is increased or decreased.
    b. The level of trust is measured individually for each customer and takes integer values from 0 to 100.
4. The parameters of the modelled customer community:
    a. Number of customers participating in the experiment (0 to 200).
    b. Probability of making a purchase by the customer – the customer's chance to purchase one item in the current simulation cycle; set globally for all customers (0 to 100 [%] with a step of 0.1).
    c. Initial trust value of the consumer in the first simulation cycle – set globally for all customers (0 to 100 with a step of 1).
    d. Customer's reaction to the lack of a product at the retailer – reduces customer's trust after an unsuccessful purchase attempt; set globally for all customers (-100 to 0 with a step of 1).
    e. Customer's reaction to purchasing a product from a retailer – increases customer's trust after purchasing the product; set globally for all customers (0 to 100 with a step of 1).
5. The retailer's characteristics:
    a. The retailer's task is to sell products to customers by reducing the current inventory of products and calculating the profit from sales. At the end of business day, if the current stock level is lower than or equal to the set reorder point, the delivery of products is made. The delivery replenishes the current stock level up to the base stock level.
    b. An important parameter for the retailer is the current stock level, which takes values which are integer positive type.
6. Other parameters characterising a retailer:
    a. Initial product stock level – the size of stock at the first simulation cycle (integer positive values).
    b. Base stock level – critical due to the research goal; determines how many products will be available at the retailer at the beginning of the business day; when the current stock level falls below the base stock level, delivery is planned (integer positive values).
    c. Unit product profit – significant due to the research goal; used to measure the effectiveness of a solution (positive real values).
    d. Daily unit storage cost – significant due to the research goal; depends on the number of products stored in the warehouse (positive real values).

   e. Daily fixed storage cost – important due to the research goal; used to measure the effectiveness of a solution; independent of the number of products stored in the warehouse (positive real values).
7. The proposed model includes a set of metrics to evaluate the potential solution:
   a. Total and daily number of completed orders by the retailer.
   b. Total number of product shortages.
   c. Total number of orders realised by the competitors.
   d. Percentage of completed orders by the retailer.
   e. Total number of deliveries made to replenish the current stock level to achieve the base stock level.
   f. Daily and current level of products.
   g. Daily and total profit generated from sales.
   h. Daily and total storage cost.
   i. Daily and total net profit/loss.
   j. Daily and current average customer trust level.

<u>Model simplifications</u>
The model created uses simplifications that consist in considering only those factors that are crucial for the research problem under consideration and were presented in the case study.

In the current version of the model, the simplifications are as follows:
- Deliveries ordered at the end of a given business day are available to the retailer at the beginning of the next business day,
- The costs of delivering products do not affect the retailer's profit;
- All customers in the population start with the same level of trust;
- All customers react in the same way to the different events like successful or not successful purchase transactions;
- The frequency of buying is the same for every customer;
- No customer's budget restrictions;
- The products offered by the retailer and its competitors are identical to each other, also in terms of price;
- All sales transactions concern one unit of a product;
- Products are sold to customers by one unit per business day.

The presented restrictions can have a significant impact on solutions generated by the developed tool, therefore further research was planned to include at least those factors in the model that were considered as the most important (see Discussion section).

Scheme of the simulation model developed

The way the model acts is presented by using activity diagrams. The first diagram (Fig. 1) shows that the developed tool works by performing four main activities:
1. Initialisation of the simulation environment.
2. Creating a population of customers visualised using coloured icons from red (low level of trust) to green (high level of trust)
3. Creating retailer.
4. Run the simulation – this subprocess is presented in detail in Fig. 2.

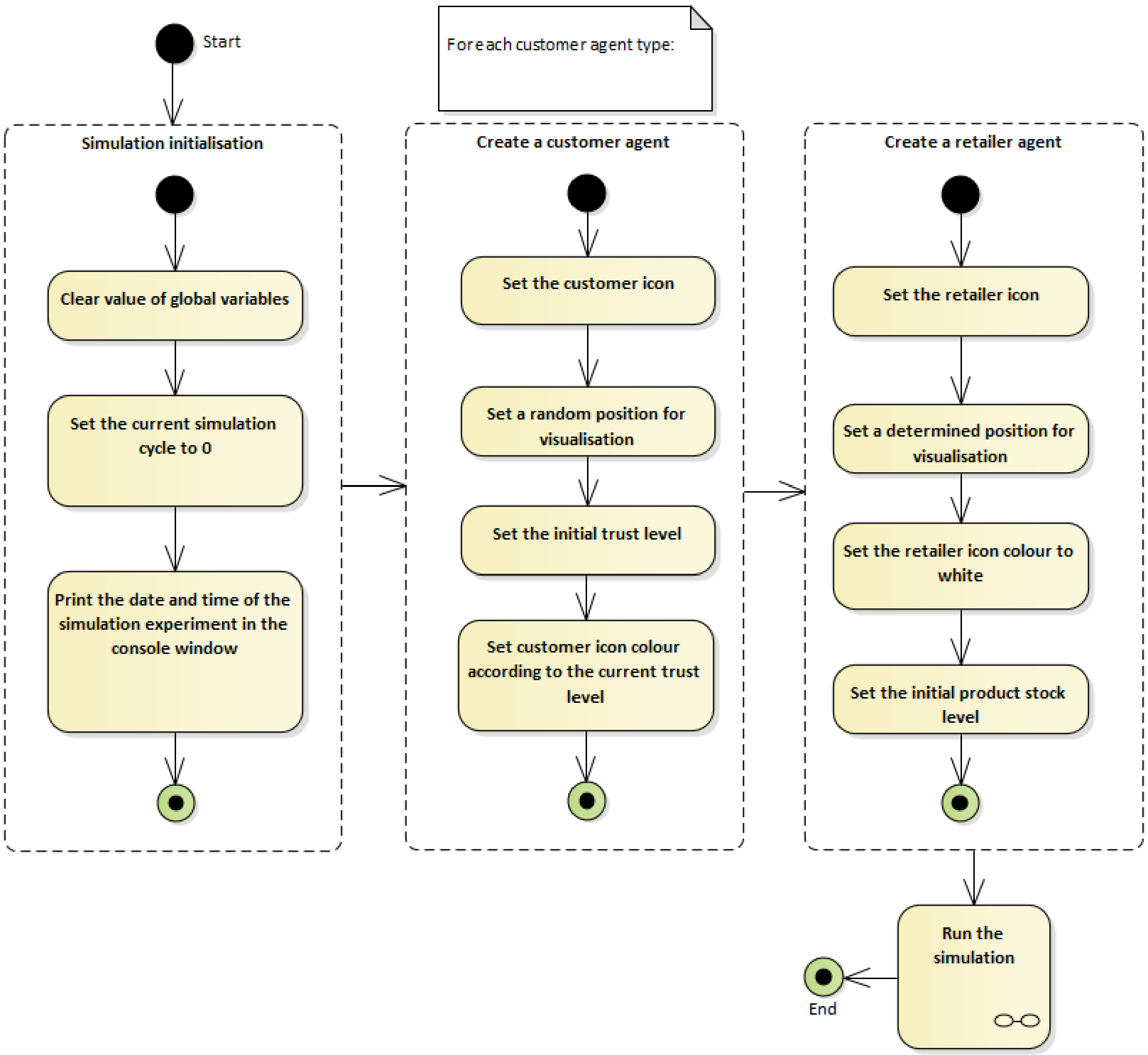

Fig. 1. Overview of the developed tool's control flow

The activities in the subprocess (Fig. 2) are conducted in an iterative way and the main steps are as follows:

