The Contingent Nature of Warehouse Flexibility in Supply Networks.

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Abstract

In a more or less volatile marketplace warehouse management is fundamentally contingent of changes in the supply network. The flexibility of a distribution centre is therefore a key logistics management issue. This study probes into the nature of warehouse flexibility in a supply network. The Flexsim simulation tool conceptualised, documented, performed simulations, analysed and evaluated the dynamic behaviour of the warehouse system. This simulation revealed that external changes affect daily processes and the reorganisation of warehouse processes. Given the extensity of resource use, simulation revealed that process reorganization should not be a daily undertaking. This is because the warehouse reacts in unpredictable and different manners to even the smallest disturbance from the environment. This reaction is not necessarily negative impending more long-term change of warehouse processes. The warehouse is a complex system that self-adapts with limited need to calculate new optimized warehouse processes to counter changes in its environment. This implies that rather than following deterministic optimization procedures, the development of flexible resources is a key issue in warehouse management. The applied simulation model is generic and therefore applicable in other distribution centres pointing to how to monitor warehouse processes to in a pre-emptively develop warehouse flexibility through change of process context.

Key words: Warehouse management; Simulation; System dynamics; Case study

1. Introduction

The aim of this article is to consider how does a studied Polish distribution centre reacts to changes in its supply chain context. We also consider to what extent of a distribution centre's flexibility affects the level of response to these changes. Contingency theory and system dynamics are used as a unified research approach. Contingency theory provides in this research design us with a fundamental stance on the contingent nature of warehouse management, while system dynamics is an approach to model, simulate and operate in the complexity.

We probe through this study into how a distribution centre behaves when different types of uncertainties arise in the form of individual changes and their combinations. This reflects the real problems in the management of a distribution centre related to its flexibility and reactions to external stimuli from the environment. To answer this question, we conducted a case study describing organizational reaction to changes in the supply chain in a high bay warehouse, which serves as the central distribution centre for a large drugstore chain in Poland.

Changes in supply chains are very often unpredictable and dynamic. Uncertainty of supply chain management is widely discussed in SCM literature (Rahdar et al., 2018; Govindan et al., 2017; Ivanov et al., 2017; Fayezi et al., 2017). Flynn et al. (2016) examined supply chain integration (SCI) as a response to uncertainty. In the study, they considered internal, customer and supplier integration, which they linked to three levels of uncertainty - micro, mezo and macro uncertainty. The results of their research indicate the inverse relationship between both micro-level uncertainty and mezo-level uncertainty and all three dimensions of SCI.

In this study we look at warehouse management as handling a set of environmentally contingent labour processes. The place occupied by a distribution centre in the supply chain includes all sorts of uncertainties related to both supplier and customer behaviour, but above all, the lack of information on the direction and pace of change. This makes the right warehouse layout one of the key issues from the point of view of distribution centre management, as it facilities the appropriate response to changes. This is an aspect of warehouse process structure and change in this aspect demands investment. An extensive literature review covering typical warehouse layout problems, such as minimising transport costs for order processing, operating costs, product allocation, storage space utilisation, warehouse throughput, or operating policies was presented by Derhami et al. (2019) when designing optimal layouts for stacking warehouses. The warehouse layout is an important aspect of warehouse process context.

Research on optimal warehouse design and optimisation is conducted using different methodologies, such as mathematical model, decision support system, heuristic algorithm, data mining, multidimensional scaling, and simulation technique (Kovács, 2011; Yener and Yazgan, 2019). However, simulation techniques are used to a lesser extent when designing warehouses. Simulation is aligned with our contingency theory approach. Our research thus provides new insights into warehouse management in the context of continuous supply chain changes, the context of warehouse management.

The remainder of the paper is organized as follows. In section 2, we review the literature and derive our research hypothesis. In Section 3, we describe and operationalise our simulation model. In section 4, we conduct the scenario analysis with different variants of disruptions. Sections 5 and 6 presents comparative analysis of the results of simulation scenarios. In Section 7, we summarize and discuss the findings. Section 8 contains the conclusion, a discussion on managerial implications of our research and identification opportunities for future studies.

2. Literature review

3. Literature review

3.1. Warehouse contingency

Empirical studies show that environmental uncertainty is directly linked to supply chain flexibility in such a manner that in a highly uncertain environment, high supply chain flexibility will lead to high performance (Merschmann and Thonemann, 2011). This assumption and the way the conclusion is drawn are supported by the contingency theory, which states that companies should adapt and link their organisational structure to external environment. Morgan (2007) describes the main ideas underlying contingency: (1) Organizations are open systems that need careful management to satisfy and balance internal needs and to adapt to environmental circumstances, (2) there is no optimal way of organizing, (3) action is dependent on the organizational context (task or environment), and (4) management concerns alignment in the industrial network structure production takes place. Organizations must therefore adapt to their environment and not two firms are therefore alike and they are also in a state of continuous change. There is therefore never any “best way” to manage companies since business processes are externally contingent, and therefore more or less uncontrollable. Action is therefore dependent on the context of the process and management must be sensitive to environmental change as it happens. Development therefore, is from a contingency theory perspective, focused on improving the production resources. From this analytical perspective, the degree of flexibility is important. This includes human resources used in business relationships as well inanimate production resources.

Klumpp (2018) points to the impact of automation on human – machine interaction in production processes. Each distribution centre, regardless of its specificity, level of process automation or the scope of services provided, will receive stimuli from the entire supply chain in the form of changes (Peter, 2004). The scale and type of changes will trigger appropriate human reactions from the distribution centre in order to best adapt to the new situation. This means that the reaction of the individual links affected by a change must be immediate and very accurate. The lack of a proper stimulus from the environment in the form of reliable information arriving in the right time and form may result in a lack of reaction to the changes and, consequently, the occurrence of negative effects and consequences (Zhenxin, 2001).

In our case study, we assume that supply chain uncertainty takes the form of external changes in the following areas: customer service, price and product changes, changes caused by suppliers, competition, economic situation, new technologies, and IT systems. They have a direct impact on the internal changes taking place in the distribution centre. These factors are key to reorganising processes or taking strategic action in the distribution centre (Onstein et al., 2019, Onstein et al. 2020). Each of the areas generates changes of a different nature, specificity and approach to reacting to them. All these suggested areas of change that affect the distribution centre generate specific reactions in order to adapt to the new situation. The spectrum of changes and reactions to them will depend not only on the specificity of a given distribution centre but also on the conditions prevailing along the entire length of the supply chain (Gunasekaran et al., 2017).

The areas of change outlined above can largely be unpredictable. Therefore, decision makers at the management level very often have problems making the right decision concerning the direction of changes in the distribution centre (Iassinovski et al., 2003; Dotoli et al., 2015). The lack of an appropriate response in due time may cause long-term negative consequences in the operation of the distribution centre, which will translate into the functioning of the entire supply chain.

2.2. Warehouse operations

Our second component in the theoretical frame reference consists of system dynamics. The essence of system dynamics, developed by Forrester in the 1950-ies (Forrester 1973), is to think about system dynamics in terms of feedback loops (Forrester, 1994). System dynamics combines theory, methods and certain philosophical foundations needed to analyse management systems. The systems dynamics approach enables the use of a computer and computer simulation to describe systems in terms of quantitative and qualitative variables (Gilbert and Doran, 2018). It should be noted that since the introduction of system dynamics, other similar approaches to the comprehensive study of complex production systems have also emerged, such as the hybrid Soft System methodology or System Dynamics Discrete Event Simulation (Lane and Oliva, 1998; Helal et al., 2007). In our article, in order to examine the impact of supply chain uncertainty on distribution centre flexibility, we need to determine causal relationships that are not captured by other approaches, which is why we used SD approach.

In line with the fundamental assumptions of contingency theory, we assume that the multitude of changes affecting the distribution centre management necessitates the optimisation of warehouse processes. System dynamics is used in warehouse management because it allows for virtual reflection of the real process by means of formulas and dependencies occurring along its entire length (Qu et al., 2017). Thanks to this, it is possible to model the process and study its dependencies, as well as observe the individual components by introducing additional variables. Before making a decision on optimization or automation of a given process, it is possible to reflect and simulate the reaction of the process and the environment to possible changes in a shorter or longer time horizon.

System dynamics is comprehensively used to study supply chain relationships, including the development of conceptual, casual loop diagrams. The created simulation models are usually generic in nature and can be useful for research in other cases originally dedicated to it. For example, (Marquez and Blanchar, 2004) used a system dynamics simulation model to analyse a portfolio of contact with suppliers. The results of their research can be used to design better policies in order to maintain suitable relationships with suppliers, where each relationship has a different purpose and must be managed differently.

(Gonul Kochan et al., 2018) present a relevant background of SD based on the most significant research recognised in the scientific community, by providing statements referring to the understanding of the essence of research which uses general systems theory and systems dynamics. In conclusion to these statements, it should be stated that system dynamics is currently a proven approach used for conceptualising, modelling, and explaining dynamic interactions with complex systems in relation to physical processes and information flow.

3.2. Warehouse flexibility

Since warehouse processes are viewed as environmentally contingent, warehouse resources and the processes the warehouse consists of need to be flexible. Flexibility concerns the operational level of distribution centre management. Changes occurring in supply chains are very often unpredictable and dynamic (Martin, 2011). This means that the reaction of the individual links affected by the change must most often be immediate and effective. The lack of a proper stimulus from the environment in the form of reliable information arriving in the right time and form may result in a lack of reaction to changes and, thus, the occurrence of negative effects and consequences. Rushton et al. (2000) note that the flexibility of a distribution centre depends on its design which takes into account a multi-stage procedure aimed at achieving an efficient design for the adopted time horizon.

The problem of incorporating flexibility into the warehouse layout at the design stage is widely discussed in the literature (Rouwenhorst et al., 2000; Shi et al., 2018). This is partially due to the complexity of the designed system, which includes such elements including building design, equipment, automation/robotisation/artificial intelligence, warehouse workers' work system, IT systems, and processes. On the other hand, there are the aforementioned areas of change that affect the processes taking place in the distribution centre. Baker (2006) described the impact of supply chain agility on the flexibility of logistics centres using semi-structured interviews, which only allowed for general conclusions about the flexibility of a distribution centre. Baker and Halim (2007, p. 5) see that warehouse flexibility should be verified at the last stage by conducting simulations with different volumes. However, their findings are based on a survey questionnaire and do not allow the flexibility of the warehouse to be tested under real conditions.Reliability of research results depends on the adopted method, which allows for a comprehensive determination of changes in distribution centre processes.

