Supply Chain Design Approach Based on Composite Simulation Models

Natalia Lychkina, Gleb Zakhodyakin, and Yulia Morozova

Abstract Strategic transformation and logistic integration in supply chain management requires systematic strategic supply chain modeling, and modern simulation provides such opportunities for analysis and synthesis of efficient and integrated supply chains. Authors suggest a method of constructing an analysis of conceptual supply chain models. The following base levels of the supply chain representation are considered: object-based, configuration/network-based, process-based, and logistics coordination levels. A general simulation model of integrative supply chain is proposed based on technologies of hybrid process and agent-based simulation modeling. Literature review on simulation modeling application for integrative and collaborative supply chains is presented. Iterative simulation and optimization procedures for complex analysis and optimization of supply chains are proposed. The suggested approaches and techniques were tested in the case of strategic transformation of supply chain. Authors present and interpret the results of supply chain optimization и simulation modeling for a set of scenarios of logistic processes transformation and inventory management policies, inter-organizational coordination mechanisms, and related technological solutions.

Keywords Simulation modeling · Supply chain · Design approach · Composite models

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1 Introduction

In the practice of supply chain management (SCM), a wide range of tasks are traditionally solved through modeling [41], among them: supply chain structure, process redesign, supplier selection, facilities/ capacity planning, supply chain integration, information sharing, bullwhip effect, reverse logistics, replenishment control policies, supply chain optimization, cost reduction, system performance, inventory planning/management, planning & forecasting demand, production planning & scheduling, distribution & transportation planning, dispatching rules. In real SC transformation projects, the range of tasks to be solved is determined by project purposes and can be significantly expanded. That will require more process details and analysis of specific phenomena of the functioning of complex and dynamic SC.

In the practice of improving logistics activities in the SC, numerous logistics technologies are being implemented (S&OP, VMI, CPFR, etc.), based on the principles of logistics integration and integrated planning mechanisms in SCM. A common task in the implementation of modern logistics concepts and technologies based on integration, embedded in the content of the holistic concept of the SC, is to ensure a synergistic effect in the SC. This is achieved by integrating and synchronizing logistics processes in the SC, combining the logistics capacities of the SC participants, effective inter-organizational coordination, improving planning and implementing integrated planning mechanisms, using a wide range of organizational and technological solutions focused on the use of modern IT technologies and creating a single information space for SCM [39]. Integration of different types provides a synergistic effect in the SC, which cannot be obtained by local optimization to detriment of system efficiency or solving specific problems in the functional areas of logistics. In practice, this is always a project of strategic development and transformation of the existing SC, including new principles of the organization of SCM, improving the mechanisms of inter-organizational interaction of participants and integrated planning, a reengineering project that ensures the integration and synchronization of logistics processes in the SC, creating an IT infrastructure that supports the implementation of logistics concepts. Without testing these numerous management decisions through modeling, it is impossible to obtain options for organizing the SC that provide a synergistic effect. It is necessary to form the best option for implementing transformations in the SC. This requires systematic strategic SC modeling, and modern simulation provides such opportunities for analysis and synthesis of efficient and integrated SC.

The article explores the possibilities of using hybrid simulation for integrated SC.

2   Background

Literature offers different qualitative and quantitative supply chain modeling methods: analytical methods, simulation and modeling (S&M), physical experiments, heuristics, etc. Depending on the goals, various combinations of optimization, computer simulation, heuristics, and statistics are used.

Several studies performed benchmarking of the applicability of different simulation paradigms for supply chain examination. Tako and Robinson [41] studied the application of discrete event simulation (DES) and system dynamics (SD) as decision-making support systems in the field of logistics and supply chain management taking account of the nature of addressed tasks and the level of management. In particular, the authors showed that SD is the leader in bullwhip effect analysis tasks, with the same application frequency as DES in studying information sharing and return flows. DES is used more often than SD for studying SC structures and tactical and operational tasks. The authors' shared view is that both DES and SD may be actively used to achieve SC strategic planning goals.