1. The number of the current simulation cycle is checked according to the simulation limit.
2. Global variables connected to the daily metrics are reset.
3. Simulation of the customer's need by drawing a random number from 0 to 100 (uniform distribution) is performed for each customer agent; each agent performs appropriate activities depending on their needs, trust level and product availability at the retailer.
4. The retailer's stock policy takes place by checking if the replenishment delivery is necessary.
5. Calculated values are linked to specific metrics and stored and the whole process is repeated until the end of the simulation.

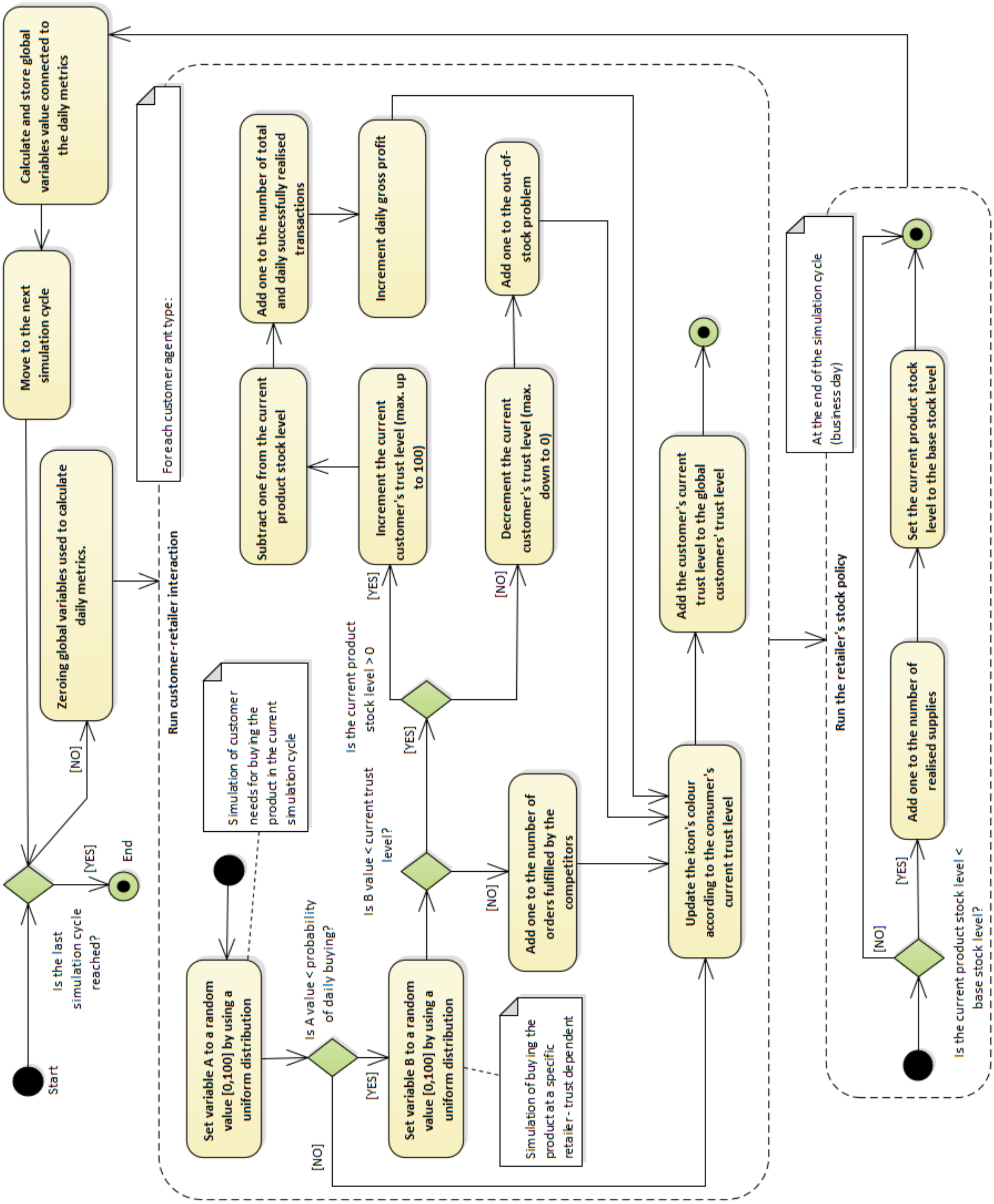

Fig. 2. Developed simulation model's control flow

Graphical User Interface (GUI) of the developed tool

The simulation model was developed in NetLogo software designed by Wilensky (1999), which also allows a user to run a simulation, as well as save and export simulation results. In the book by Wilensky and Rand (2015) detailed information about the used software can be found.

The model was prepared in the form of a software tool with a GUI, which enables defining the parameters of the model itself and the simulation experiment parameters as well. The GUI consists of monitor components, which allow it to read the generated simulation results connected to specific metrics. The GUI also contains plot components, which allow for quick check of changing values during the simulation. The overview of the entire GUI is shown in Fig. 3 with sections numbered from A to E, which are described in the following paragraphs.