The dynamics of environmental change in integrated supply chains affects all links along the supply chain. The extent to which it will be possible to react early enough to changes and prevent disorganisation of work in the warehouse strictly depends on early enough anticipation of potential risks, starting from the conceptual phase and the design stage of both the building and the specificity of individual processes (Gu et al., 2010; Lam et al., 2015). The more intelligent the decisions and planning aimed at the synergy of warehouse processes, the greater the spectrum of possibilities in making strategic decisions (Yang, 2019).

2.3. Research issues

A flexible approach applied fundamentally based on contingency theory thinking and operationally on system dynamics. This combined approach to warehouse design increases the ability to adapt to dynamic changes in the environment (Baker and Canessa, 2009; Sprock et al., 2017). During a calendar year, events will occur in each warehouse that will necessitate the use, in many aspects, of the maximum possible warehouse capacity. It may also be necessary to react immediately to sudden problems or the need to modify individual processes without the possibility to rebuild the warehouse due to lack of time. Therefore, we put forward two research issues formulated as hypothesis, both susceptible to verification based on our empirical findings. First, based on contingency theory that:

H1: The multitude of changes affecting the distribution centre management necessitates the continuous development of warehouse processes.

And, furthermore based on system dynamics that:

H2: A flexible approach to warehouse design increases the ability to adapt to dynamic changes in the environment.

4. Methodology

Founded on contingency theory, system dynamics is applied to unveil the systemic workings of the warehouse at the operational level. This approach provides the fundamental way to simulate the warehouse processes as contingent of external change. The set of data used in the simulation model in the study reflects confidential historical data from the period of two years of operation of the distribution centre. The data obtained from the ERP and WMS systems was classified due to the request of the management board of the cooperating company. The data covered a group of 20,000 orders for a database of 100 customers in 16 locations. The orders included a group of more than 600 articles, sourced from 10 key suppliers.

Warehouse processes are simulated to answer reflect upon the stated hypothesis. A simulation is a process that allows a specific real-world phenomenon to be reflected in artificial conditions in order to examine its response to changes or modifications in individual constraints. It is necessary to use three basic elements that must work together in order for the simulation to work properly. These are the computer, the real system and the mathematical model (Heragu * et al., 2005). A real system is an actual phenomenon or process that is to be reproduced in virtual reality. A model describes a real system by means of various constraints, functions and parameters, the number of which depends strictly on the complexity of a given real system. In this case study we use Flexsim as a simulation tool, which allows us to conceptualise, document, perform simulations, analyse and evaluate the dynamic behaviour of the system. User of mixed-methods is key to case studies (Thomas 2011). In this study data was collected through observations and secondary data provided by one of the co-authors working in the studied company. These data ware applied to carry out simulation-based analytics. In addition findings were later discussed with the firm to find out the applicability of the simulation-based findings.

The case study we use the parameter scenario and check the impact of different scenarios on the change of the model parameters. At the same time, we do not use a structure scenario in the form of adding new parameters, which is a limitation of this model. Sterman (2000) developed a 5-stage procedure for building simulation models, including: problem articulation, dynamic hypothesis, formulation, testing, policy formulation and evaluation, which was used in the conducted research. Before starting the modelling process, a procedure algorithm was developed to illustrate the subsequent stages of the research problem implementation, as shown in Figure 1 below:

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Figure 1. Problem implementation procedure

Figure 1 shows that the subsequent steps, starting from the concept phase and ending with the implementation phase, reflected the causal sequence of the warehouse system modelling process. An error in the initial stage of analysis, for example, due to an erroneous definition of a research problem, could lead to incorrect conclusions being drawn from the research conducted. Every mistake in the conceptual phase may generate additional costs, causing the investment budget to be unnecessarily exceeded. The use of simulation programmes makes it possible to not only avoid unnecessary costs but also reduce the risk of failure in the project due to an erroneous decision.

The distribution centre was treated as a system in which external and internal changes take place. These changes are very dynamic and often unpredictable, which made it impossible to use other research methods, such as questionnaires or interviews. In our case, the use of a simulation tool can be considered unique, because such programmes are mainly used to reflect less complicated production processes. Simulation of a complex system with multidirectional relations required a precise mathematical description of all the relationships in the simulation programme (e.g. Douglas, 2005; Staudt et al., 2015; De Koster et al., 2017).

To determine the distribution centre's response to changes in the supply chain, model of a high bay warehouse was built (Yafei et al., 2018). To build the model, objects were used that were connected by mutual relations which allowed for the mapping of the real flow of goods. The flows in the warehouse and the specifics of each process were described using algorithms (23 process flow charts). Each route, starting from the delivery and unloading of the truck at the warehouse and ending with the dispatch of completed orders to customers from the output ramps, was described in the form of a separate algorithm. All algorithms were linked by relationships that reflected the existing relationships in the warehouse. Real data based on processes and flows in the high bay warehouse was also imported. All calculations were based on a real case study and expert knowledge. The parameters, both quantitative and temporal, defining the model relationships are detailed in Table 1.

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Table 1. Main quantitative and time data defining the model

The system of modelling uses a high bay warehouse model. It is dedicated to the storage of a specific group of goods (G) delivered from suppliers (Dn, n – number of suppliers) and sent in roll-containers to customers (Cm, m - number of customers) in the distribution network. Each supplier has a defined location (Ln) and related time of arrival (Tn), vehicle capacity in pallets (Pn), the number of pallets of a material ordered to the warehouse (AAn) and the time it takes to fulfil an order (Fn). The group of customers also has an assigned location (Lm) and a specified amount of a single ordered product (AAmi - the amount of article A ordered by the *m*-th customer in the *i*-th order). The maximum weight of the pallet (Wp) and roll-container (Wrc) were also estimated. Goods are received at inbound docks (Din) and sent from outbound docks (Dout). Intra warehouse processes are operated by forklifts (FLw, w - number of teams), divided into teams. It was assumed that the forklifts are manually operated by warehouse workers in a three-shift mode (7.5h work + 0.5h break). Orders (O) are generated daily and appear in the system once, at the beginning of the morning shift. Orders are not divided between the three shifts; therefore, each shift carries out the maximum number of orders available.

The forklifts unload pallets at the inbound docks and, after approval in the system, the pallets are transported to storage buffers (each forklift transports two pallets at once). The pallets wait to be transported to the storage area. Another group of forklifts takes the pallets and puts them in assigned locations in the rack space. The places of the order picking (Sp, p - the number of picking areas) are on the floor, while the safety stock (Ss, s - number of places) are placed at higher levels in the rack area. The specification of the dedicated storage areas for the goods (G) is related to the picking path. The heaviest items are stored at the beginning of the route, while the lightest ones are at the very end.

Orders are processed by another group of trucks (the order picking team), which collects three roll-containers at the same time. Each roll-container corresponds to a different order number. First of all, the storage space is replenished and the order picking process begins when all picking spaces are filled with pallets. Goods are collected from storage areas according to the picking unit (carton or pack). In order to minimise the risk of not enough goods being available to fulfil the customer's order, a safety stock (SFs), unique for each article, was determined.

When the order is completed, or the roll-container reaches the maximum allowable weight, the loaded roll-containers are transported to storage buffers where they await picking and shipping to the customer. Then another team of trucks transports ready-to-dispatch roll-containers to the outbound docks from where they are transported to a specific location. Orders are divided into groups according to the location of the customers. When the number of roll-containers on the dock reaches the defined level (Ctr - defined capacity of trucks with the same loading capacity), it is released. Table 2 shows the key parameters that will be used to compare the system's behaviour during the scenario analysis.

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Table 2. Parameters in scenario analysis

The first parameter from the table above refers to the total number of roll-containers shipped from the output ramps during the simulation (RCon). The total number of completed orders (ORD) and the average order processing time (Tord) are data on all orders completed by Brigade_2. The number of deliveries from suppliers (DELs) is the total number of arrivals of delivery trucks to the warehouse, while the number of deliveries to the customers' locations (DELc) applies to all departures with goods to the customers. The average delivery time to customers (Tshp) is counted from the moment the first roll-container appears on the outbound docks until the last roll-container is placed on the truck. The percentage of not fully completed orders (ORDnfc) is the percentage of incomplete orders that have been sent to customers (there was at least one article necessary to complete the order for the customer) in relation to the total number of completed orders. The Brigade_2 (SSB2) state statistics parameter contains information about the capacity of the forklifts completing the orders.

The simulation of the base model showed that an average of 83,800 roll-containers were sent from the warehouse which was related to an average of 13,600 orders. The average delivery time was 24.7 minutes. The inbound docks transferred an average of 550 deliveries to the warehouse, while the number of shipments from the outbound docks amounted to an average of 2,900 transports. The average delivery time was 11 minutes. The percentage of not fully completed orders averaged 4%, and the load of picking forklifts reached an average level of 53%. The results are consistent with the results in the real warehouse with the analysed parameters, which confirms the correctness of the model.

In the next section of the article, a scenario analysis of the simulation model is presented. Various variants of changes occurring in the supply chain and their impact on the internal processes of the distribution centre were simulated.

5. Scenario analysis of a simulation model

The model behaviour study included 20 replications. On the basis of the results obtained, the minimum, maximum, average and standard deviation were calculated for each of the analysed parameters. Detailed results of the baseline analysis are presented in Annex 1. The scenario analysis contains 17 variants that affect the organisation of work in the warehouse. These events mean disruptions to the standard process, generating changes and forcing a reorganisation and optimisation of internal processes in the distribution centre’s management. The scenarios are divided into a baseline scenario, in which the model changes only in one area, and mixed scenarios, which are a combination of previous base scenarios.

Baseline scenarios:

- Scenario B1: *Changing the capacity of the supplier's truck*

The simulation scenario referred to the reduction of car capacity at one of the suppliers. It analysed the situation in which a supplier decides to change the fleet of trucks, reducing their capacity by 40%. Such circumstances resulted in a 13% increase in the number of deliveries to the warehouse at the supplier and a 11% decrease in the average number of pallets per delivery. In the case under consideration, the supplier increased the frequency of deliveries to the warehouse and, at the same time, increased the number of truck fillings. In the baseline scenario, delivery vans were on average filled with 54% of the total capacity, and the change in the rolling stock increased their filling to 80%. Compared to the baseline analysis, and with an assumed level of materiality greater than or equal to 10%, there was also a significant increase in average lead time (up 12% on average). The situation also translated into a total increase in the percentage share of incomplete orders sent to customers. Despite maintaining the quantitative level of shipments, the change of car capacity at the supplier's had a negative impact on the level of customer service.