The status and prospects of supply chain simulation were analyzed in a review by Oliveira, Lima and Montevechi [31], which discussed the most popular application of mono methods (DES, SD, ABMS) in scientific publications and determined the prospects of hybrid simulation modeling. Kersten and Saeed [20] have reached similar conclusions. The authors examined the application of various simulation methods for the description of core processes in a supply chain (as per SCOR reference process model) and pointed out the fragmented nature of the well-known models, since only a few studies examine more than one SC process. It proved that simulation tools were more often used for improvement and reengineering of individual processes rather than for complex analysis of synergies in the performance of integrated supply chains.

ABMS, DES and SD paradigms have essentially different points of view on the modeling of the structure and dynamics of a supply chain for different representations [26]. DES best works for describing network configurations and core processes in a supply chain and is wildly used in case studies [7, 11, 13, 29, 42–45]. Modeling by core processes (Plan, Source, Make and Deliver) and subprocesses in a supply chain is based on a reference process model using SCOR recommendations. Barnett and Miller [4] described the architectural components used to implement the distributed supply chain modeling tool (e-SCOR), and e-SCOR applications that demonstrate how businesses are modeled and analyzed to determine the validity of alternative, virtual business models. Herrmann et al. [19] described a new supply chain modeling framework that follows the SCOR model. The development and application of e-SCOR technique are presented in Chatfield et al. [9, 15, 30, 33, 40].

Application of SD in studying supply chains and engineering activities helps to study fluctuations in supply chains, the bullwhip effect; show complex interaction in managing material, finance and information flows when making managerial decisions. Several studies address adaptive SC modeling using SD methods [1, 6, 12,

23]. Angerhofer and Angelides [1] suggested a system dynamics model of collaborative supply chains highlighting such model components as agents, interconnections system (topology), interrelations system (cooperation levels), processes, supporting technology and business strategy. Langroodi and Amiri [23] investigated supplier–buyer relationships in each level of five-level multi-product supply chain depending on the operational costs and in conditions of non-stationary demand. Crowe et al. [12] studied disruptions of supplies in three echelon food retail supply chain. Therefore, system dynamics best fits the object-based approach to SC decomposition. SD and DES reproduce (emulate) the actual performance of logistics infrastructure at various levels of aggregation of SC objects or processes.

Behdani [5] evaluated paradigms for modeling supply chains as complex sociotechnical systems. At micro-level author highlighted such systemic properties of supply chains as numerousness and heterogeneity, local interactions, nestedness, adaptiveness. At macro-level supply chains have such properties as emergence, self-organization, co-evolution, path dependency. Author concluded that agent-based modeling and simulation (ABMS) covers these properties most of all.

The dynamics of collaborative supply chains and behavior of supply chain partners were studied in Baratt [3, 16, 24]. ABMS methodology was proposed to address the lack of methodologies supporting collaborative supply chain planning. It was shown in review [37] that capabilities of the ABMS method in exploring complex cooperation between supply chain partners related to organizational and technological changes in a supply chain, information and knowledge sharing have been understudied. Hernández et al. [18] considered the technologies of multi-agent systems as a powerful modeling tool for all kinds of complexities that arise in the process of planning supply chains during negotiations in the context of cooperation. In paper [26] author concluded that ABMS best works for representing processes and occurrences of inter-organizational coordination within a supply chain. Arvitrida et al. [2] examined competition and collaboration in supply chains using ABMS. The proposed model could assess supply chain revenue and supply chain service level depending on collaboration strategy including duration of collaboration between supplier and manufacturer and manufacturers' number of sourcing and competition behavior.

Ponte et al. [35] used agent-based model of the four-echelon supply chain to prove that decision-making process requires evolving "from a reductionist approach (where the overall strategy is the sum of individual strategies) to a holistic approach (where global optimization is sought through collaboration)". Additionally, authors applied the theory of constraints to define an appropriate framework and the Drum–Buffer–Rope method to integrate supply chain processes and synchronize decisions.