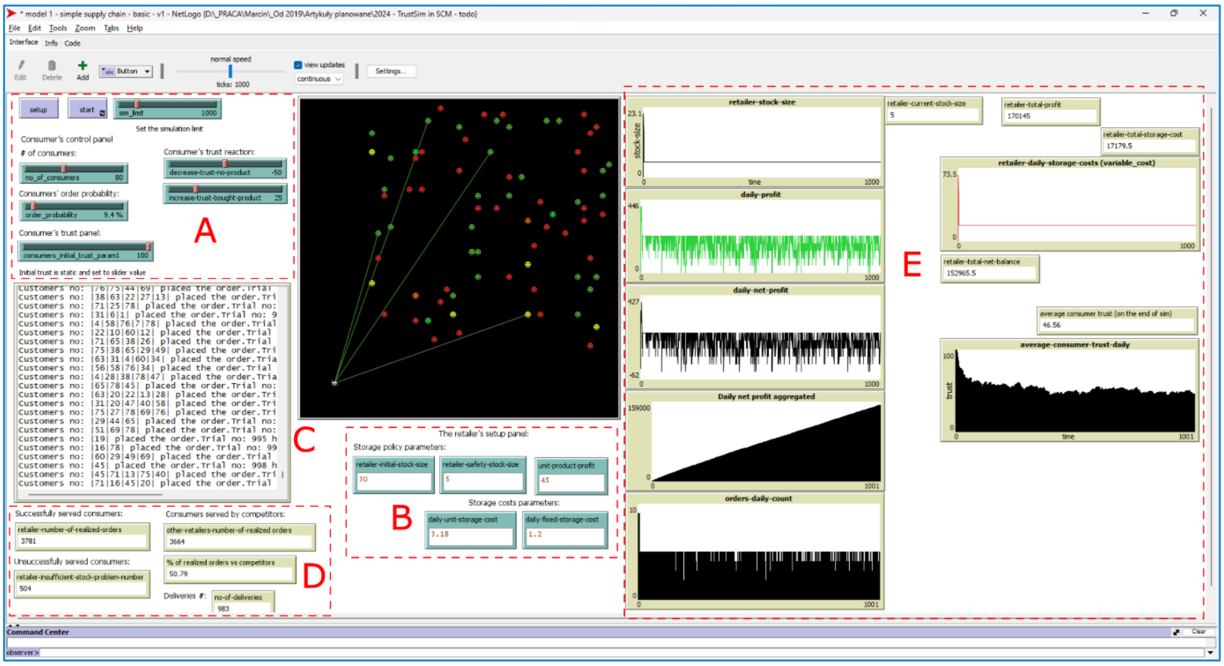

Fig. 3. The overview of the GUI of the developed tool

Functionalities in section A (Fig. 4) are as follows:

- Setting the customer population size,
- Defining the chance of the customer to make a purchase in the current simulation cycle,
- Setting the initial level of customer's trust,
- Defining the customer's reaction to the out-of-stock problem,
- Setting the customer's reaction to the successful purchase of the product,
- Determining the duration of the simulation experiment,
- Initialising the simulation and sending the initial parameters to local and global variables,
- Running the simulation experiment.

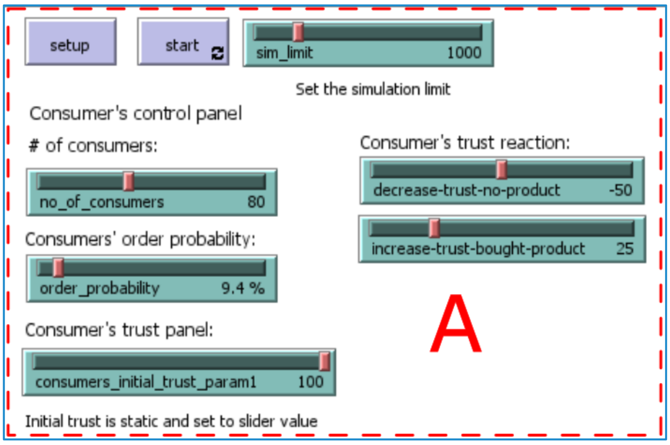

Fig. 4. Customer's control panel

Section B (Fig. 5) allows to set parameters related to the retailer such as: the initial product's stock level, the proposed base stock level, the gross profit of the product per sale, the daily variable storage cost, the fixed storage cost.

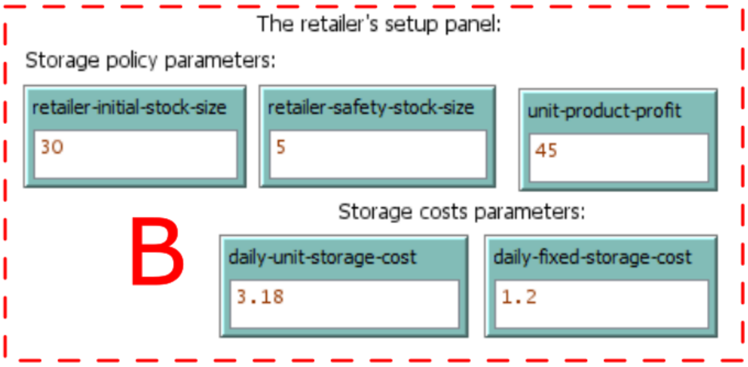

Fig. 5. Retailer's control panel

Section C (Fig. 6) consists of the console screen, as well as the visualisation screen. The console screen allows to track information about the current simulation cycle and customers who wanted to make a purchase at the retailer at this time. The visualisation screen presents the customers population and the retailer by the icons, as well as interactions between these agents represented by lines.

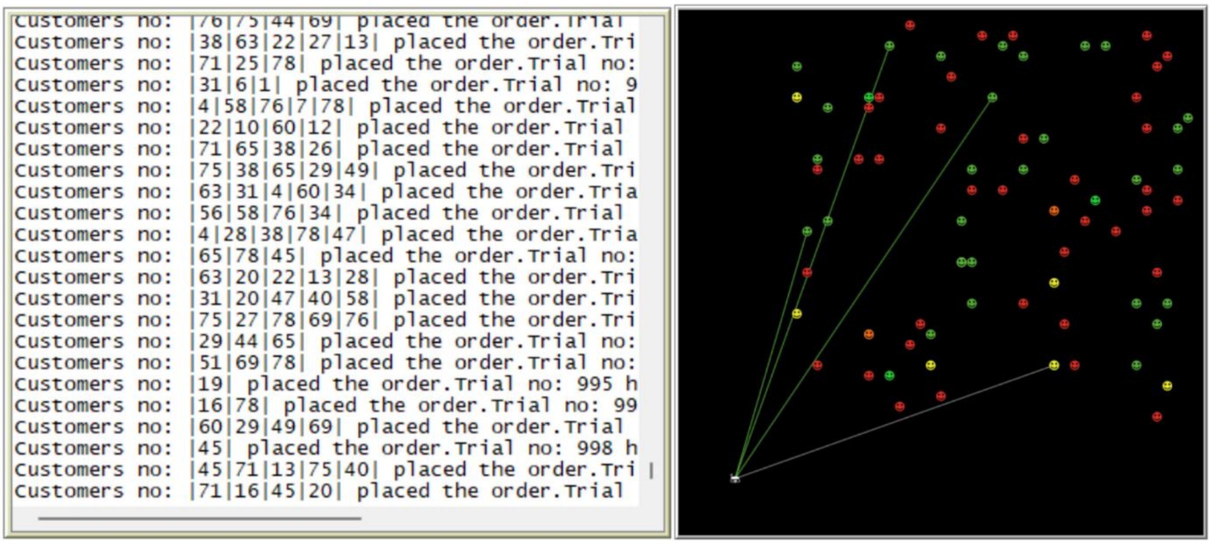

Fig. 6. System console and visualisation screen

Section D (Fig. 7) consists of the 'monitors' that enable to display the proposed metrics (see Section 3.2.1).

