Creation of a Decision Support System for Improving Multimodal Transportation

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Abstract. The article presents an approach to solving the problem of choosing a vehicle fleet when delivering goods via the multimodal logistics channel "Producer - Central Warehouse - Shop" using simulating. Transportation costs are considered target functionality. Additional restrictions are the minimum allowable level of loading of a transport unit and the minimum required level of assortment of goods in the store. The optimization experiment carried out has shown the effectiveness of this approach. The developed simulation model acts as the core of the decision support system for improving multimodal transportation.

1. Introduction

In recent decades, the governments of many developed and developing countries have been working towards ensuring the priorities of environmental friendliness of transport, which is one of the main environmental pollutants and consumers of non-renewable natural resources. The basis for solving this problem lies in the principles of sustainable development, which now constitute the basis of the transport policy of many countries of the world. The set of principles of sustainable development implemented in the logistics complex is also called “green logistics”. They provide a choice of logistics solutions that reduce the need for transportation \cite{1}.

The road to a climate neutral economy would require joint action in seven strategic areas: energy efficiency; deployment of renewables; clean, safe and connected mobility; competitive industry and circular economy; infrastructure and interconnections; bio-economy and natural carbon sinks; carbon capture and storage to address remaining emissions \cite{2}.

According to Violeta Balk, Commissioner for Transport of the European Commission, all transport modes should contribute to the European mobility system’s decarbonisation. The goal is to achieve net zero emissions by 2050. This requires a systematic approach with low and zero-emission vehicles, a significant increase in the capacity of the railway network and a much more efficient organization of the transport system based on digitalization; incentives for behaviour change; alternative fuels and intelligent infrastructure; and global commitments. All this is due to innovation and investment.

Circular economy principles are becoming increasingly integrated in manufacturing and distribution strategies. Firms that have reached their products market saturation are therefore more probably to implement circular supply chains as a strategy to gain or retain market share. Benefits are mainly derived from resource and energy efficiency gains, which are indirectly the outcome of reverse supply chains improvements.
2. New directions in the field of transport technology
The latest developments in network connections and intelligent database software, together with the development of outsourcing and strategic partnerships among leading multinational companies, have led to the emergence of a new logistics outsourcing level – 5 PL (Fifth Party Logistics) [3].

Canadian Industry Ministry describes 5PL as an organization that “plans, organizes and implements logistics solutions on one of the contracting parties behalf (mainly in the information systems field) through the appropriate technologies use” [4].

The activities of 5PL-providers are supported by modern networked computer technologies. 5PL do not have tangible assets, their goal is strategic supply chain management, but to a large extent they represent a “virtual enterprise” model. A virtual enterprise is understood as a “dynamic open business system based on the formation by legally independent enterprises of a single information space in order to share their technological resources for the implementation of all project (customer order) stages from primary raw materials sources to the product delivery at final consumer” [5].

Characteristic features of virtual enterprises are: (1) decentralization; (2) distribution; (3) availability of mechanisms for flexible formation of new organizational structures; (4) the ability to quickly adapt to changing market demands; (5) self-regulation and self-organization; (6) coordination and interaction based on process and resource management agreed with business partners [6].

As a rule, 5PL activities are connected with large companies for which supply chain management is difficult to organize. Therefore, 5PL seeks to transform the supply chain of its customers into IT-managed communication systems between suppliers and customers.

The European Union is actively financing from its budget the development of new global IT technologies in the logistics field, and in 20-30 years, with the political will, a single logistics information network may appear in the European Union, and, as a result, 5PL providers.

Obviously, the logistics service future lies in the information technologies development, which implies the fundamentally new services types development based on IT solutions (route selection, online tracking, client blocks for integrated customers, etc.). In this case, the main IT functions will change from simply ensuring the company single information space operation to its service level development, which will become the IT sectors main function of 5PL-level logistics-providers.

At the same time, recently, the logistics companies and other market participants (carriers, stevedores, terminals, etc.) depend on electronic trading intermediaries (ETP) - Internet exchanges, stores, etc. has been increasing. Today, the e-commerce sector is beginning to compete successfully with traditional commerce using physical infrastructure (markets, retail chains, etc.). According to the numerous expert communities assessments, in the near future, it is Internet commerce that is focusing on the individual customers needs and will develop rapidly. Many customers now prefer to purchase goods on the Internet and require ordered products’ fast delivery, which will be delivered “to the door”. In the future, the goods delivery will increasingly be carried out from the warehouse directly to customers, bypassing the retail network. In turn, “convenience stores” will begin to transform into issue points to pre-ordered goods [6].