Long [25] confirmed that inter-organizational collaborative simulation requires covering the knowledge of agent, flow and process to qualifiedly represent the supply chain network operation. For this purpose, author proposed a multi-methodological collaborative simulation framework, in which a multi-agent system is adopted to represent the inter-organizational structure of a supply chain network; the three flows of material, information and time are enabled to represent the operational mechanisms; and the processes are used to represent the micro behaviors of agents.

Compensatory combination of SC simulation paradigms was addressed in several studies [14, 21, 27, 28, 36]. Hennies et al. [17] offered the mesoscopic approach for modeling supply chains that combines discrete impulse-like flows with piecewise constant flow rates. Palma-Mendoza [32] built a hybrid SC model, using different modeling paradigms at different levels of representation (SD was used for aggregated model and DES for more detailed model). Castilho et al. [8] proposed a hierarchically integrated set of models consisting of a system dynamic model to support strategic decisions, an analytical-optimization model to support tactical decisions, and a discrete event model to support decisions at the operational level. Various combinations of agents and processes in hybrid SC models are discussed in Chatfield [10, 22, 25, 34].

However, literature analysis has shown that the presented supply chain models are fragmentary and do not cover a broad class of SC design and strategic transformation tasks sufficiently. The current task is to create a general supply chain simulation model that can be applied in supply chain transformation projects.

3 Proposed Approach

The integrated nature of activity within a supply chain and systemic representation of its issues require the concurrent achievement of a number of goals focused on integration and the systemic representation of a supply chain: the alignment and optimization of key business processes by adding more value (a supply chain as a set of interacting processes), management of interrelated material, finance and information flows, and inter-organizational coordination or collaborative interaction and cooperation of supply chain participants. Description of a supply chain as an integral whole from the viewpoint of a systemic approach calls for studying the aggregate of multiple interrelated structures, flows, processes, participants and coordination mechanisms. The conceptualization, structuring and detailing of objects and processes in a supply chain may be performed from any angle of vision depending on the addressed tasks. In real tasks of supply chain analysis and synthesis, configuration and supply chain development analysis, these representations may overlap and complete each other. It is also necessary to address the static and dynamic descriptions of a supply chain in conceptual modeling, in addition to structural descriptions.

Comprehensive SCM challenges require a combined use of different modeling methods. A description of a supply chain, as shown above, should combine representation methods for network structures, processes, flows, cooperation and inter-organizational coordination and many other occurrences or phenomena in the description of dynamic supply chains are considered: object-based, configuration/network-based, process-based, and logistics coordination levels. Composite simulation models allow combining simulation approaches for creating more adequate supply chain models.

This defines a compensatory (composite) combination of simulation paradigms in high-level SC models based on the above proposed conceptual model. DES and

SD are used to describe SC logistic processes and some properties of adaptive SC (SD). The iterative optimization simulation design procedures developed by applying heuristics are more efficient in management consulting and are usually tested on solutions for network structure optimization and SC logistics process modeling.

Process and system dynamic simulation models can be more detailed depending on addressable tasks of supply chain analysis and synthesis. Agent-based modeling is used to model inter-organizational coordination between supply chain partners.

The general methodology for constructing conceptual SC models is based on the description of the network structure and configuration of the supply chain and the process approach to the decomposition of the SC and includes the following descriptions and stages of forming a simulation model, in which the following parameters are specified:

- Setting the forecast characteristics of demand.
- Network structure of the logistics system. Structure of input and output material flows.
- Description of the spatial structure of the system with reference to the map of the territory. Location of intermediate storage and transshipment points.
- Description of material flows or the structure of dynamic logistics objects that are moved and stored in the system, volume-time characteristics of material flows, rules for processing cargo flows, models for combining and separating material flows in network nodes.
- Detailed processes based on the SCOR model. Algorithms, time characteristics, and the cost of performing operations in network nodes. Logistics processes are asynchronous and are defined in the SC model as a description of parallel and interconnected processes.
- Description of supply chain management strategies. Inventory control and management policies related to the nodes of the network structure of the CPU.
- Characteristics of transport channels (participants in the transport process, type of transport, routes, tariffs, etc.). Transport policies and parameters.
- Description of the mechanisms used for interaction and inter-organizational coordination of supply chain participants.
- Creating output characteristics and performance indicators of the modeled logistics system.