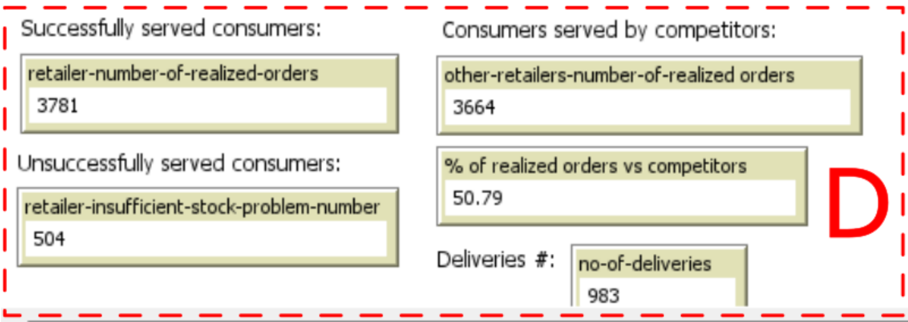

Fig. 7. Metrics info panel

The E section (Fig. 8) is created using the 'monitor' and 'plot' components in order to display and visualise another metrics.

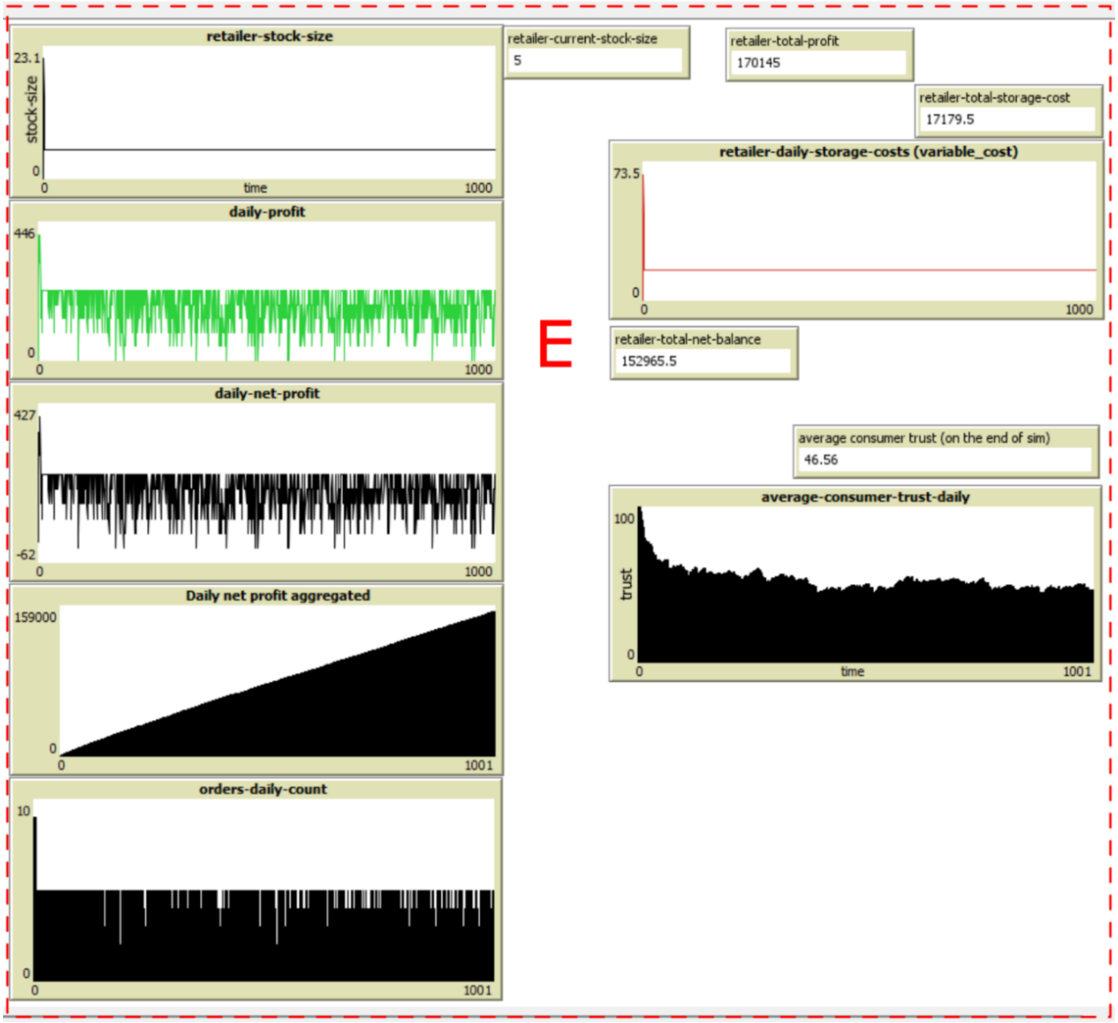

Fig. 8. Graphs info panel

Experimental research

During experimental research, the proposed software tool was used to examine the case study in order to answer the two research questions:

1. How different the proposed levels of base stock influence the generated profit by the retailer and the trust level in the customers population?
2. How do modelling and simulation techniques help to find the optimal cost-balance between generated storage costs and costs due to lost sales and customer churn?

Other auxiliary questions have been formulated: does NetLogo environment allow to develop the software tool, which can be used to model specific situations and problems in the SCM area as well as solve them? Is the tool elastic enough to incorporate some modifications of the basic model to discover new analysis perspectives?

At first, the information presented in the case study (section 3.1) has been mapped into model characteristics in the following way:

- number of customers (‘no_of_consumers’) = 80, as an average of the range <50, 110>;
- ‘order_probability’ = 9.4%, because number of orders placed by customers = 7.5 pcs/day and the ‘order probability’ p is calculated as follows: $80 \cdot p = 7.5 \leftrightarrow p = 0.09375 \approx 9.4\%$;
- initial customer’s trust level in the retailer (‘consumers_initial_trust_param1’) = 100%;
- change in the current customer’s trust level due to the product out-of-stock (‘decrease-trust-no-product’) = -50%;
- change in the current customer’s trust level due to the successful purchase (‘increase-trust-bought-product’) = 25%;

- daily variable storage costs per product unit (‘daily-unit-storage-cost’) = $3.18;
- daily fixed storage costs (‘daily-fixed-storage-cost’) = $(8.31 \cdot 10.5 \cdot u) / 365$, where u is proposed base stock level;
- initial product stock (‘retailer-initial-stock-size’) = 30;
- unit profit from sales (‘unit-product-profit’) = $150 − $150 · 70% = $150 − $105 = $45.