- Scenario B2: *Changing the travel time and delivery time of the supplier's order*

The simulation scenario assumed a change in the travel time and delivery time of the supplier's order. It was assumed that acquiring a new supplier and, at the same time, terminating the contract with the previous one would reduce the time of arrival from the supplier's location to the warehouse by 40%. The capacity of the new supplier's fleet of cars does not change in relation to the base model. In addition, the total order completion time has been reduced by 60% (in this case, the order completion time should be understood as the maximum time the supplier has to complete the shipment from the moment the demand for the first product is submitted). Simulation results showed that the contract with the new supplier resulted in an 80% increase in the number of deliveries to the warehouse with a simultaneous decrease in the average number of pallets for delivery by 50%. The new supplier is able to respond more quickly to warehouse demand. Interestingly, the customer service level deteriorated in the analysed scenario. An increase in the number of incomplete orders sent to customers was observed (average delivery time remained at the same level as in the base scenario). The change in the parameters described above related to the acquisition of a new supplier instead of the previous one did not significantly affect the processes within the warehouse and the organisation of the distribution centre's operation.

- Scenario B3: *Changing the location of the supplier*

The scenario assumes a change of supplier location due to the opening of a new production plant near the analysed warehouse. As a result, the travel time was reduced by 40% and the order completion time by 60%. Additionally, the supplier decided to reduce the capacity of the truck fleet by 40%. Compared to the baseline analysis, and with the assumed level of significance of the changes greater or equal to 10%, there was a 70% increase in the number of deliveries to the warehouse from the supplier from the new location, while the average number of pallets for delivery decreased by 40%. It is worth noting, however, that despite the decision to reduce the capacity of the truck fleet servicing the analysed warehouse, the degree of filling did not change. Deliveries from the new location are still serviced by vehicles filled to half their maximum capacity on average. Average lead times and shipping times did not change to a degree that would disrupt the operation of the distribution centre, so there was no need to optimise the internal processes of the warehouse as a reaction to the changes. The level of shipment of goods to customers was also maintained at the level of basic analysis.

- Scenario B4: *Promoting the product group*

The simulation scenario assumed an increase in the shipment of a group of articles due to promotion. The promotion covered 20% of all goods handled by the warehouse. It should be noted that the increase in the volume of shipment was not constant for all products covered by the promotion. Individually for each promotional item, the quantity ordered by customers (in items and units issued from the warehouse) was increased. The results of the simulation showed a 25% decrease in the number of completed orders while maintaining a constant level of roll-containers sent to customers. The average order completion time was more than doubled. These changes are directly related to the increase in the number of promotional items ordered by customers. The increase in the volume of orders translated into all internal processes in the warehouse, starting from the increase in the number of deliveries from the entire group of suppliers by 70% and ending with the shipment of goods and the related fact, a 20% increase in shipments to customer locations. The level of customer service significantly deteriorated due to an increase in the percentage of incomplete orders for customers. On the other hand, the load index of trucks responsible for order fulfilment has improved. The simulation scenario proved that despite the promotion of products (an event beneficial in terms of maintaining positive relations with customers), the warehouse was not able to handle all orders without shortages in the assortment.

- Scenario B5: *Promoting the product group and additional employment—option 1*

The simulation scenarios B5, B6 and B7 are an extension of variant B4 (increasing the consignment of a group of articles due to promotion), enriched with additional employment in the form of another order picker (scenario B5 assumes one additional forklift, B6 - two, B7 - three). If one additional forklift is included (scenario B5), roll-container shipment increased by 11% while the total number of completed orders decreased by 12% compared to the baseline model. What is more, the average lead time increased by 2.4 times. The number of deliveries to the warehouse and deliveries to customers increased by 67% and 21%, respectively, while the average delivery time decreased by 11%. The level of customer service remains at a low level (similar to scenario B4) due to over 7-times increase in the number of incomplete orders sent to customers. This is directly related to the shortage of goods in the warehouse.

- Scenario B6: *Promoting the product group and additional employment—option 2*

The baseline scenario B6 (two new picking forklifts) is characterised by similar results as in the case of the above described variant of increasing employment by one additional forklift, with the difference that the load index of order-picking forklifts dropped to 87%.

- Scenario B7: *Promoting the product group and additional employment—option 3*

The variant assuming employment of three additional forklifts showed an increase in the number of roll-containers sent to stores by 21%, while the average order completion time decreased more than 2.5 times in relation to the base model. Scenario B7, out of three analysed variants of additional employment, is the most advantageous in terms of the exploitation of Brigade_2 forklifts (load is 84%). Interestingly, despite three additional picking forklifts, the average delivery time did not change significantly.

- Scenario B8: *Changing the location of the group of customers*

Scenario B8 assumes a change in the location of a group of customers that constituted 10% of the total base of customers to whom goods are shipped from the warehouse. The change was supposed to reflect the actual process of acquiring new customers while resigning from supplying other customers.

- Scenario B9: *Inspection of the forklifts in the picking process*

In scenario B9, periodic reviews of order-picking trolleys were examined. All the trucks of the picking brigade are inspected every two weeks, but not more than one truck can be inspected at the same time. The inspection period is one hour each time.

- Scenario B10: *Damage of the inbound and outbound dock*

Scenario 10 refers to the variant of blocking entry and exit ramps. We analysed the situation in which each input ramp was blocked once a week for an hour, while the blockade of a single output ramp lasted three hours but took place every three weeks. It is worth noting that both input and output ramps were blocked individually—there was no case of simultaneous blocking of two ramps of the same type.

Mixed scenarios:

- Scenario M1: *Promoting the product group + Inspection of the forklifts in the picking process*
- Scenario M2: *Changing the capacity of the supplier's truck + Changing the travel time and delivery time of the supplier's order + Changing the location of the supplier + Damage of the inbound and outbound dock*
- Scenario M3: *Promoting the product group + Inspection of the forklifts in the picking process + Damage of the inbound and outbound dock*
- Scenario M4: *Changing the location of the supplier + Inspection of the forklifts in the picking process*
- Scenario M5: *Changing the capacity of the supplier's truck + Changing the travel time and delivery time of the supplier's order + Changing the location of the supplier + Damage of the inbound and outbound dock + Inspection of the forklifts in the picking process*
- Scenario M6: *Changing the capacity of the supplier's truck + Changing the travel time and delivery time of the supplier's order + Changing the location of the supplier + Damage of the inbound and outbound dock + Inspection of the forklifts in the picking process + Promoting the product group + Changing the location of the group of customers*

- Scenario M7: *Changing the capacity of the supplier's truck + Changing the travel time and delivery time of the supplier's order + Changing the location of the supplier + Damage of the inbound and outbound dock + Inspection of the forklifts in the picking process + Promoting the product group + Changing the location of the group of customers + Additional forklift in the picking process*

The scenario simulation was conducted analogously to the baseline analysis (assuming the same number of replications for each scenario), which allowed us to verify the changes. As a next step of simulation research, a comparative analysis has been carried out, where a diagram of the impact of changes in baseline and mixed scenarios on the examined parameters were presented. This shows also the influence of scenario analyses on the examined parameters for changes at the different level of significance.

6. Comparative analysis of the results of simulation scenarios

The comparative analysis of simulation scenarios was carried out separately for the baseline and mixed scenarios (due to the clarity of the presented dependencies) by means of causal diagrams. The diagrams, using arrows, show the influence of simulated scenarios on the examined parameters. The '+' sign indicates the positive impact of scenario changes on each parameter, while the '-' sign refers to the negative impact. The following figure presents a diagram of the influence of changes in the base scenarios on the examined parameters.

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Figure 2. Diagram of the impact of changes in baseline scenarios on the examined parameters

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As described above, each baseline scenario (except for B8, B9 and B10) is characterised by its influence on a specific group of parameters. Both the above diagram and the scenario analysis relate to the assumed 10% level of significance of changes. This means that each change smaller than 10% (both positive and negative) does not significantly affect the examined parameters. An analogous assumption applies to the diagram of the influence of changes in mixed scenarios on the examined parameters, presented in Figure 3:

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Figure 3. Diagram of the influence of changes in mixed scenarios on the examined parameters

Figure 4 also refers to the assumed 10% level of significance of changes on the examined parameters in mixed scenarios. In this case, there were no significant changes in the M4 simulation scenario. Other mixed scenarios are characterised by the influence on specific parameters.

In both diagrams presented above, a one-directional character of the impact of scenario changes on the examined parameters can be observed in relation to the base model. This means that for each parameter analysed, the impact of changes in all base and mixed scenarios is always positive or negative. Therefore, it was decided to trace the reaction of the model parameters to the change in significance level in three variants (decreasing first from 10% to 7% and finally to 4%). The 'baseline' variant, with the assumed level of significance of changes equal to 10%, is presented in Table 3 below.

Take in table 3 here

Table 3. Table of influence of scenario analyses on the examined parameters for changes at the 10% level of significance.

As previously mentioned, Table 3, which presents the changes resulting from implementing each of the analysed simulation scenarios (baseline and mixed), shows a unidirectional character of impact. A '+' indicates the positive impact of the scenario changes on each parameter, while a '-' indicates the negative impact. A blank field reflects no impact. To test the system's response to less flexible storage, a variant reducing the materiality level to 7% was analysed, as shown in Table 4.

Take in table 4 here

Table 4. Table of influence of scenario analyses on the examined parameters for changes at the 7% level of significance

Table 4 shows that two significant changes occurred in relation to the 10% materiality level. First, there is a trend that those scenarios that did not affect any of the parameters started to affect the parameters gradually. For example, the M4 mixed scenario of relocating 10% of customers in the distribution network and periodic maintenance of forklifts has a negative impact on the load of forklifts. Second, the multi-directionality of the impact of changes on a given parameter begins to appear.

At the 10% level of significance of changes, each analysed parameter was characterised by a positive or negative impact (in relation to all scenarios that concerned it). If the significance level of changes is reduced to 7%, one can observe that two parameters (Tshp and SSB2) begin to react in two directions, depending on the type of changes taking place.

The average time of delivery to customers (DELc) is positively influenced by baseline scenarios B4, B5 and B6, relating to promoting the group of articles and additional employment, and mixed scenarios M1 (promoting the group of articles and a periodic review of the order-picking forklifts), M3 (promoting the group of articles), M6 (a set of changes contained in all base scenarios and not related to additional employment in the picking brigade) and M7 (all assumptions of the previous mixed scenario, M6, and a change in the form of employment of an additional forklift for customers). With a decrease in materiality from 10% to 7%, scenarios B1 (change in the supplier's truck capacity), B3 (change in the supplier's location) and M5 (change in the supplier's location, a 40% reduction in the capacity of the truck fleet, shortening of the time to reach the warehouse and order completion time, periodic blocking of entry and exit ramps and a review of customer forklifts) had a negative impact on the Tshp parameter. Similar changes occurred in the case of the Brigade_2 (SSB2) statistics. The same scenarios as for the Tshp parameter and the base scenario B7 (promoting a product group and additional employment of three forklifts) have a positive impact on this parameter. When the materiality level decreased from 10% to 7%, a negative impact of the mixed M4 scenario appeared, which did not have a significant impact on any of the analysed parameters.