The network configuration of the supply chain can be refined in a series of studies, based on the use of optimization models. The selected configuration is embedded in the description of the SC structure, and is supplemented with policies, as well as a detailed description of processes and material flows based on the object and process approach to SC decomposition.

The SCOR reference model is basic for the process model. The SCOR reference model consists of processes at three hierarchical levels that help integrate the supply chain from supplier to customer. At the first level, the SCOR models distinguish five main types of processes (Plan, Source, Make, Deliver, and Return), which are defined for the top level of the description of all supply chain operations. The SCOR reference model defines the structure and content of the supply chain model through these five

different management processes. All SC entities, such as the supplier, manufacturer, distributor, and seller in the supply chain, can be described using these five processes. At levels 2 and 3, these processes can be detailed.

However, the SCOR model is a static tool that does not include any capabilities for dynamic SC analysis and active reengineering of business processes using quantitative methods for analyzing SC performance indicators and dynamic parameters.

The integration of simulation modeling and the SCOR reference model of operations provides advantages for the formation of a common simulation methodology for solving a wide range of supply chain management tasks.

The e-SCOR technique offers and supports a common methodology and hierarchical structure for modeling processes in supply chains, based on the conceptual structure of the SCOR reference model, the building blocks of which combine standard processes from the SCOR model and simulation models of multiple processes in supply chains, performed at various levels of detail, most often implemented using the DES process simulation technique (as well as ABMS), which provide not only improvement, but also synchronization of processes in the SC. When modeling the supply chain, a quantitative analysis of the efficiency of business processes is carried out, which allows you to analyze the order lead time, delivery accuracy and delivery speed, and other indicators defined in the SCOR recommendations, as well as to identify bottlenecks in the processes, and problems with the synchronization of processes in the SC.

The scenario study of collaborative supply chains and defining strategies for inter-organizational interaction and cooperation of supply chain participants using ABMS is based on the reference model of the maturity of inter-organizational relations "4C", in which [24] levels and models of maturity of inter-organizational interaction of SC counterparties: communication, coordination, collaboration, and cooperation, corresponding to the integration of processes, information exchange, joint decision-making based on trust, the formation of a community of equal partners demonstrating commitment to common strategic goals). The conceptual foundations for building a multi-agent SC model are presented in the paper [38].

Key phases of the iterative optimization and simulation design procedure of supply chain include:

- a preliminary synthesis of the SC structure through optimization;
- a detailed simulation of SC processes and scenario analysis of simulation results;
- SC optimization (reducing multiple scenarios with the optimization function built into the simulator);
- SC engineering and scenario analysis using heuristics and simulation considering additional risk factors (stress testing).

The effective modeling constructs of developing supply chains build on the principles of a composite combination of system dynamic, process-based, and agent-based simulation models. Composite dynamic SC models function based on a single model and information framework, thus enabling to arrange information sharing

processes and interaction mechanisms between the model-based system representations. The top level of a model layer represents the logistics infrastructure of a supply chain and the business environment where economic agents manifest their individual behavior and which predefines decision-making rules, agents' experience, knowledge, and cooperation strategies. In turn, the model layer, which describes behavior and interaction between agents, launches the processes of self-organization, cooperation strategy, and new organizational forms that define overall supply chain performance and management. Such an approach to building multi-model complexes based on composite simulation models allows studying the dynamics and development of a supply chain by using interconnection of model strata in the examined organizational system [26].

4 Case-Study

To illustrate the applicability of the approach presented in this paper we consider a supply chain design case for an online home appliances retailer operating on Russian market. Currently the company operates in Moscow region only but is considering expansion into new regions within Central and Povolzhsky Federal Districts. The key questions the supply chain model should answer are:

- How many distribution centers (DC) are required to serve the demand?
- Where should they be located?
- What is the service zone for each DC?
- What transportation mode should be used for each leg of the distribution network?
- What storage and handling capacity is required?
- What cyclic and safety stock should be kept in each DC?
- What will be the cost of the whole distribution network? What will be the profit?