The simulation experiment parameters were as follows:

- a single run of the simulation experiment was 1000 cycles,
- each simulation experiment was conducted with a different value of the base stock level ‘u’,
- each simulation experiment was repeated five times to ensure the right implementation of the proposed distributions in the model’s variables, as well as to average output values,
- the following set of metrics was proposed according to case study’s problem:
    - the number of orders completed by the retailer,
    - the number of out-of-stock problems,
    - the number of orders completed by the competitors,
    - the percentage of orders completed by the company compared to the numbers of orders fulfilled by the competitors,
    - the total gross profit generated,
    - the total storage cost generated,
    - total net profit/loss,
    - customer trust level measured by average, minimum, maximum, and standard deviation values.

80 simulation runs were performed. After that, the source data was exported and the proposed metrics were calculated using appropriate formulas in MS Excel.

Results of the simulation experiment

Fig. 9 helps find out which base stock level will be able to generate maximum net profit. A significant increase of net profit can be noticed while increasing the current level of base stock. Such an increase cannot continue to infinity because the retailer cooperates with a finite number of clients, for which saturation point occurs. Therefore, the net profits earned by the company will reach a certain maximum level for a specific base stock level. Continuing to make the base stock level higher no longer increases the net profit because all customers were served. Moreover, such an increase will result in increasing storage costs, which will consume the generated profit. In the presented case study, the highest net profit will be achieved when the base stock level of products is set at 13 pieces. The net profit generated in such a situation should be in the range of $308,684.56 to $316,524.10 with a mean of $312,618.29 and a standard deviation of $2,871.13.

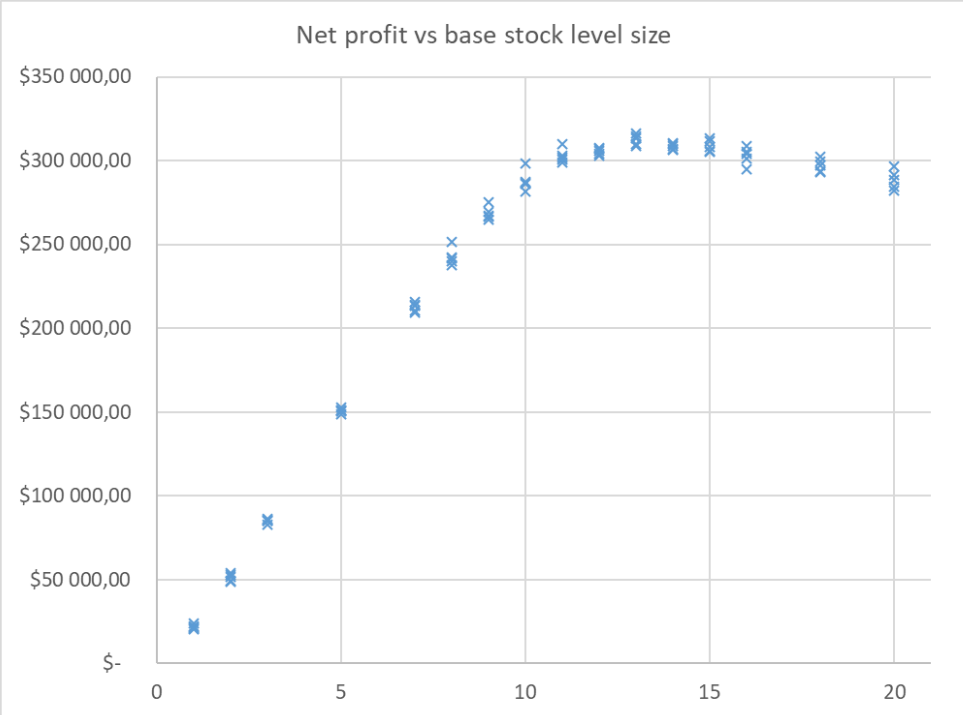

Fig. 9. Net profit according to the base stock level

To check whether the average level of customer's trust exceeds the indicated threshold of 95%, Table 1 was made.

Table 1. Base stock level according to the customer population's trust

Base stock level	Min. avg. trust in 5 sim. runs	Avg. trust in 5 sim. runs
1	4.06	10.25
2	11.56	20.33
3	22.19	31.53
5	40.63	51.89
7	59.69	70.60
8	66.25	79.39
9	73.75	86.76
10	85.94	92.71
11	88.75	96.16
12	91.88	98.06
13	95.31	99.31
14	96.25	99.48
15	96.25	99.85
16	97.50	99.91
18	99.38	100.00
20	100.00	100.00

In Table 1, the base stock level, which generates the highest average customer's trust level, is marked green. It means that all of the customers will be served successfully. The proposed 13 pcs for base stock level (marked yellow) results in the average customer's trust equal to 99.31%, which exceeds the assumed threshold value. What is more, the lowest average customer's trust value from one of five simulation runs also exceeds the threshold and it is equal to 95.31%.

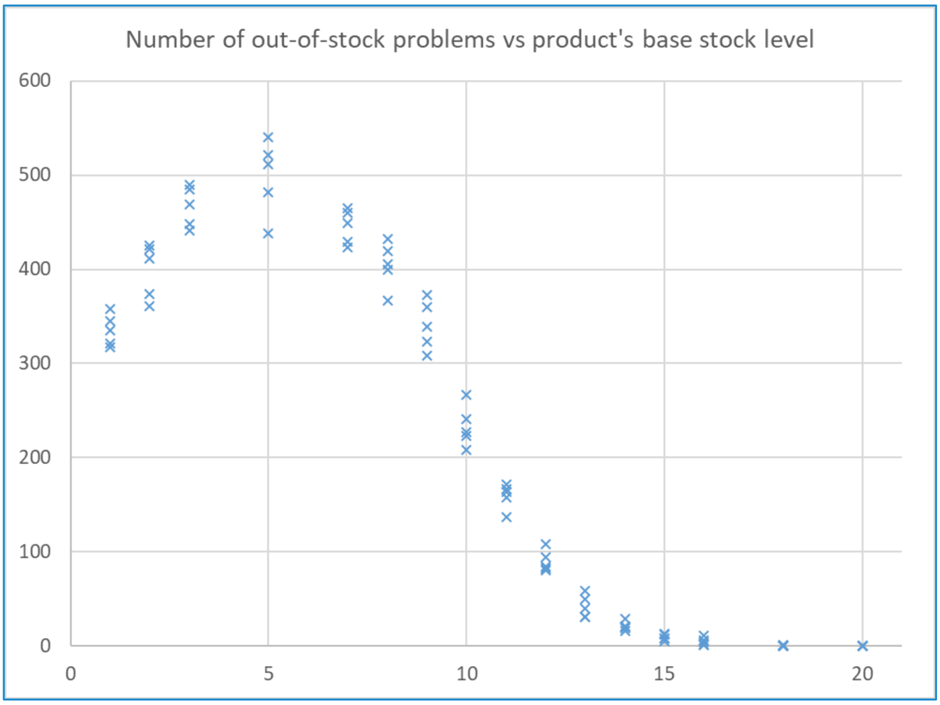

Fig. 10. Number of recorded out-of-stock problems with respect to product's base stock level

Fig. 10 and 11 are the result of additional analyses, which were out of scope of the basic case study, but found interesting to the retailer's decision makers. Fig. 10 shows the dependency between product availability and product's base stock level was checked. The relation seemed very simple; the bigger base stock level, the availability of the products is higher, but experimental data have shown something more. The shape of the presented curve is partially easy to interpret. If a product's base stock level increases, it reduces the number of out-of-stock problems because the product is available in larger quantities. However, it is initially difficult to explain why the curve inclination rises, when the base stock level is from the range between 1 and 5 pieces. Why using 1 pc. as the product's base stock level generates less out-of-stock problems than, for example, adopting a product's base stock level equal to 5 pcs?