The changes that have taken place concerning the increase in the impact of a larger number of scenarios on the examined parameters, and the appearance of the bidirectionality of the impact of changes on a given parameter, have already taken place with the 10% variant of the materiality level. However, as a result of the decrease in the materiality level to 7%, they became important for the simulated model.

It can, therefore, be assumed that by reducing the level of materiality, the changes will intensify even more. Namely, scenarios that did not affect the examined parameters will start to affect some of them and for an increasing number of parameters, a two-way reaction to the changes may appear. Table 5 presents the option reducing the materiality level to 4%.

Take in table 5 here

Table 5. Table of influence of scenario analyses on the examined parameters for changes at the 4% level of significance

The assumptions about the initiated changes in the case of the materiality level of 7% were confirmed for the above option (materiality level of 4%). Scenarios with no significant impact for the 10% option are becoming increasingly relevant as the materiality level of the changes decreases.

Compared to the 7% materiality scenario, baseline scenarios B8 (change of customer group location) and B9 (review of forklifts) start to have a negative impact on the Brigade_2 (SSB2) statistics parameter. Additionally, the parameters of ORD and Tord were characterised by a one-way impact of changes at the 7% level of significance. When the materiality level is reduced to 4%, they begin to manifest a two-way impact of changes through an increasing number of scenarios affecting these parameters.

It can, therefore, be concluded that reducing the level of the materiality of the changes does in fact reduce the flexibility of the warehouse, which would allow to adopt the H3 hypothesis. This means that if there is greater flexibility, a relatively small reaction to changes will force a reorganisation and optimisation of warehouse processes in the management of the distribution centre.

The level of materiality lower than 4% was not analysed because from the point of view of the continuity of warehouse operations and all processes in the logistic transport and warehouse system, warehouse flexibility should not decrease below 4% (a level of warehouse flexibility of 4% is already very low). As a result of comparative analysis with different levels of significance, it has been decided to also simulate model variability in time for one of the most comprehensive scenarios, and include all the assumptions of the previous simulation scenarios (baseline and mixed) along with the employment of an additional forklift operator.

7. Comparative analysis of model variability in time

In order to analyse the variability in time, the average daily performance of roll-container shipping in the base model and the M7 mixed scenario were compared over the entire simulation period (75 days). The M7 scenario was selected for benchmarking because it is the most comprehensive and includes all the assumptions of the previous simulation scenarios (baseline and mixed) along with the employment of an additional forklift operator. Additionally, the changes considered in the M7 mixed scenario are characterised by an impact on all parameters studied in the model, regardless of the percentage value of the previously analysed variants of the levels of significance of the model changes. Figure 4 shows the change in the daily efficiency of roll-container shipment during the simulation period.

Take in figure 4 here

Figure 4. Variability in time of sending roll-containers in the base model

The lack of shipments on the first day of the simulation is caused by the initial loading of the warehouse, during which pallets are received in the warehouse and placed in the rack space. Up to the 30th day of the simulation, the regularity in the shipment of roll-containers during the week can be observed. Then a one-day peak (3000 roll-containers) appears, followed by a downward trend in shipment until the end of the simulation period.

The variability in the time of dispatch of the roll-containers in the base model was compared with the mixed scenario of M7. As mentioned above, the scenario focuses on the largest number of variables affecting warehouse processes in the model. In addition, the changes have a significant impact on all previously examined parameters, regardless of the level of the materiality of the changes (for the 10%, 7% and 4% levels of materiality). Therefore, the M7 mixed scenario is the best option to compare the time variability of roll-container shipments with the base model. The daily output for M7 is shown in Figure 5.

Take in figure 5 here

Figure 5. Variability in time of sending roll-containers in the M7 scenario

Similar to the baseline model, in the M7 mixed scenario, the first day of the simulation referred to the initial warehouse loading, which indicates that no roll-containers were sent to customers in the distribution network. In the following days of the simulation, a much greater regularity of shipment can be observed compared to the base model throughout the entire simulation period (increased shipments of roll-container volume is a natural result of the assumptions of one scenario, concerning an increase in shipment of a group of articles due to promoting a part of the assortment). Comprehensive results for the compilation of the quantities of roll-containers shipped in each scenario studied, during each of the 75 days of simulation, are presented in Annex 2.

It can, therefore, be concluded that the numerous and varied changes that have taken place in the modelled warehouse during the entire simulation period have not adversely affected the shipping of roll-containers. On the contrary, they led to an increase in the regularity of shipments in weekly simulation cycles. The changes that have taken place have not forced the dispatch process to be optimised at all, nor would they have led to managerial decisions regarding this warehouse process. This means that the flexibility of the shipping process was so high that the warehouse did not have the slightest problem with order processing and there was even improved workflow and employee productivity.

The conducted research clearly indicates that the research hypothesis H2: multitude of changes affecting the management of the distribution centre necessitates the optimisation of warehouse processes, has been rejected.

In summary, the contributions of this study to the literature are: 1) development of the concept of building a virtual high bay warehouse, 2) use of SD approach to demonstrate the impact of supply chain changes on distribution centre flexibility, 3) investigation of impact of distribution centre flexibility at various levels of significance of changes on internal processes.

8. Discussion

The research may lead to several valuable conclusions along with recommendations concerning the management of the distribution centre. First, it is worth noting that the model has an implied character, which means that by introducing minor changes to the model architecture and inputting appropriate data, it is possible to simulate and study various types of optimisation and decision-making variants concerning internal processes in logistics transport and warehouse systems. In addition, the model is an excellent management tool, helping to make key management decisions in terms of expansion and process optimisation, or ensuring the smooth running of a distribution centre.

The research shows that the optimisation of warehouse processes does not have to be a continuous process. In the distribution centre, characterised by a diverse assortment of stored articles and an extensive distribution network, there are changes every day that affect internal processes, work organisation, and established standards of operation. This does not mean, however, that the warehouse will react negatively each time to even the smallest disturbance from the environment. Also, the multitude of changes does not translate into the need to optimise warehouse processes in the distribution centre.

It is the flexibility of warehouse processes that will determine the significance of the changes in the distribution centre. The more flexible the warehouse processes, the less often the warehouse will feel the negative impact of changes in the current work and the efficiency of processes. The flexibility of warehouse processes should be understood as both their sensitivity to deviations from the accepted norm and the management skills of the management team, who are able to react early enough and make the right decisions. Therefore, it is necessary to keep a register of various types of performance and process efficiency indicators which provide current information about the actual quality of all processes. The constant monitoring of processes makes it possible to make management decisions at an early stage, using the flexibility of the warehouse. They may include:

- posting workers to other processes,
- modifying the warehouse layout according to needs,
- changing the destination of the ramps,
- modifying traffic volumes on transport roads,
- using additional sources of employment for staff in the event of an emergency,
- making system changes concerning the dispatch of goods.

The practical use of system dynamics tools, such as programmes for simulating discrete events, also makes it possible to identify the presence of synergy of internal processes in logistics transport and warehouse systems. The presence of synergy in the functioning of processes is of considerable importance in relation to the management of distribution centres. Optimisation of warehouse processes, if necessary, should aim at the uniform improvement of the efficiency and effectiveness of all internal processes and integrate their functioning into one coherent operating system. Only in this way is it possible to achieve maximum effects of warehouse work in relation to the functioning of the entire distribution centre, where the level of flexibility ensures an appropriate response time to changes in the environment.

9. Concluding remarks

The research has shown that the changes occurring in the supply chain determine the reorganisation of distribution centre processes. However, this is not tantamount to taking optimisation actions. The key aspect in this area is the flexible approach to warehouse design, which increases the possibilities of adapting to dynamic changes in the environment. Moreover, the application of system dynamics to model and simulate real processes has measurable benefits in relation to management decisions taken as a result of changes in the supply chain.

It was noted that the multitude of changes affecting the distribution centre does not force the need to optimise warehouse processes at all. Flexibility of warehouse processes will determine the significance of changes in the distribution centre. The more flexible the warehouse processes, the less often the warehouse will feel the negative impact of changes in current work and process efficiency. A comparison of the significance of changes for variants 10%, 7% and 4% showed that decreasing the significance level of changes is, in fact, reducing the flexibility of internal processes in the warehouse. This means that the greater the flexibility, the less the reaction to changes will force reorganisation and optimisation of warehouse processes in distribution centre management.

With the help of the model, it is possible to simulate new management concepts aimed at implementing new solutions in the warehouse, optimising current processes or automating selected areas. An additional advantage of the model is the ability to test and simulate various scenarios generating changes and their impact on the need to optimise warehouse processes in terms of distribution centre management. The model can be freely extended in terms of adding new facilities reflecting a larger number of ramps, rack space or additional employment of employees.

Using the model to analyse the simulation variants, one can not only make decisions concerning automation or robotisation of the distribution centre but also use the support from the very beginning of the warehouse design phase. Thanks to model elements and dependencies described in algorithms, any distribution centre can be mapped. In case of several investment variants, it is possible with the help of the model to simulate each of them. This will not only save costs due to a wrongly made decision or wrongly selected optimisation method, but will also enable early identification of limitations in the perspective of expansion or future changes. Thanks to the model, it will also be possible to eliminate potential risks at an early stage. The built model can be used to make many strategic managerial decisions such as:

- The model can be used as a tool to make managerial decisions, simulating various scenarios of changes taking place in the distribution centre,
- Possibility of simulating new management concepts to implement new solutions in the warehouse,
- Possibility of optimizing current processes or automating selected areas,
- Decisions to recruit additional staff,
- Decisions concerning the automation or robotisation of the distribution centre,
- Support in the initial design phase of the warehouse,
- Identifying inefficient processes and saving operating costs,
- Possibility of early identification of restrictions in the perspective of distribution centre expansion.

Implementation of strategic managerial decisions relating to the management of distribution centres is always associated with incurring significant project costs.

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Glossary

Brigade_2 – group of forklifts, responsible for picking process. State statistics parameter contains information about the capacity of the forklifts completing the orders.

Causal diagram –a graphical representation of the relations taking place in the modelled system. Combining objects by means of arrows makes it possible to visualise the influence of particular parameters tested in simulation scenarios. Additionally, placing '+' and '-' signs on each arrow shows the direction of the impact of the scenarios on the analysed parameters (a positive or negative impact).

ERP – Enterprise Resource Planning

FMCG – fast-moving consumer goods

Roll-containers – transport containers used to protect and transport goods. Using them to ship goods is much better than in the case of pallet load units because they do not require the use of a hand forklift during unloading.

Safety stock – was estimated on the basis of the number of items on the pallet, in the carton and in the container. If the amount of goods in the warehouse together with the amount of goods that has already been ordered but has not yet arrived at the warehouse (stock in transit) is lower than the accepted safety stock, the system generates another order from the supplier for the number of pallets specified as a standard order from the warehouse.