4.1 Conceptual Modeling

In this section we describe a conceptual model of the supply chain according to the proposed methodology.

Demand Characteristics

To estimate demand historical order data is used: the average number of orders per month and the average items per order. These numbers are be scaled based on population data to new regions. Historic data shows high variability of the order size that can be described by Poisson distribution.

To be competitive on a crowded online retail market the company must ensure that the order fulfillment time is within 2 days.
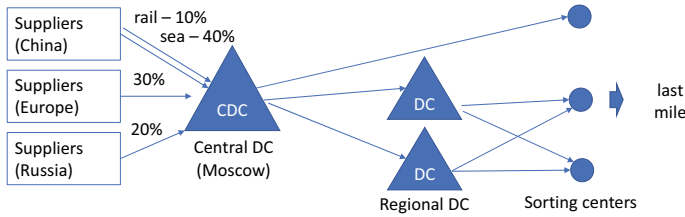
Fig. 1 Network structure of the logistics system

Network Structure of the Logistics System Structure of Material Flows

Currently the goods are delivered from the central warehouse to customer locations and self-pickup points operated by the logistics service providers. Local sorting centers will be established in major cities to split the material flow into different logistics channels in the last mile (Fig. 1). These sorting centers are considered as demand endpoints in this case study, so the demand forecast is aggregated by sorting center.

To guarantee the order fulfillment time below 2 days the company must establish regional warehouses (distribution centers) to hold the stock close to the customers. Considering the processing time at the fulfillment, sorting and last-mile stages, the transportation should not take more than 1 day. This converts to approximately 500 km distance limit for the leg between a DC and a sorting center.

The regional DCs are supplied from the central DC located near Moscow. This allows to consolidate orders to suppliers and simplifies importing operations. This DC is also servicing orders from Moscow region. Some of the newly added regions can be served from here as well.

Most goods sold by the company originate from China. Currently 80% of such goods are shipped via sea and 20% via rail in standard containers. The sea route terminates in Finland from where the goods are transported with trucks to the Moscow DC. The rail route flows through a multi-modal terminal near Moscow. Approximately 30% of goods are shipped by European suppliers. The remaining 20% of goods come from local suppliers.

The company sells multiple product categories. Since they all share the same distribution network and are assumed to have similar demand patterns in regions, the products were aggregated into one category. The average number of items per pallet is 20.

Supply Chain Processes and Inventory Control Policies

The supply chain operates according to the Source Stocked Product and Deliver Stocked Product process as described in the SCOR model. The end customers (consumers) cannot be incorporated into the model directly. Instead, they are aggregated to nearest sorting center. Such aggregated demand points are represented as

customers in the model. The customer's order fulfillment time requirements are translated to the Expected Lead Time for the modeled demand points (sorting centers). Each sorting center is ordering the consolidated daily demand for a given city.

The regional DCs serve the sorting centers' orders on a FIFO basis. Due to strict lead time requirements the orders are shipped from the DC daily. The regional DC must maintain stock required to fulfill the orders of the allocated sorting centers. A simple Min/Max (S, s) policy is used.

The regional DCs are supplied from the central DC, which also is also using the Min/Max policy. The central DC sources the goods from the suppliers according to the breakdown shown in Fig. 1. Supply constraints can be ignored for the purpose of this case study.

Characteristics of the Transport Channels

Delivery from DCs to sorting centers uses trucks of different capacities (20, 5 and 1.5 ton). The shipments must be made daily to keep the order fulfillment time within the limit. The choice of a truck for a particular route is based on the daily demand. The transportation rate is 60 Rubles per km per a 20-ton truck (50 and 40 Rubles for smaller trucks).

Delivery from Central DC to regional DCs and from Local Suppliers to DCs employs 20- and 5-ton trucks with the same rates. Delivery from European distributor is also using 20-ton trucks.

Shipments from China come via rail and sea routes. For these routes, flat rates of 200 and 150 Rubles per pallet are used. The delivery via sea route takes much longer compared to the rail route (70 days vs 20 days on average).