After a detailed analysis, it turned out that if the product's base stock level is very low, customers will rarely be able to buy the product. It causes quick loss their trust in the retailer. If this happens repeatedly, because of the low base stock level, customers quickly learn that the retailer is unreliable and they start to buy the products from competitors. So, the retailer does not even know about its lost customers.

The last element examined was the relation between the standard deviation of customer's trust level according to the product's base stock level (Fig. 11). The relation is not surprising. Low product availability causes that only few customers have a chance to buy the product. So large disparities in the level of trust between individual customers who bought and did not buy products occur. It will translate into the large standard deviation. Beneficial to the retailer was the analysis of the slope of the presented curve and the fact that the relationship is not linear. This means that increasing the stock level by each unit will not translate into a linear increase in trust in the analysed community. The following trends were noted:

- in the values range between 0 and 5 pcs the curve has a significant slope, but smaller than in the ranges from 5 to 10 pcs,
- in the values range from 5 to 10 pcs the decrease of the standard deviation is the most rapid, which suggests that setting the stock level value in this range will translate into the largest increase in the average level of customer's trust to the retailer,
- if the range above 10 pcs is taken under consideration, the curve flattens, which means that the trust levels of individual customers are levelling out, due to the full availability of the product. However, getting 20 pcs as the product's base stock level may not be optimal as shown before.

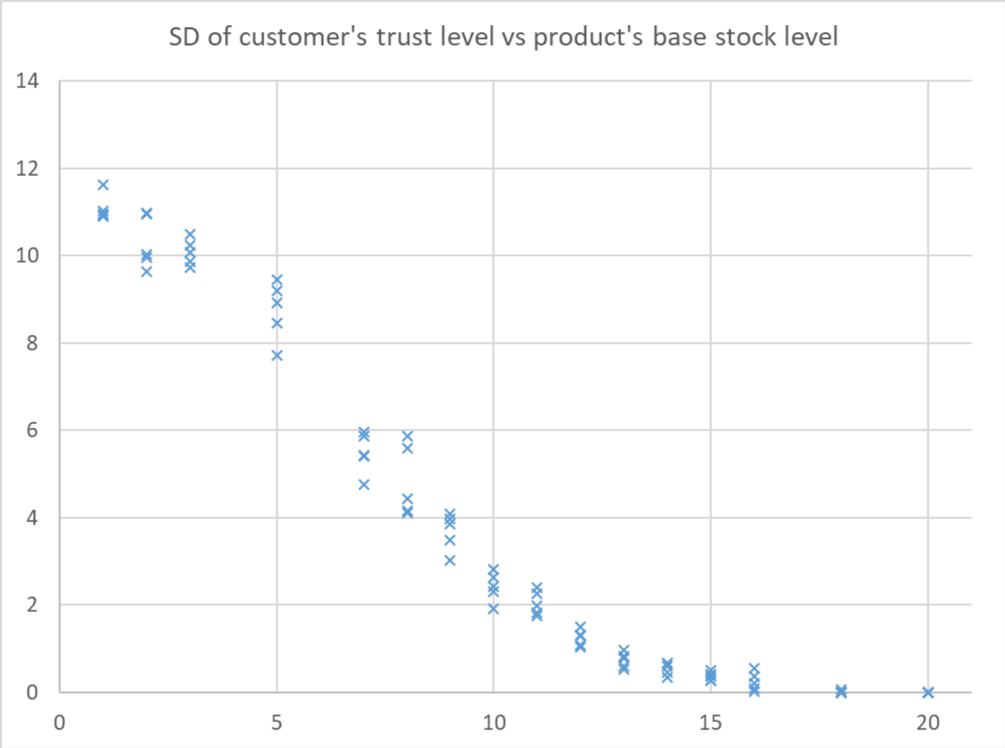

Fig. 11. Customer’s trust level SD and product’s base stock level

Discussion

The analysis of the results gave an opportunity to answer both research questions. The results of the experiment clearly show the impact of the reorder point (the base stock level in our case study) on the retailer’s net profit, which answers the RQ1. The relationship between the reorder point and the retailer’s net profit is non-linear. The net profit increases if the reorder point value increases, but only up to a certain value of the reorder point. After exceeding this value, the net profit decreases. The simulation experiments conducted, allowed determining the optimal base stock level, which maximises the net profit while ensuring appropriate, high level of customer’s trust, on the other hand.

Considering the impact of the reorder point on the level of customer trust in the retailer (the second part of the RQ1), the results reveal the non-linear relationship between them. In general, the trust grows if the reorder point value increases. When the reorder point value rises, we see a rapid increase in trust at first. However, after exceeding a specific value of the reorder point, the increase in trust slows down significantly. The developed tool calculates the average trust of the customers’ population for each reorder point considered, which allowed to determine this specific value.

The adopted process of research problem solving allowed for the development of the model and the use of multi-agent simulation to determine the desired reorder point for the optimal cost-balance trade-off (RQ2). Thanks to the developed tool, all case study assumptions were successfully incorporated within the simulation model. Moreover, the tool was flexible enough to support some modifications of the simulation model. This is possible due to the GUI in NetLogo that gives a model’s user the ability to introduce some changes in a simple and intuitive way. The proposed solution gives the possibility to extend the basic analysis process and – in some cases – discover new information that can be potentially important to the decision makers.

Moreover, incorporating elements of the GUI such as monitors and plots, gives the possibility to make additional analysis, e.g., dependency between product availability and product’s base stock level. It turns out that setting the base stock level too low, not only has a negative impact on the number of successfully served customers and lower generated profit, but it causes loss of the information about the customer population that buy products at competitors. The analysis of the relationship between the standard deviation of customer’s trust level and the product’s base stock level provides a picture of another nonlinear dependency. Its observation allows us to estimate how much trust differentiation will occur in the customer population for a given base stock level.