Simulation – mapping of a real event, a process in virtual reality using mathematical formulae and information technology.

Storage buffers – the 'waiting room' storage areas for pallets which have been delivered to the warehouse and are waiting for picking and placement in the storage area.

WMS – Warehouse Management System

Table 1.

Source	Type of flexibility	Covered topic	Approach
(Dowlatshahi, 1994)	flow; operating	Systematic facilities design	Cluster Identification (CI) Algorithm
(Vaughan and Petersen, 1999)	order picking	Warehouse storage locations	A shortest path pick sequencing model
(Rowley, 2000, p. 4)	volume	Simulation of the proposed warehouse with different volumes	simulation
(Baker and Halim, 2007)	design; long term	Exploration of the reasons for, and nature of, warehouse automation implementation	semi-structured interview
(Venkitasubramony and Adil, 2019)	design	Robust design model (RDM)	scenario-based

(Dharmasiri et al., 2020)	workload	Automated Guided Vehicle (AGV) system implementation	simulation

Figure 1.

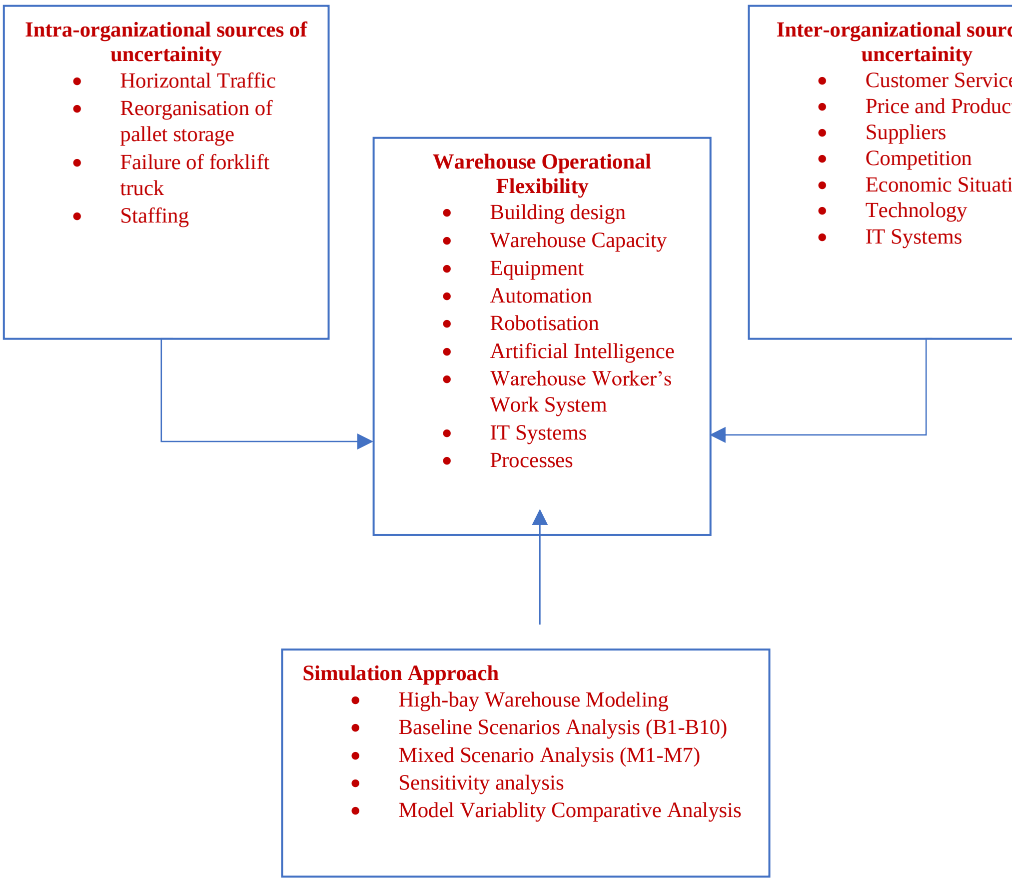


Figure 2.

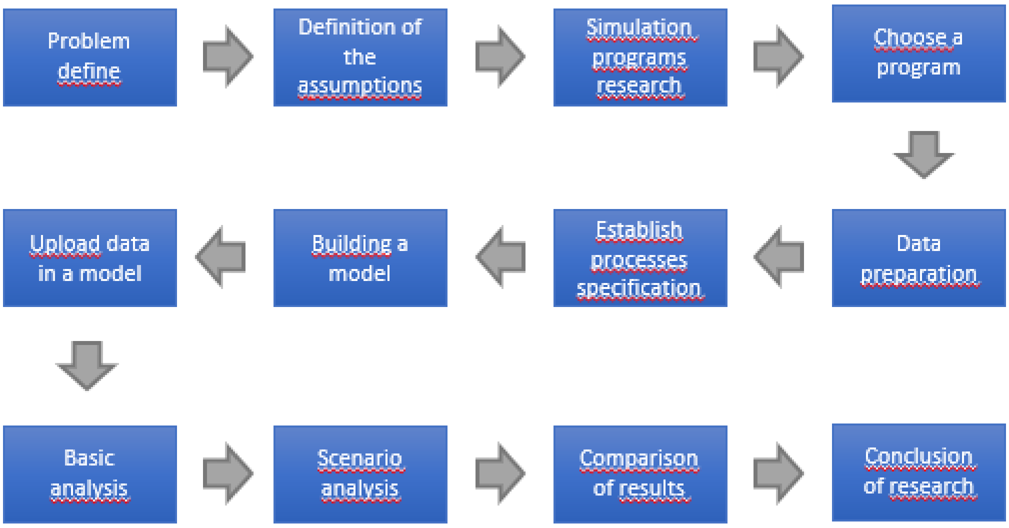


Table 2.

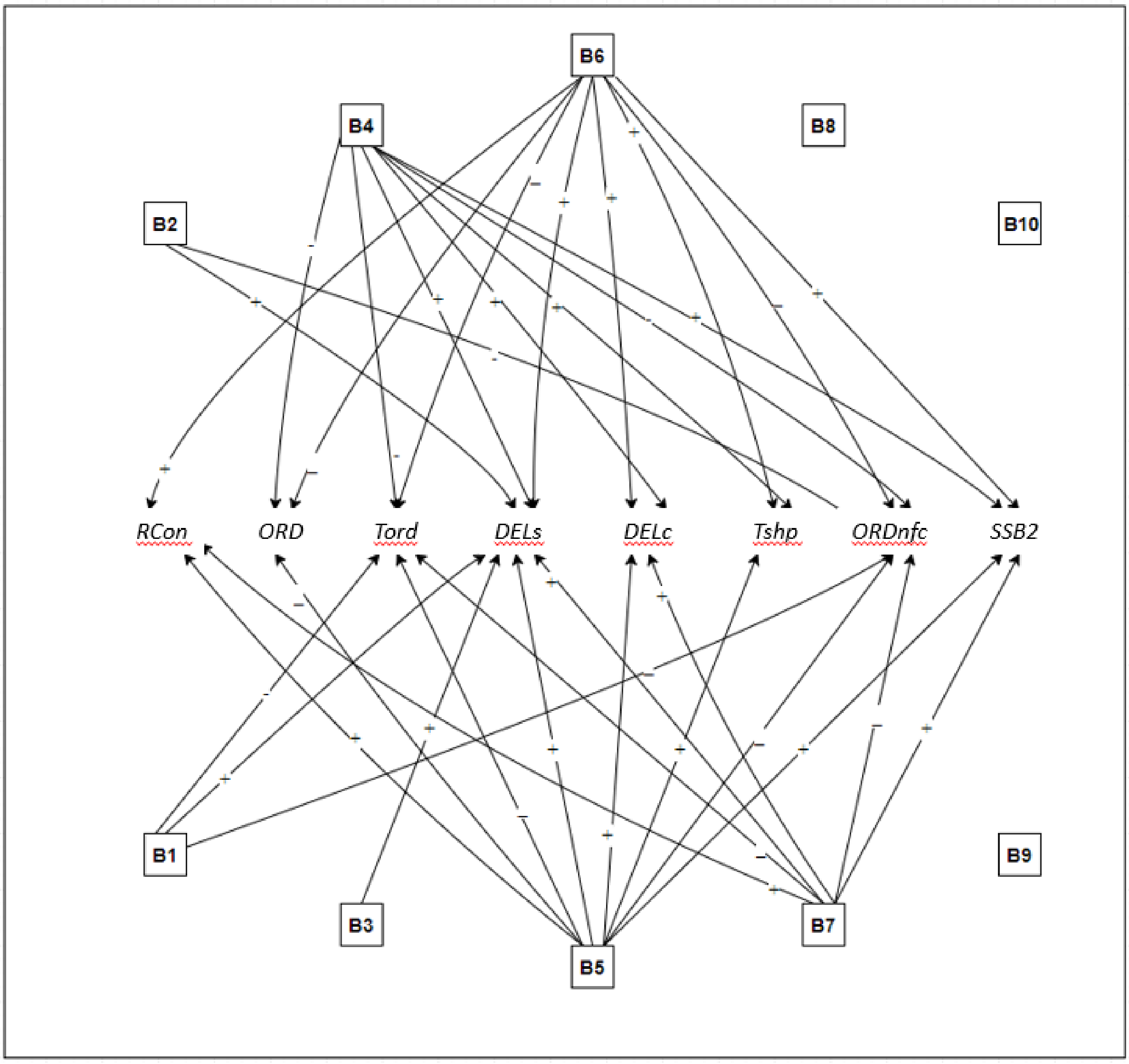
Parameter	Symbol
The total number of roll-containers shipped	*RCon*
The total number of completed orders	*ORD*
The average duration of the order	*Tord*
The number of deliveries from suppliers	*DELs*
The number of deliveries to customer locations	*DELc*
The average delivery time to customers	*Tshp*
Percentage of not full completed orders	*ORDnfc*
State statistics of Brigade_2	*SSB2*

Table 3.