The Choice of the Performance Indicators

The economic KPIs such as profit and total cost are commonly used to compare the alternative supply chain networks. The choice of the main KPI, will it be profit or cost, determines the ability of the model to support commercial decisions in addition to logistics decisions. For example, what market coverage or what service level is profitable to maintain. In our case demand is fixed, so there is no difference between profit- and cost-based network design.

But cost alone is not enough to guide the final decision. In our case the second most important KPI is the service level, which is defined as the proportion of orders that are delivered within the lead time expected by the end customer (Expected Lead Time, or ELT Service Level). In addition, we can use the aggregated order lead times for all orders to explore the problematic areas of the distribution network.

The choice of a right transportation mode for a route requires also to consider the vehicle capacity utilization metric.

Finally, when setting the inventory control parameters, the dynamic inventory levels, or aggregated metrics, such as demand lost due to out-of-stock or late orders, must be considered.
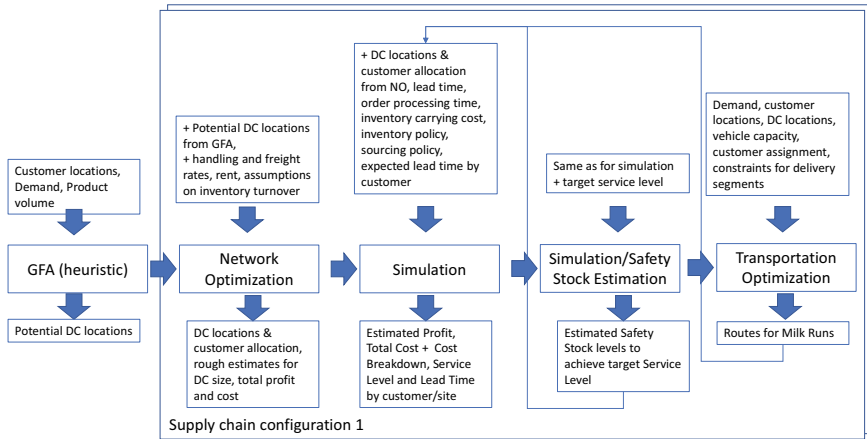
Fig. 2 Phases of the supply chain design

4.2 Model Implementation

To implement the proposed conceptual model, we use the Anylogistix software (ALX). The final supply chain design is obtained via a series of experiments using analytical, heuristic or simulation-based approaches (Fig. 2).

The preliminary synthesis of the supply chain structure involves two phases: the Greenfield Analysis (GFA) and the Network Optimization.

The GFA experiment in Anylogistix employs the Center of Gravity method to find the best locations for DCs servicing the demand based on an extremely limited amount of data: customer locations, demand, and product volume/weight characteristics only. The required number of DCs must also be provided. The outputs of the GFA experiment are the proposed DC locations, the groups of customers serviced from each DC, and a distribution of demand according to specified distance bands. We found that minimum 3 regional DCs in addition to the Central DC are required to deliver orders on time.

The second phase is Network optimization which is implemented in ALX as an uncapacitated facility location-allocation model solved by CPLEX solver. This experiment input uses potential DC locations to choose from and cost data that includes handling and freight rates and inventory holding cost. The basic model in ALX accounts only for a pre-specified safety stock level and for a seasonal inventory that can appear in a multi-period model. The space required to hold cyclic stock is not considered. However, one can define custom constraints, that can estimate this space and properly account for the corresponding storage cost in the objective function. This requires an assumption on the inventory turnover rate for each DC (1 turn per month in our case).

We specified the DC locations proposed by the GFA experiment as candidate locations. In our case the proposed locations were appropriate, so no more alternative

locations were added. We did not use any customer assignments proposed by the GFA since these ignored the difference in storage and handling rates between DCs.

The output of the Network Optimization experiment is a complete supply chain network structure (Fig. 3) with rough estimates for inventory levels and DC capacities, as well as total profit and cost (Table 1).