Conclusions

This paper presents a developed tool for creating a simulation model using multi-agent approach, which can be used to analyse the relationships occurring in supply chains. From the point of view of the research described, the impact of the reorder point on customer trust in the retailer and on the retailer's profit, is of particular interest. The simulation model developed and its implementation in the form of multi-agent simulation in the NetLogo allows to determine optimal product's base stock level, as well as find the optimal cost-balance between generated storage costs and costs due to lost sales and customer churn. The simulation model gives the opportunity to examine how changes in the base stock level influence, e.g., the gross and net profit generated by the retailer, the availability of the products and out-of-stock problems, the generated storage costs, the number of orders made or changes in customer's trust.

Directions of practical applications

Practical use of the simulation model implemented by companies is possible, but in this case, it is necessary to provide or estimate all required parameters of the simulation model and accept its limitations and simplifications. Some required input parameters can be quite easily provided by the enterprise, e.g. from the sales data analysis or warehouse management costs analysis. However, some of the input parameters, mainly related to the customer's trust modelling, can be more difficult to obtain.

The results generated during simulation experiments can bring potential benefits to the company. The proposed simulation model seems interesting for decision-makers, who manage the specific area of an enterprise, in order to find the optimal product's base stock level according to the metrics formulated.

The selected target implementation platform (NetLogo) also allowed the development of a software tool, which can be effectively used by a user who is not an IT specialist. It is because of the clear and easy-to-use GUI, where various model parameters can be set and modified, and the user can perform his own analysis.

The implemented model allows to conduct simulation experiments and obtains results that can be analysed and lead to the selection of the optimal product's base stock level according to the proposed metrics. The current version of the model already allows an extended analysis of the generated results to find new information or unknown or previously unobserved dependencies. The developed solution may be addressed to researchers, who are interested in the human factor in the economics of production or in the management of supply chain elements, to show how difficult-to-measure issues can be translated into financial results.

The use of multi-agent simulation is interesting because it enables the creation of communities with specific structural and behavioural characteristics, where relatively simple actions of the agent in a microscale can generate interesting results in a macro scale that were initially not expected.

Further research

During the current research, some ideas according to further research has been formulated. Main research areas are as follows:

- It seems obvious that delivery time, size of the delivery, as well as delivery costs should be taken under consideration in the solution generated by the proposed model.
- There is a need to check how various initial customer's level of trust will change the proposed solution, because the customers in the population are different from each other.

Moreover, there is a need to diversify the customer population according to the degree of sensitivity to positive and negative events related to the successful or unsuccessful sale transactions. It seems that creating groups of customers, which share common characteristics in the group will bring the model realism higher. To implement presented features, the conceptual and simulation model must be modified and tested, but the proposed changes seem to be possible to incorporate.

References

- Abdul-Jalbar, B., Segerstedt, A., Sicilia, J. and Nilsson, A. (2010) 'A new heuristic to solve the one-warehouse *N*-retailer problem', *Computers & Operations Research*, 37 (2), 265-272. https://doi.org/10.1016/j.cor.2009.04.012

- Al-Hawari, T., Gailan Qasem, A., Smadi, H., Arauydah, H. and Al Theeb, N. (2022) 'The effects of pre or post delay variable changes in discrete event simulation and combined DES/system dynamics approaches in modelling supply chain performance', *Journal of Simulation*, 16 (2), 147-165. https://doi.org/10.1080/17477778.2020.1764399
- Axsäter, S. (2015) Inventory Control, Springer International Publishing, Cham. https://doi.org/10.1007/978-3-319-15729-0
- Ayadi, O., Cheikhrouhou, N. and Masmoudi, F. (2013) 'A decision support system assessing the trust level in supply chains based on information sharing dimensions', *Computers & Industrial Engineering*, 66 (2), 242-257. https://doi.org/10.1016/j.cie.2013.06.006
- Casalin, F., Pang, G., Maioli, S. and Cao, T. (2017) 'Inventories and the concentration of suppliers and customers: Evidence from the Chinese manufacturing sector', *International Journal of Production Economics*, 193, 148-159. https://doi.org/10.1016/j.ijpe.2017.07.010
- Chang, L., Ouzrout, Y., Nongaillard, A., Bouras, A. and Jiliu, Z. (2014) 'Multi-criteria decision making based on trust and reputation in supply chain', *International Journal of Production Economics*, 147, 362-372. https://doi.org/10.1016/j.ijpe.2013.04.014
- Chen, J.V., Yen, D.C., Rajkumar, T.M. and Tomochko, N.A. (2011) 'The antecedent factors on trust and commitment in supply chain relationships', *Computer Standards & Interfaces*, 33 (3), 262-270. https://doi.org/10.1016/j.csi.2010.05.003
- Chen, R.R., Cheng, T.C.E., Choi, T.M. and Wang, Y. (2016) 'Novel Advances in Applications of the Newsvendor Model', *Decision Sciences*, 47 (1), 8-10. https://doi.org/10.1111/deci.12215
- Collier, Z.A., Guin, U., Sarkis, J. and Lambert, J.H. (2021) 'Decision model with quantification of buyer-supplier trust in advanced technology enterprises', *Benchmarking: An International Journal*, 29 (10), 3033-3056. https://doi.org/10.1108/BIJ-06-2021-0336
- Daudi, M., Hauge, J.B. and Thoben, K.-D. (2016) 'Behavioral factors influencing partner trust in logistics collaboration: a review', *Logistics Research*, 9 (1), 19. https://doi.org/10.1007/s12159-016-0146-7
- de Siqueira Braga, D., Niemann, M., Hellingrath, B. and de Lima Neto, F.B. (2017) 'The Game of Trust: Using Behavioral Experiment as a Tool to Assess and Collect Trust-Related Data', Trust Management XI, Steghöfer, J.-P., Esfandiari, B. (eds.), Springer International Publishing, Cham. https://doi.org/10.1007/978-3-319-59171-1_4
- Diabat, A. (2014) 'Hybrid algorithm for a vendor managed inventory system in a two-echelon supply chain', *European Journal of Operational Research*, 238 (1), 114-121. https://doi.org/10.1016/j.ejor.2014.02.061
- Doney, P.M. and Cannon, J.P. (1997) 'An Examination of the Nature of Trust in Buyer-Seller Relationships', *Journal of Marketing*, 61 (2), 35-51. https://doi.org/10.2307/1251829
- Gayon, J.-P., Benjaafar, S. and de Véricourt, F. (2009) 'Using Imperfect Advance Demand Information in Production-Inventory Systems with Multiple Customer Classes', *Manufacturing & Service Operations Management*, 11 (1), 128-143. https://doi.org/10.1287/msom.1070.0201
- Ghondaghsaz, N. and Engesser, S. (2021) 'Identification of factors and outcomes of trust in mobile supply chains', *European Journal of Management and Business Economics*, 31 (3), 325-344. https://doi.org/10.1108/EJMBE-05-2021-0155
- Giannoccaro, I. and Pontrandolfo, P. (2002) 'Inventory management in supply chains: a reinforcement learning approach', *International Journal of Production Economics*, 78 (2), 153-161. https://doi.org/10.1016/S0925-5273(00)00156-0
- Guo, C. and Li, X. (2014) 'A multi-echelon inventory system with supplier selection and order allocation under stochastic demand', *International Journal of Production Economics*, 151, 37-47. https://doi.org/10.1016/j.ijpe.2014.01.017
- Hossain, S.A. and Ouzrout, Y. (2012) 'Trust model simulation for supply chain management', 15th International Conference on Computer and Information Technology (ICCIT), ISBN: 978-1-4673-4833-1, December 2012, Chittagong, Bangladesh, 376-383. https://doi.org/10.1109/ICCITechn.2012.6509744
- Hou, Y., Wang, X., Wu, Y.J. and He, P. (2018) 'How does the trust affect the topology of supply chain network and its resilience? An agent-based approach', *Transportation Research Part E: Logistics and Transportation Review*, 116, 229-241. https://doi.org/10.1016/j.tre.2018.07.001
- Ian Stuart, F., Verville, J. and Taskin, N. (2012) 'Trust in buyer-supplier relationships: Supplier competency, interpersonal relationships and performance outcomes', *Journal of Enterprise Information Management*, 25 (4), 392-412. https://doi.org/10.1108/17410391211245856
- Kiwala, Y., Olivier, J. and Kintu, I. (2023) 'Antecedents and enablers of supply chain value creation: An analysis of trust and competences', *Development Southern Africa*, 40 (3), 580-598. https://doi.org/10.1080/0376835X.2022.2029356