Parameter	Quantity
Quantitative data	
Trolley capacity [palettes]	2
Trolley capacity (Brigade_2) [roll-containers]	3
Average trolley speed [km/h]	8
Buffer capacity with completed orders [roll-containers]	20
Buffer capacity with pallets [palettes]	10
Maximum pallet weight [kg]	800
Maximum roll-container weight [kg]	350
Maximum input ramp capacity [pallets]	41
The capacity of the truck with completed orders [roll-containers]	30
Number of entry ramps [pieces]	4
Number of output ramps [units]	6

Number of suppliers [units]	5
Number of clients [pieces]	100
Number of customer locations [units]	16
Number of articles [pieces]	432
Number of orders [pieces]	10 000
Number of shelving places [units]	4320
Number of storage places for pallets [units]	4320
Time data	
Average pallet inspection time on the input ramp [seconds]	30
Frequency of generating new orders [hours]	24
Number of simulation days [days]	75
Supplier's lead time_1 [hours]	9
Supplier's lead time_2 [hours]	3
Supplier's lead time_3 [hours]	7,5
Supplier's lead time_4 [hours]	3,5
Supplier's lead time_5 [hours]	12

Figure 3



B6
B4
B8
B2
B10
RCon
ORD
Tord
DELs
DELc
Tshp
ORDnfc
SSB2
B1
B9
B3
B7
B5

Figure 4

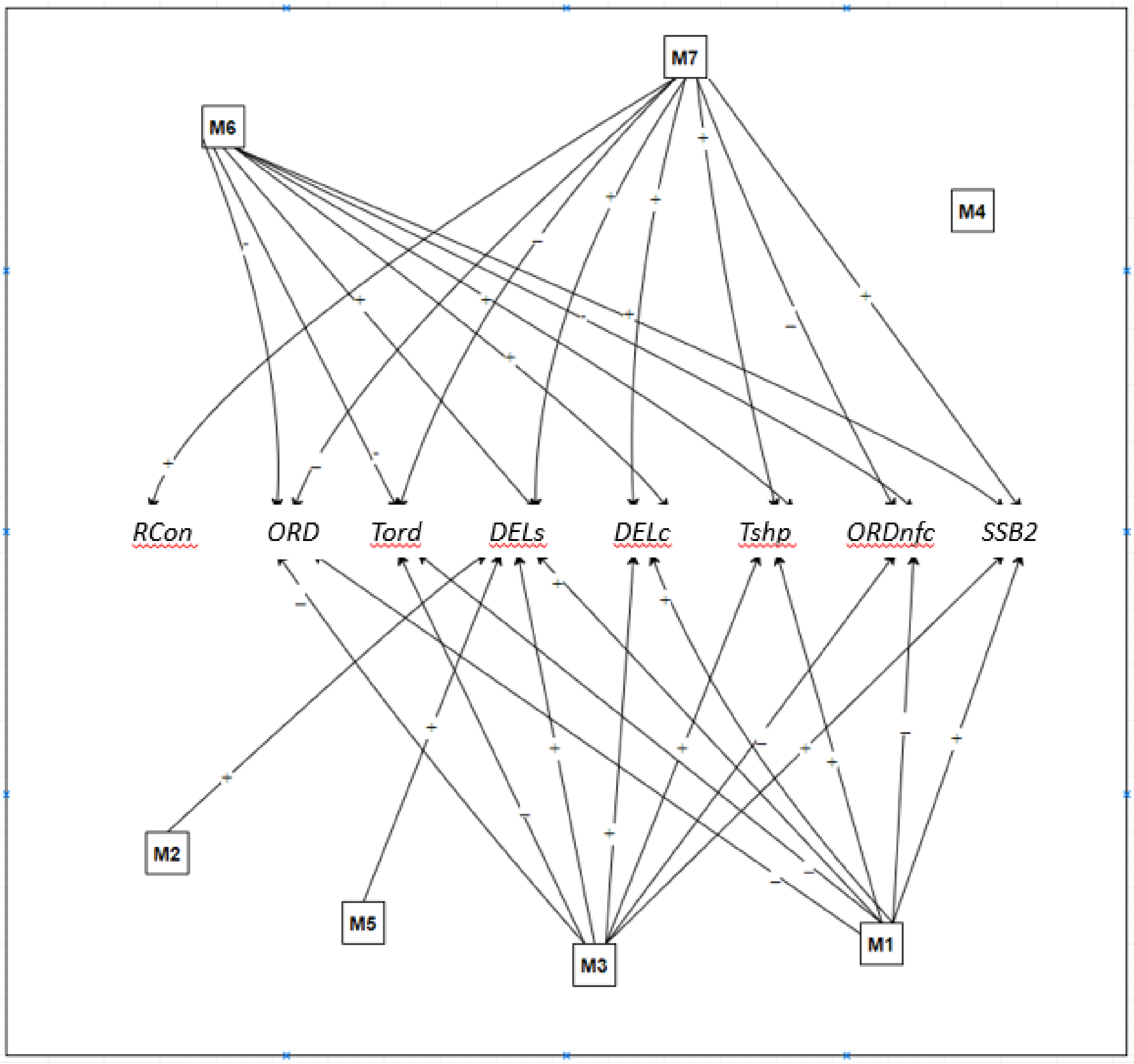


Figure 5

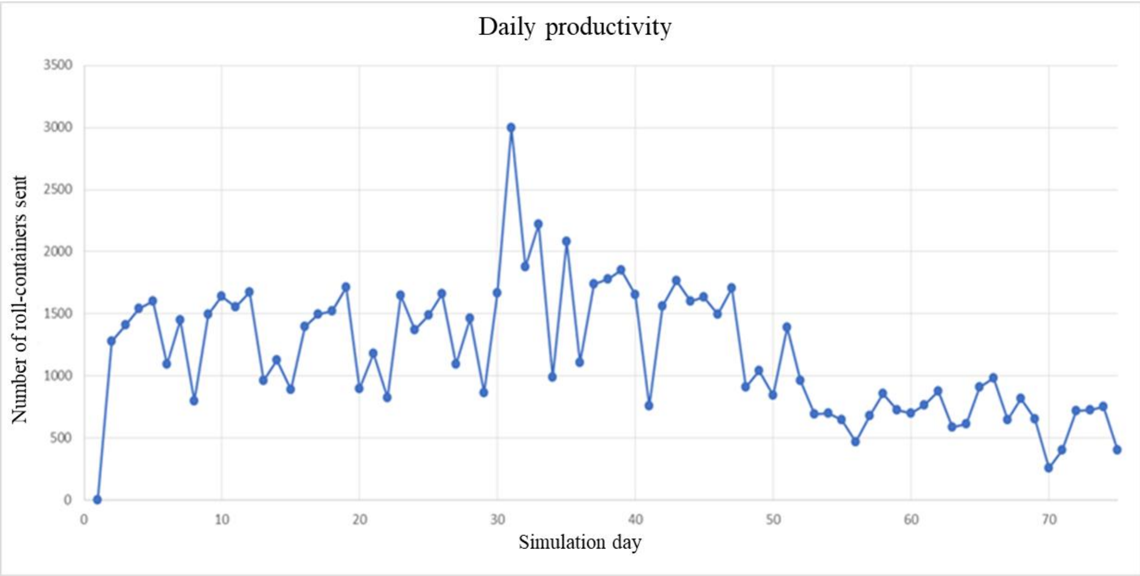


Figure 6

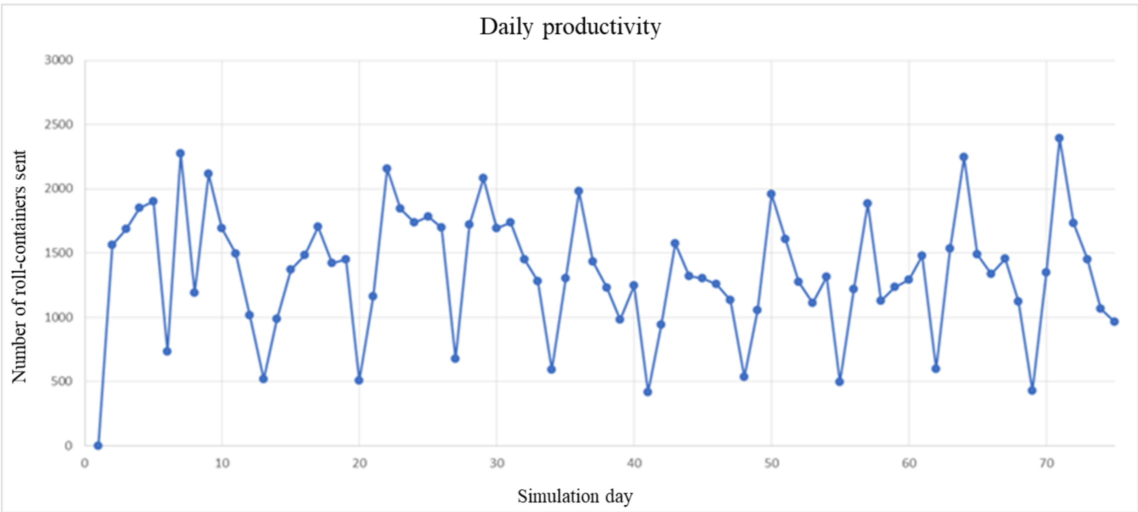


Table 4

Scenario	Tested parameter							
	RCon	*ORD*	*Tord*	*DELs*	*DELc*	*Tshp*	*ORDnfc*	*SSB2*
B1			-	+			-	
B2				+			-	
B3				+				
B4		-	-	+	+	+	-	+

B5	+	-	-	+	+	+	-	+
B6	+	-	-	+	+	+	-	+
B7	+		-	+	+		-	+
B8								
B9								
B10								
M1		-	-	+	+	+	-	+
M2				+				
M3		-	-	+	+	+	-	+
M4								
M5				+				
M6		-	-	+	+	+	-	+
M7	+	-	-	+	+	+	-	+

Table 5

Scenario	Tested parameter							
	RCon	*ORD*	*Tord*	*DELs*	*DELc*	*Tshp*	*ORDnfc*	*SSB2*
B1			-	+		-	-	
B2				+			-	
B3			-	+		-		
B4		-	-	+	+	+	-	+
B5	+	-	-	+	+	+	-	+
B6	+	-	-	+	+	+	-	+
B7	+		-	+	+		-	+
B8								
B9								
B10								
M1		-	-	+	+	+	-	+
M2				+				
M3		-	-	+	+	+	-	+
M4								-
M5				+		-		
M6		-	-	+	+	+	-	+
M7	+	-	-	+	+	+	-	+

Table 6.

Scenario	Tested parameter							
	RCon	*ORD*	*Tord*	*DELs*	*DELc*	*Tshp*	*ORDnfc*	*SSB2*

B1			-	+		-	-	+
B2			-	+			-	
B3			-	+		-		
B4		-	-	+	+	+	-	+
B5	+	-	-	+	+	+	-	+
B6	+	-	-	+	+	+	-	+
B7	+	-	-	+	+	+	-	+
B8						-		-
B9								-
B10								
M1		-	-	+	+	+	-	+
M2		+		+		-		
M3		-	-	+	+	+	-	+
M4			+		+	-	-	-
M5			-	+		-		
M6		-	-	+	+	+	-	+
M7	+	-	-	+	+	+	-	+

Annex 1.