To obtain a better estimate of the supply chain performance, a detailed simulation of SC processes and scenario analysis is required which is accomplished during the third phase of the study.

The simulation requires a much more detailed data compared to the Network Optimization (Fig. 2). Most notable differences are the use of order size distribution for each customer instead of aggregated demand, lead times and processing times for shipments and orders, inventory policy specifications, sourcing rules, shipping rules, vehicle selection rules. As a result, simulation provides a dynamic picture of the supply chain performance at a detailed level. The results of the supply chain simulation (Fig. 4) suggest that the baseline structure obtained from the Network Optimization experiment cannot provide the required service level for all customers.
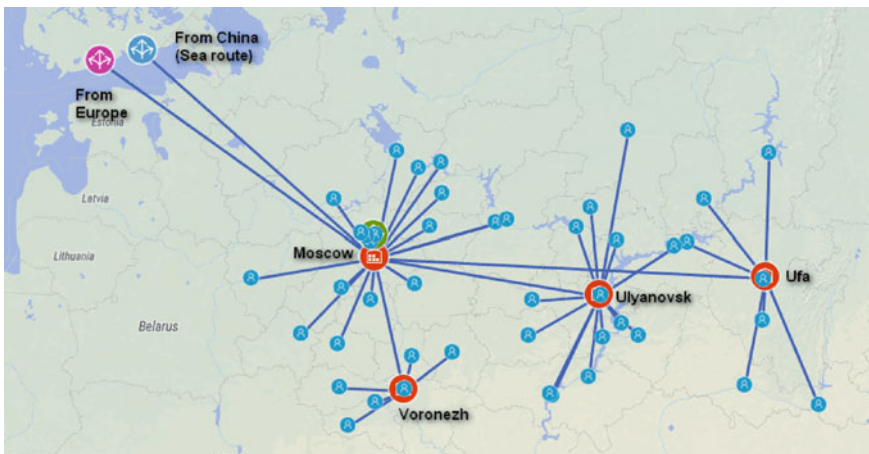

Fig. 3 Supply chain structure from Network Optimization

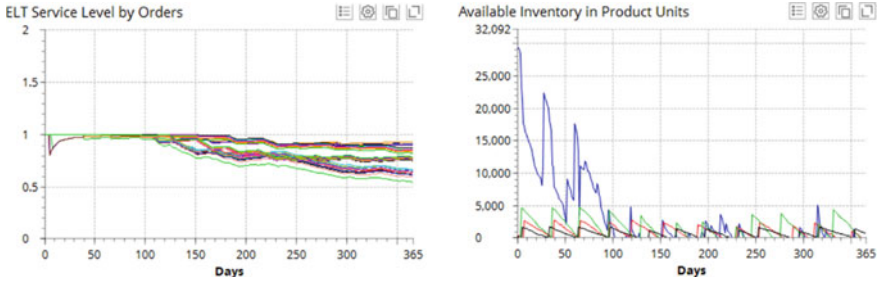| **Table 1** Supply chain cost estimates from Network Optimization		Amount. million Rubles
	Revenue	6 161
	DC rent cost	6.7
	Transportation cost	48
	Supply cost	4 005
	Outbound processing cost	2.9
	Inventory holding cost	3.3
	Profit	2 095

Fig. 4 Service level and available inventory from simulation experiment

This is caused by an insufficient safety stock level at the central DC. Combined with a long lead time to suppliers, this leads to long periods of out-of-stock.

The third phase of the supply chain design involves experiments with the model aimed at improvement of the supply chain performance. In our study we employed simulation-based optimization to estimate the safety stock levels for all DCs (Safety stock estimation experiment in ALX). Next, we considered introduction of milk-run routes for some customers to improve the vehicle capacity utilization. The routes were obtained from the Transportation optimization experiment in ALX. The results are provided in Table 2 and Fig. 5. The Facility Cost estimate from NO is quite close to the results from the simulation. Otherwise, an update for inventory turnover and re-run of the network optimization would be necessary. This could potentially change the customer assignments and require a further re-run of the simulation model as well. The improved supply chain designs updated with safety stock policies and milk runs have worse performance compared to the baseline due to higher inventory carrying cost, however the baseline is certainly unacceptable in terms of customer service.