- Kwon, I.-W.G. and Suh, T. (2004) 'Factors Affecting the Level of Trust and Commitment in Supply Chain Relationships', *Journal of Supply Chain Management*, 40 (1), 4-14. https://doi.org/10.1111/j.1745-493X.2004.tb00165.x
- Lam, C.Y. and Ip, W.H. (2011) 'A customer satisfaction inventory model for supply chain integration', *Expert Systems with Applications*, 38 (1), 875-883. https://doi.org/10.1016/j.eswa.2010.07.063
- Lee, H.L. and Whang, S. (2000) 'Information sharing in a supply chain', *International Journal of Technology Management*, 20 (3), 373-387. https://doi.org/10.1504/ijtm.2000.002867
- Mathew, M., Sunny, J. and Pillai, V.M. (2020) 'Review on Perspectives in Supply Chain Trust Evaluation', Proceedings of International Conference on Intelligent Manufacturing and Automation, Vasudevan, H., Kottur, V.K.N., Raina, A.A. (eds.), Springer, Singapore. https://doi.org/10.1007/978-981-15-4485-9_30
- Msanjila, S.S. and Afsarmanesh, H. (2008) 'Trust analysis and assessment in virtual organization breeding environments', *International Journal of Production Research*, 46 (5), 1253-1295. https://doi.org/10.1080/00207540701224350
- Paluri, R.A. and Mishal, A. (2020) 'Trust and commitment in supply chain management: a systematic review of literature', *Benchmarking: An International Journal*, 27 (10), 2831-2862. https://doi.org/10.1108/BIJ-11-2019-0517
- Paparoidamis, N.G., Katsikeas, C.S. and Chumpitaz, R. (2019) 'The role of supplier performance in building customer trust and loyalty: A cross-country examination', *Industrial Marketing Management*, 78, 183-197. https://doi.org/10.1016/j.indmarman.2017.02.005
- Ries, S., Kangasharju, J. and Mühlhäuser, M. (2006) 'A Classification of Trust Systems', On the Move to Meaningful Internet Systems 2006: OTM 2006 Workshops, Meersman, R., Tari, Z., Herrero, P. (eds.), Springer, Berlin, Heidelberg. https://doi.org/10.1007/11915034_114
- Ruohomaa, S. and Kutvonen, L. (2005) 'Trust Management Survey', Trust Management, Herrmann, P., Issarny, V., Shiu, S. (eds.), Springer, Berlin, Heidelberg. https://doi.org/10.1007/11429760_6
- Sahay, B.S. (2003) 'Understanding trust in supply chain relationships', *Industrial Management & Data Systems*, 103 (8), 553-563. https://doi.org/10.1108/02635570310497602
- Salam, A., Panahifar, F. and Byrne, P.J. (2016) 'Retail supply chain service levels: the role of inventory storage', *Journal of Enterprise Information Management*, 29 (6), 887-902. https://doi.org/10.1108/JEIM-01-2015-0008
- Stravinskienė, J., Matulevičienė, M. and Hopenienė, R. (2021) 'Impact of Corporate Reputation Dimensions on Consumer Trust', *Engineering Economics*, 32 (2), 177-192. https://doi.org/10.5755/j01.ee.32.2.27548
- Takeda Berger, S.L., Tortorella, G.L. and Frazzon, E.M. (2018) 'Simulation-based analysis of inventory strategies in lean supply chains', *IFAC-PapersOnLine*, 51 (11), 1453-1458. https://doi.org/10.1016/j.ifacol.2018.08.310
- Wang, C.-N., Dang, T.-T. and Nguyen, N.-A.-T. (2020) 'A Computational Model for Determining Levels of Factors in Inventory Management Using Response Surface Methodology', *Mathematics*, 8 (8), 1210. https://doi.org/10.3390/math8081210
- Wang, H., Tao, J., Peng, T., Brintrup, A., Kosasih, E.E., Lu, Y., Tang, R. and Hu, L. (2022) 'Dynamic inventory replenishment strategy for aerospace manufacturing supply chain: combining reinforcement learning and multi-agent simulation', *International Journal of Production Research*, 60 (13), 4117-4136. https://doi.org/10.1080/00207543.2021.2020927
- Wilensky U. (1999). NetLogo Home Page. [Online], [Retrived August 23, 2024], http://ccl.northwestern.edu/netlogo/ (accessed).
- Wilensky U., Rand W. (2015). An Introduction to Agent-Based Modeling: Modeling Natural, Social, and Engineered Complex Systems with NetLogo, The MIT Press, Cambridge.
- Yin, Lisong, Yin, Lisheng, He, Y. (2012) 'The quantify and dynamic evolution of trust among supply chain', 2012 2nd International Conference on Uncertainty Reasoning and Knowledge Engineering, ISBN: 978-1-4673-1459-6, August 2012, Jalarta, Indonesia, 248-251. https://doi.org/10.1109/URKE.2012.6319557
- Zhang, X., Wang, H., Nan, J., Luo, Y. and Yi, Y. (2022) 'Modeling and Numerical Methods of Supply Chain Trust Network with the Complex Network', *Symmetry*, 14 (2), 235. https://doi.org/10.3390/sym14020235