In this regard, new tasks for logistics systems appear: combining the providing the actual stores range functions with the timely delivery mechanism of cargoes directly to the final customers who ordered specific goods through the company’s online store. At the same time, it is necessary to solve problems in terms of frequency and volume of deliveries, finding a balance between the speed and cost of delivery, the time the customer waits for the product and its final price, the level of customer’s satisfaction by interaction with the seller and the company’s profit. Since the interval between deliveries directly depends on the one-time deliveries volume, which, in turn, is limited by the vehicle carrying capacity, the task will be to select the vehicle fleet. Transport is a capital-intensive asset for a logistics company, because the optimization of its carrying capacity and type structure has a tactical significance.

3. Review of existing methods
Many researchers offer various versions of deterministic optimization models that are solved by linear programming [7–10]. Such models’ advantages are the efficiency of their application at the tactical
management level and the ability to solve large-scale tasks. Other researchers propose robust optimization for determining the optimal motor vehicle fleet structure [11, 12]. A significant part of the research studies the metaheuristics or solves vehicle fleet’s selection problems, as well as a complex task (with no detailed route selection) due to the difficulty of accurately solving large cases [13–15]. Comparative analysis of models shows that their complexity and the number of parameters taken into account are increasing with the optimization methods improvement, the computing power growth, as well as technologies and means of accumulating information that can be taken into account in the form of parameters in the model. For example, there is open information about congestion and traffic jams on road sections at different day times, as well as location data obtained from GPS on vehicles and RFID to facilitate goods tracking. The transportation management dynamics is increasing, which leads to the need to develop tools for rapid adjustment and adaptation to various input data sets.

Of course, the transition to a new logistics concept will cause changes in the models that implement it. A significant amount of researches is devoted to the supply chains characteristics’ analysis in the circular economy (CE). Thus, article [16] analyzes the difference between the green supply chain and the traditional supply chain and reveals the green supply chain management content. The authors of the article [17] propose to combine a circular economy, an economic concept with an emphasis on long-term sustainability, with well-established concepts of inter-organizational systems. The proposed CESC (circular economy supply chains) structure combines a circular economy model with a SCOR (Supply Chain Operations Reference model) to create a sustainable SCM model outside of green SCM. The holistic approach is demonstrated by applying CESC to the selected Green SCM concept. CESC can be used to analyze inter-organizational systems for their long-term sustainability and as a basis for the sustainable development, inter-organizational ecosystem. The document [18] explores and analyzes the circular economy concept by conducting a systematic literature review for an in-depth understanding of the CE growing trends, its structure, implementation and barriers.

Flows of products, components and materials in the company’s production, operations and supply chains involve multiple loops, open loops and multiple cascades. Open loops and multiple cascades intersect in different supply chains and sectors, so finding the right volume is a difficult task. The authors of the article [19] represent the basis for the development of CE indicators, which are related to the main objectives, principles and building blocks of the CE.

4. Results and discussion
As can be seen from the previous review, the transition to a circular economy, changing the organizing supply chains concept, requires finding new methods and models to optimize processes when external factors change and promptly make adjustments. This requires an integrated approach both to the rational routes selection and delivery methods, including the vehicle fleet selection, transshipment terminals, containers, tracking methods, etc. Mathematical and simulation modeling is well suited for these purposes. We will consider a simple example to demonstrate the principle of rational solution finding.

4.1. Practical problem formulation
The task is to optimize the logistic processes of regular (twice a week) goods delivery for retail sale to the company stores network in Naberezhnye Chelny, Kazan, Nizhny Novgorod, Krasnoyarsk, Krasnodar, Novosibirsk, Petrozavodsk, St. Petersburg, Chelyabinsk, Arkhangelsk, Omsk, Surgut, Penza, Lipetsk, which are the official dealers of the factory located in Spain. The factory carries out the production and goods delivery by air to the central warehouse in Moscow, at the time moment when goods remain less than N units. Requests for delivery from stores arrive at the central warehouse on the order form. At the same time, goods ordered directly by Internet users, which will be given to the customer in a particular city’s stores, are added to the order for the expected positions. After the order arrival, it is completing and shipped. It takes time $t_{wp}$ to load goods from a factory into airplanes, and time to unload it $t_{pw}$. $t_{wp}$ is spent on loading goods from the warehouse into the truck. In the store, unloading the truck takes $t_{uw}$. After receiving the goods, the store notifies the central warehouse and vehicles from the stores are sent back to the warehouse in Moscow. In some cases, it may be advisable
to transport individual goods between stores. This situation arises if the product ordered by the Internet user is available in a nearby store warehouse, the delivery from which will be faster than from the central warehouse.