Parameter	REP_1	REP_2	REP_3	REP_4	REP_5	REP_6	REP_7	REP_8	REP_9	REP_10	REP_11	REP_12	REP_13	REP_14	REP_15	REP_16	REP_17
Total_number_sent_roll-containers	86987	95116	93308	75168	93644	84281	87707	93499	92985	93163	93678	83080	93402	82453	83768	89687	93193
Total_number_of_ylek_z_ramp_output	2899	3170	3110	2505	3121	2809	2923	3116	3099	3105	3122	2769	3113	2748	2792	2989	3106
Total_number_of_completed_purchases	13233	14581	14393	10636	14581	12818	14581	14581	14416	14384	14578	12587	14459	12283	12412	14405	14393
Average_implementation_times_orders [min]	20,168	24,613	19,986	26,331	21,081	24,828	27,323	19,149	24,433	22,175	21,164	33,998	21,286	31,13	26,534	24,066	20,859
Number_supplier_1	69	75	76	75	85	80	80	75	83	79	78	82	78	85	84	77	83
Number_supplier_2	145	142	144	137	149	153	155	146	173	162	153	150	150	170	165	148	155
Number_supplier_3	106	104	109	105	110	109	109	106	107	111	108	112	107	116	108	107	107
Number_supplier_4	140	141	146	145	158	161	155	150	173	156	159	158	152	180	160	156	161
Number_supplier_5	58	63	61	60	63	70	64	58	65	62	63	72	66	63	63	66	68
Average_number_pallet_na_supplier_1	19,913	18,573	18,737	18,667	18,094	18,688	17,975	18,773	17,349	18,367	20,218	18,512	18,179	19,329	16,94	17,844	17,843
Average_number_pallet_na_supplier_2	9,476	9,81	9,889	10,219	10,322	9,771	9,277	9,644	8,324	8,957	10,307	10,12	9,453	9,665	8,624	9,284	9,555
Average_number_pallet_na_supplier_3	12,962	13,394	13,064	13,333	13,982	13,716	13,193	13,283	13,458	13,072	14,602	13,554	13,252	14,164	13,176	12,841	13,841
Average_number_pallet_na_delivery_supplier_4	9,814	9,879	9,753	9,655	9,734	9,286	9,277	9,387	8,324	9,301	9,918	9,608	9,329	9,128	8,894	8,808	9,199
Average_number_pallet_na_supplier_5	23,69	22,111	23,344	23,333	24,413	21,357	22,469	24,276	22,154	23,403	25,032	21,083	21,485	26,079	22,587	20,818	21,779
Number_supply_location_1	96	96	96	96	96	96	96	96	96	96	96	96	97	96	97	96	96
Number_supply_location_2	184	184	184	184	184	183	184	184	184	184	184	184	184	184	184	185	184
Number_supply_location_3	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Number_supply_location_4	197	197	197	197	197	197	197	197	197	196	196	197	196	196	197	197	197
Number_supply_location_5	112	113	112	112	112	112	112	113	112	112	112	112	112	112	112	112	112
Number_supply_location_6	175	175	173	174	174	174	175	174	175	174	174	174	174	173	174	175	174
Number_supply_location_7	204	204	204	205	204	204	204	204	205	204	205	204	205	204	204	204	204
Number_supply_location_8	153	154	153	154	153	154	153	154	153	154	153	153	153	153	154	154	154
Number_supply_location_9	216	216	217	216	216	216	216	216	215	217	216	216	216	216	216	216	216
Number_supply_location_10	115	115	114	114	114	114	115	115	114	115	115	115	114	115	115	115	115
Number_supply_location_11	143	142	143	143	143	143	142	143	143	143	143	143	143	143	143	143	143
Number_supply_location_12	194	194	194	194	194	194	194	194	194	195	194	194	194	193	194	194	194
Number_supply_location_13	122	122	123	122	122	123	122	122	122	123	122	122	123	122	123	122	123
Number_supply_location_14	88	87	88	88	88	88	88	88	87	88	88	87	88	87	88	88	87
Number_supply_location_15	127	127	127	127	127	127	127	127	127	127	127	127	127	126	127	127	127
Number_supply_location_16	683	954	895	289	907	594	708	899	885	887	907	555	897	538	574	771	890
Number of_syllables_Rampa_1	469	531	534	434	511	477	490	523	505	539	512	454	536	447	451	512	542
Number of_syllables_Rampa_2	480	503	498	386	513	504	516	535	538	486	549	452	525	460	482	477	511
Number of_syllables_Rampa_3	509	548	535	427	494	463	497	501	515	495	502	473	512	445	480	523	484
Number of_syllables_Rampa_4	472	539	495	425	563	435	479	535	510	531	502	485	509	474	463	464	543
Number of_syllables_Rampa_5	493	497	507	432	526	459	484	515	503	521	550	450	527	461	449	518	508
Number of_syllables_Rampa_6	476	552	541	401	514	471	457	507	528	533	507	455	504	461	467	495	518
Share_ramps_in_total_number_of_yourself_Ramp_1	0,162	0,168	0,172	0,173	0,164	0,17	0,168	0,168	0,163	0,174	0,164	0,164	0,172	0,163	0,162	0,171	0,175
Share_ramps_in_total_number_of_yourself_Ramp_2	0,166	0,159	0,16	0,154	0,164	0,179	0,177	0,172	0,174	0,157	0,176	0,163	0,169	0,167	0,173	0,16	0,165
Share_ramps_in_total_number_of_yourself_Ramp_3	0,176	0,173	0,172	0,17	0,158	0,165	0,17	0,161	0,166	0,159	0,161	0,171	0,164	0,162	0,172	0,175	0,156
Share_ramps_in_the_total_number_of_yourself_Ramp	0,163	0,17	0,159	0,17	0,18	0,155	0,164	0,172	0,165	0,171	0,161	0,175	0,164	0,172	0,166	0,155	0,175
Share_ramps_in_total_number_of_yourself_Ramp_5	0,17	0,157	0,163	0,172	0,169	0,163	0,166	0,165	0,162	0,168	0,176	0,163	0,169	0,168	0,161	0,173	0,164
Share_ramps_in_the_total_number_of_yourself_Ramp	0,164	0,174	0,174	0,16	0,165	0,168	0,156	0,163	0,17	0,172	0,162	0,164	0,162	0,168	0,167	0,166	0,167
Average_implementation_time_executions [min]	11,354	11,92	11,84	12,151	11,596	11,846	11,06	11,342	9,801	9,319	9,684	10,296	10,246	10,411	10,62	11,862	10,844
Percentage_incomplete_orders_location_1	0,038	0,043	0,036	0,043	0,051	0,036	0,051	0,038	0,049	0,038	0,049	0,036	0,031	0,054	0,038	0,041	0,049
Percentage_incomplete_order_location_2	0,037	0,04	0,044	0,041	0,043	0,051	0,043	0,033	0,047	0,04	0,045	0,045	0,048	0,043	0,043	0,036	0,037
Percentage_incomplete_orders_location_3	0,052	0,052	0,052	0,05	0,042	0,047	0,047	0,042	0,045	0,06	0,055	0,045	0,05	0,05	0,045	0,045	0,058
Percentage_incomplete_orders_location_4	0,04	0,038	0,04	0,038	0,038	0,048	0,042	0,045	0,047	0,047	0,048	0,042	0,048	0,052	0,044	0,04	0,048
Percentage_inflate_order_location_5	0,05	0,038	0,044	0,042	0,046	0,042	0,042	0,038	0,044	0,044	0,048	0,05	0,044	0,042	0,044	0,042	0,05
Percentage_inflate_order_location_6	0,038	0,043	0,054	0,04	0,045	0,043	0,039	0,04	0,045	0,043	0,05	0,05	0,052	0,061	0,047	0,039	0,047
Percentage_incomplete_orders_location_7	0,047	0,044	0,041	0,038	0,041	0,043	0,043	0,04	0,041	0,04	0,036	0,043	0,038	0,044	0,042	0,04	0,046
Percentage_incomplete_orders_location_8	0,039	0,038	0,036	0,036	0,038	0,03	0,033	0,038	0,039	0,036	0,035	0,041	0,036	0,039	0,036	0,035	0,03
Percentage_incomplete_orders_location_9	0,035	0,037	0,031	0,038	0,041	0,039	0,038	0,045	0,05	0,033	0,038	0,038	0,037	0,034	0,042	0,038	0,04
Percentage_inflate_order_location_10	0,029	0,039	0,047	0,041	0,047	0,041	0,037	0,035	0,047	0,035	0,037	0,025	0,041	0,033	0,025	0,037	0,035
Percentage_inflate_order_location_11	0,034	0,041	0,034	0,028	0,036	0,03	0,041	0,041	0,039	0,03	0,038	0,03	0,03	0,033	0,041	0,028	0,036
Percentage_inflate_order_location_12	0,036	0,038	0,041	0,037	0,041	0,036	0,036	0,037	0,041	0,033	0,039	0,042	0,033	0,046	0,038	0,037	0,041
Percentage_inflate_order_location_13	0,033	0,033	0,023	0,033	0,035	0,027	0,033	0,033	0,029	0,031	0,029	0,033	0,027	0,042	0,033	0,033	0,027
Percentage_inflate_order_location_14	0,04	0,048	0,048	0,038	0,043	0,051	0,046	0,043	0,054	0,043	0,048	0,054	0,043	0,054	0,051	0,043	0,054
Percentage_inflate_order_location_15	0,029	0,033	0,042	0,044	0,042	0,033	0,039	0,039	0,042	0,037	0,039	0,046	0,04	0,05	0,035	0,039	0,039
Percentage_inflate_order_location_16	0,008	0,006	0,007	0,025	0,006	0,007	0,007	0,006	0,006	0,007	0,007	0,01	0,007	0,013	0,011	0,007	0,007
State statistics Brigade_2 - Brigade_2	45,20	51,52	41,48	62,73	41,89	59,67	57,31	39,39	52,38	47,68	44,05	68,35	45,42	69,32	62,76	54,60	45,41