Table 2 Supply chain KPIs from network optimization and simulation experiments

KPI	Baseline (estimate from NO)	Baseline (estimate from Simulation)	+ Safety stock optimization	+ Milk Runs
Facility cost	6.7	7.0	6.2	6.3
Inventory carrying cost	3.3	11.4	31.4	29.7
Sourcing	4 005	3 517	3 769	3 913
Outbound processing cost	2.9	2.8	2.9	3.0
Transportation cost	48.3	153.7	201.4	165.8
Revenue	6 161	6 015	6 105	6 258
Profit	2 095	2 322	2 094	2 141

Fig. 5 Service and inventory levels after safety stock optimization and introducing milk runs

The fourth phase of supply chain design involves scenario analysis and simulation considering additional risk factors. In the supply chain under study the most prominent risk factor is a long (70 days on average) supplier lead time for the sea route. To estimate the possible impact, we simulated a temporary increase in demand by 100% for a short period (days 59–89) using Risk analysis experiment in ALX. Figure 6 shows the simulated results for the baseline supply chain design (40% of goods are sourced via the sea route) compared to an alternative design where all import from China is switched to the rail route, that is just 20 days on average. Our results show that the alternative design is robust to changes in demand. There is a trade-off however: the transportation cost has increased from 165 Million Rubles to 170 Million Rubles due to higher freight rates for the rail route. The bulk of
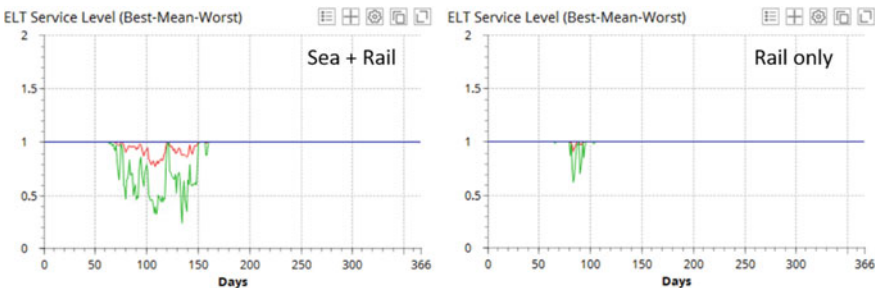

Fig. 6 Supply chain response to a short-term spike in demand

transportation cost is however related to DC-DC and last-mile routes, so the relative change is only 3% despite the 30% difference in freight rates for sea and rail routes.

5   Conclusion

The authors proposed a method of constructing and analysis of conceptual supply chain models, which is based on multilayered representations of supply chain structures and processes that describe strategic planning and development of the supply chain and logistics infrastructure. The following base levels of the supply chain representation were considered: object-based, configuration/network-based, process-based, and logistics coordination levels.

The proposed approach was tested and the set of scenario studies based on iterative simulation and optimization design procedures and simulation modeling was carried out.

The study has shown that efficient system and simulation solutions in supply chain management rest on the following:

- principles of managerial integration and balanced strategic, tactical and operational decisions, and principles of alignment of models of different levels;
- systemic representation and simulation of the logistics and supply chain as a basis for creating a single model framework;
- composite system dynamic and agent-based supply chain models based on integral SCM paradigm, which allows describing network structure, logistic processes, performance of a supply chain, and its measurable characteristics, as well as the behavior of supply chain agents, their cooperation strategies and logistics technologies based on collaboration.

Composite simulation models include descriptions of transforming supply chains development (by using SD and DES constructs) and descriptions representing inter-organizational coordination processes of supply chain agents based on ABMS.

Such modeling constructs help to study the structural and dynamic aspects of SC, solve the tasks of long-term development and efficient transformation of supply chains, evaluate inventory and transportation management policies, achieving overall supply chain efficiency and synergies, align strategic managerial decisions at inter-organizational levels, and search for efficient long-term cooperation strategies between supply chain participants.

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