It is necessary to optimize the vehicles’ fleet structure for goods delivery from the central warehouse to the branch stores Nizhny Novgorod - Kazan - Chelyabinsk - Omsk - Surgut when they are loaded more than P%.

4.2. Vehicle selection mathematical model for cargo delivery

Based on the classical economic and mathematical model of the transportation problem, we can formulate the following simplest mathematical model for the selection of the vehicles’ fleet for cargo delivery. The goal function will minimize the transporting goods summary cost:

$$Z = \sum_{k \in M} \sum_{j \in U} C_{j}^{k} \cdot X_{j}^{k} \rightarrow \min$$

(1)

where

- $C_{j}^{k}$ - the goods transportation cost by vehicle $k$ to destination $j$;
- $k$ - list vehicle number in the fleet;
- $M$ is a fleet size;
- $U$ is a lot of destinations point.

$X_{j}^{k} \in \{0,1\}$ – this is a boolean variable that determines whether vehicle $k$ will be transported to destination $j$ or not:

$$X_{j}^{k} = \begin{cases} 1, & \text{if the trip is carried out} \\ 0, & \text{if the trip is not carried out} \end{cases}$$

(2)

where

- $\gamma_{\text{carr}}$ – load capacity.

The solution of this problem is a solution of the transportation problem, where we have a matrix, where the rows correspond to the interchangeable rolling stock types of the same body type, but with a different capacity, and the columns will correspond to delivery points (orders). Then the goods delivering cost from row $i$ to column $j$ will correspond to the transporting estimated cost the freight unit on vehicle $i$ to destination $j$. The difference from the classical transport problem is that the lines will not correspond to the capabilities of the manufacturer, but the maximum carrying capacity of the vehicle type $i$, available in the enterprise. If the available capacity is less than the required, then a fictitious carrier (or several such carriers) is introduced from which it is possible to rent vehicles.

It is rather difficult to describe the supply chain management system solely by analytical methods due to the large number of elements, parameters and factors affecting it. Moreover, external factors, input processes parameters and system characteristics themselves have a stochastic nature. Therefore, the system’s behavior predicting results by analytical functions may be completely unreliable. In contrast, simulation models make it possible to take into account the stochastic behavior of such parameters as demand, the vehicles fleet reliability, loading-unloading time, travel time, supply failures. Also, on this model, you can explore a few valid solutions.

4.3. Simulation of the vehicles’ selection when cargo delivery

The AnyLogic software was chosen as the modeling environment due to the fact that this modeling system is based on an object-oriented concept that allows developers to organize and present the structure of complex systems in a simple and natural way [20]. The model is presented as a functional actions set interacting in parallel. In AnyLogic, the model components that represent these interacting functional processes are called “agents”. An agent is a model design unit that can have its own behavior, memory (history), time, contacts, etc. In the agent, you can define variables, events, state diagrams. This approach is the best for modeling a logistics system, since its elements are closely related to each other.
and should be presented as interacting objects. Thus, the proposed model for supply management in the logistics chain includes such agents as “Main” (includes a GIS-linked map with the production site, central warehouse and stores, Fig. 1), “Central warehouse” (A block diagram is presented, including assigning a vehicle to an incoming order, loading, delivery of goods, unloading and returning the vehicle to the central warehouse), “Truck” and “Airplane” (represented by state diagrams), “Shop”, “Factory”, “Order”.

During an optimization experiment the total costs of delivering goods were minimized by varying the number of trucks and their loading. It has shown that there are 12 trucks needed for the smooth operation of the logistics system. In order to ensure a given level of assortment of goods in the store in Naberezhnye Chelny, it is necessary to supply 8,000 units of goods from the central warehouse in Moscow with an interval of 26.6 days.

Figure 1. Agent “Main” view when simulation running.

5. Conclusion
In modern conditions, information technologies are becoming the main tool for improving enterprise management. Solving the problems related to improving the large systems efficiency, which include logistic systems, is impossible without using them. In particular, this tool is relevant in the transition to a circular economy, when the very principle of the supply chains formation is changing. This paper shows the choosing possibility of a cargo delivery rational method through the “Manufacturer – Central Warehouse – Shop” logistics channel using simulation modeling. In the simulation model the delivery optimization case is implemented by selecting the vehicle. The performed optimization experiment
showed efficiency of this approach. In subsequent studies, it is planned to implement multidimensional optimization of direct and inverse logistic chains through a factors combination such as transport type, vehicles type, route of delivery.

6. References

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