Annex 2

Simulation Day	Number of roll-containers sent - daily capacity																
	Basic scenario	Scenario B1	Scenario B2	Scenario B3	Scenario B4	Scenario B5	Scenario B6	Scenario B7	Scenario B8	Scenario B9	Scenario B10	Scenario M1	Scenario M2	Scenario M3	Scenario M4	Scenario M5	Sce
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	1281	1284	1269	1282,5	1545	1566	1564,5	1546,5	1320	1284	1284	1554	1288,5	1554	1324,5	1288,5	
3	1410	1405,5	1390,5	1411,5	1674	1687,5	1650	1647	1378,5	1398	1398	1657,5	1396,5	1657,5	1374	1396,5	
4	1543,5	1539	1557	1545	1888,5	1873,5	1867,5	1885,5	1549,5	1545	1545	1903,5	1551	1903,5	1563	1551	
5	1597,5	1584	1593	1591,5	1839	1867,5	1870,5	1860	1554	1596	1596	1876,5	1597,5	1876,5	1546,5	1597,5	
6	1093,5	808,5	1326	811,5	819	979,5	1134	1239	1146	1060,5	1060,5	808,5	810	808,5	1111,5	810	
7	1447,5	1740	1209	1714,5	2112	1999,5	1861,5	1744,5	1357,5	1471,5	1471,5	2181	1713	2181	1407	1713	
8	795	804	808,5	816	1278	1188	1207,5	1185	843	798	798	1206	811,5	1204,5	823,5	811,5	
9	1497	1501,5	1470	1479	2145	2134,5	2134,5	2121	1485	1485	1485	2137,5	1477,5	2134,5	1458	1477,5	
10	1641	1633,5	1692	1581	1590	1765,5	1839	2038,5	1662	1663,5	1663,5	1548	1641	1566	1698	1641	
11	1554	1539	1524	1600,5	1500	1552,5	1561,5	1597,5	1539	1530	1530	1312,5	1540,5	1365	1537,5	1540,5	
12	1675,5	1603,5	1663,5	1612,5	889,5	976,5	1354,5	1164	1671	1663,5	1663,5	900	1668	823,5	1651,5	1668	
13	960	781,5	1204,5	831	429	586,5	732	858	1002	985,5	985,5	307,5	829,5	337,5	945	829,5	
14	1129,5	1371	942	1279,5	1326	1407	1144,5	1246,5	1120,5	1144,5	1144,5	1075,5	1314	1077	1140	1314	
15	891	894	856,5	885	964,5	1608	1551	1947	864	856,5	856,5	1335	852	1221	924	855	
16	1396,5	1368	1384,5	1402,5	1410	1801,5	1963,5	2154	1395	1389	1390,5	1174,5	1399,5	1162,5	1360,5	1393,5	
17	1497	1498,5	1506	1471,5	1437	1884	1932	1762,5	1464	1491	1494	1359	1497	1212	1477,5	1501,5	
18	1524	1537,5	1522,5	1464	1347	1296	1488	1627,5	1572	1531,5	1537,5	1282,5	1539	1171,5	1488	1534,5	
19	1713	1620	1671	1650	1146	1242	1807,5	1639,5	1665	1710	1699,5	1263	1680	1000,5	1747,5	1687,5	
20	892,5	646,5	1122	708	484,5	502,5	759	724,5	936	934,5	922,5	525	687	388,5	892,5	709,5	
21	1180,5	1302	861	1320	1150,5	1075,5	1591,5	1330,5	1186,5	1137	1168,5	1329	1320	814,5	1236	1324,5	
22	823,5	960	865,5	856,5	1734	1666,5	1555,5	1732,5	789	852	825	2052	904,5	1494	789	873	
23	1648,5	1632	1612,5	1626	1497	1612,5	1906,5	2092,5	1644	1624,5	1627,5	1491	1636,5	1416	1641	1632	
24	1369,5	1326	1303,5	1471,5	1623	1687,5	1647	1627,5	1410	1380	1360,5	1699,5	1384,5	1200	1383	1389	
25	1486,5	1491	1315,5	1534,5	1384,5	1524	1320	1531,5	1525,5	1521	1471,5	1359	1527	1702,5	1408,5	1539	
26	1662	1573,5	1444,5	1690,5	1300,5	1414,5	1161	1375,5	1639,5	1623	1629	1312,5	1648,5	1342,5	1561,5	1576,5	
27	1090,5	739,5	1140	811,5	492	613,5	486	555	1023	979,5	1003,5	670,5	807	517,5	964,5	741	
28	1461	1666,5	1159,5	1651,5	1069,5	1518	1135,5	1350	1492,5	1549,5	1402,5	1383	1726,5	1252,5	1428	1666,5	
29	861	900	919,5	904,5	1809	2466	1614	1515	865,5	867	883,5	2130	825	1926	880,5	850,5	
30	1663,5	1602	1443	1630,5	1413	1948,5	1393,5	1786,5	1641	1671	1624,5	1732,5	1671	1860	1626	1603,5	
31	2997	2905,5	2496	2929,5	1284	1695	1044	1635	2959,5	2964	2716,5	1291,5	3114	1590	2947,5	2986,5	
32	1878	1923	1708,5	1864,5	1509	1689	1150,5	1516,5	1899	1941	1989	1299	1875	1360,5	2022	1852,5	
33	2221,5	2148	2322	2163	1714,5	1452	1222,5	1285,5	2335,5	2281,5	2391	1293	2245,5	1347	2362,5	2317,5	
34	985,5	754,5	967,5	745,5	637,5	591	430,5	555	982,5	897	960	559,5	792	498	933	838,5	
35	2083,5	2335,5	1711,5	2350,5	1242	1450,5	852	1393,5	2152,5	2103	2026,5	1165,5	2367	1140	2022	2406	
36	1105,5	1029	1383	928,5	1915,5	2352	1404	2820	916,5	997,5	1227	1809	945	1996,5	1117,5	1066,5	
37	1741,5	1780,5	1786,5	1813,5	1344	1807,5	1140	1744,5	1762,5	1761	1803	1467	1786,5	1404	1729,5	1878	
38	1776	1468,5	1866	1483,5	1396,5	1510,5	1146	1597,5	1734	1878	1899	1323	1612,5	1096,5	1710	1492,5	
39	1851	1998	1756,5	2049	1335	1167	1255,5	1450,5	1989	1945,5	1876,5	1138,5	1912,5	1350	1780,5	1945,5	
40	1654,5	1590	1788	1894,5	1476	1089	1488	1287	1723,5	1762,5	1888,5	1092	1440	1251	1807,5	1869	
41	754,5	552	963	712,5	463,5	352,5	589,5	552	813	786	864	439,5	520,5	472,5	873	637,5	
42	1561,5	1543,5	1521	1771,5	1087,5	807	1140	1350	1563	1545	1641	988,5	1501,5	1248	1743	1800	
43	1762,5	1927,5	1605	1674	1663,5	1303,5	2082	2419,5	1411,5	1587	1458	1381,5	2076	1743	1377	1632	
44	1603,5	1465,5	1444,5	1528,5	1422	1165,5	1872	1614	1479	1488	1528,5	1089	1686	1546,5	1525,5	1515	
45	1633,5	1510,5	1549,5	1806	1354,5	1144,5	1626	1474,5	1707	1554	1612,5	964,5	1656	1396,5	1686	1605	
46	1495,5	1384,5	1464	1585,5	1383	1207,5	1575	1510,5	1615,5	1557	1512	966	1399,5	1455	1563	1486,5	
47	1704	1416	1570,5	1573,5	1389	1189,5	1647	1417,5	1615,5	1716	1455	996	1506	1263	1773	1510,5	
48	906	589,5	1108,5	729	489	450	654	540	853,5	994,5	741	423	640,5	445,5	1023	651	
49	1041	1122	759	1285,5	1026	955,5	1254	934,5	984	1116	954	810	1243,5	925,5	1131	1149	
50	841,5	916,5	888	883,5	1681,5	1617	2514	1615,5	934,5	946,5	751,5	1281	1125	1731	1032	1065	
51	1392	1254	1324,5	1338	1609,5	1336,5	1975,5	1707	1383	1389	1183,5	1299	1314	1296	1444,5	1425	
52	963	949,5	1086	960	1062	1183,5	1459,5	1293	1050	988,5	913,5	1195,5	955,5	1180,5	1009,5	1056	
53	691,5	847,5	903	682,5	1024,5	1351,5	1119	1447,5	690	754,5	766,5	1122	702	1069,5	690	618	
54	699	985,5	600	816	1080	1105,5	988,5	1480,5	610,5	633	964,5	1261,5	765	1135,5	690	696	
55	648	640,5	796,5	726	345	468	387	733,5	811,5	751,5	750	555	663	481,5	780	532,5	
56	469,5	768	522	484,5	951	970,5	805,5	1711,5	571,5	660	613,5	1173	814,5	946,5	423	916,5	
57	679,5	846	912	516	1524	1719	1323	2587,5	609	585	724,5	1914	679,5	1567,5	696	660	
58	858	805,5	786	873	1416	1332	1057,5	1396,5	918	849	937,5	1608	990	1164	874,5	919,5	
59	723	666	699	838,5	1150,5	1206	1035	1147,5	915	796,5	784,5	1246,5	786	1156,5	805,5	726	
60	697,5	787,5	609	744	1068	1075,5	1135,5	912	879	879	732	1225,5	792	952,5	787,5	693	
61	765	885	621	882	1017	1195,5	1282,5	1111,5	906	961,5	823,5	1215	873	825	837	718,5	
62	874,5	682,5	681	628,5	307,5	481,5	463,5	768	862,5	1048,5	864	372	750	382,5	967,5	658,5	
63	588	693	348	585	691,5	1125	844,5	1509	504	511,5	450	757,5	811,5	985,5	562,5	874,5	
64	609	546	529,5	574,5	1120,5	1998	1458	2437,5	484,5	520,5	550,5	1465,5	816	1464	480	700,5	
65	912	828	739,5	739,5	1105,5	1396,5	1324,5	1708,5	798	882	853,5	1216,5	1155	1215	852	783	
66	979,5	805,5	963	841,5	1146	1054,5	1011	1383	865,5	948	930	1026	1017	1392	1000,5	754,5	
67	648	660	703,5	652,5	733,5	1162,5	1177,5	1405,5	691,5	723	687	885	837	1314	781,5	576	
68	817,5	894	837	837	1045,5	1071	1144,5	1404	858	910,5	852	1233	1090,5	1404	1048,5	729	
69	651	502,5	934,5	547,5	421,5	616,5	570	994,5	778,5	807	753	453	715,5	553,5	876	517,5	
70	256,5	508,5	421,5	309	907,5	984	1242	600	157,5	163,5	379,5	1012,5	591	1285,5	247,5	357	
71	400,5	664,5	708	405	1507,5	1378,5	2011,5	1324,5	385,5	399	633	1371	673,5	1570,5	462	393	
72	720	718,5	909	687	1207,5	1297,5	1233	1044	744	705	976,5	1119	1018,5	1450,5	847,5	612	
73	723	589,5	780	624	1030,5	1170	1282,5	988,5	688,5	661,5	864	850,5	868,5	1392	760,5	553,5	
74	751,5	579	868,5	769,5	918	1378,5	1515	1056	978	795	988,5	973,5	927	1023	1030,5	579	
75	400,5	328,5	561	316,5	982,5	1239	973,5	1086	540	474	598,5	975	639	1113	441	375	