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REQUIREMENTS FOR LOGISTICS MULTIMODAL NETWORKS SIMULATION

1. Introduction

Many publications provide information on benefits derived from simulation experiments used for building transport infrastructure. In the late 1970s, it was forecast that transport services provided by Canadian National Railway (CNR) would double in the next decade, and this would result in necessary expenditure of 2.2 billion CAD, including 1.2 billion costs of building the second track. However, at the cost 300,000 CAD a simulation model was created in order to perform some experiments with its use. It turned out that building the second track is not always necessary. There was no need to build a 128-mile section and as a result 350 million CAD were saved [14]. This example shows clearly what benefits can be obtained from using simulation methods in practice. Yet, there is often a problem with selecting a proper simulation due to a wide selection of simulation tools that are contemporarily available. Owing to the extensive literature on the subject (books and journals), the internet sources (websites devoted to simulation tools, access to open-source software), conference materials (e.g. Winter Simulation Conference – www.wintersim.org) and wide market offer of software manufacturers, the choice of the right simulation tool is quite difficult.

The Research Highlights of performed works is:

- Definition of requirements for simulation in multimodal logistics networks. Based on analysis concerning multimodality and intermodality the main characteristic feature of them are defined.

The major objectives of the present paper are:

- to define the requirements that should be met by simulation tools used for practical modeling and designing multimodal logistics networks,
- to make an attempt to select such a tool and show its applications.

The paper structure is as follow. Section 2 presents the basic characteristics and benefits from using multimodality and intermodality. Section 3 describes the multimodal and intermodal applications from the viewpoint of object simulation. As a result, it was possible to formulate requirements for simulation in this area, which is described in Section 4. The final conclusions are stated in section 5.

2. Characteristics of logistics multimodality and intermodality and benefits from their use

Both logistics practice and literature on the subject provide various interpretations of intermodal and multimodal transport. These notions are similar in their scope and meaning, yet there are two significant differences between them. According to the Convention on International Multimodal Transport of Goods [9], multimodal system of transport is defined as internally integrated system of carrying goods along with accompanying services provided with use of at least two modes of transport on the basis of a multimodal transport contract. The multimodal transport contact is concluded by a multimodal transport operator who assumes responsibility for the performance of the contract. In case of intermodal transport, also at least two modes of transport are involved, however its specific feature is the fact that in the whole freight lane only one unit load is used.

The advantages of limiting the use of intermodal transport are as follows [7]:

- the possibility of offering combined freight services so that benefits can be derived from various modes of transport,
- the possibility of reducing the cost of moving goods without deteriorating the quality of freight services,
- the possibility of reducing damages and losses as well as handling and storage of goods by using pallets and containers,
- increasing the elasticity of deliveries by providing customers with better availability of services over time and space.

In simple words, we can assume that an intermodal chain of deliveries is a specific kind of multimodal logistics, which is characterized by a unified load unit, constant in the whole freight line.

In the logistics practice the most commonly used multimodal solutions are sea-air transport and rail-air transport. The multimodality in transport results from the development of containerization: various modes of transport have become more closely related due to fact that the modes of freight, storage and loading of unified load units had to become similar.

The main units of multimodal transport are as follows [10]:

- JTI container,
- UTI swap body,
- ITU semi trailer.

To sum up, logistics multimodality is characterized by the following features:

- using at least two modes of transport,
- only one freight contact,
- one contractor responsible for the delivery of goods,
- an all-in price for the freight delivery service,
- loading and handling of the whole load unit (e.g. container, transporter or means of transport).

Therefore, the main idea of multimodality is the formula: "one partner, one price, one document, unitary responsibility". Apart from ecological issues, the development of multimodal logistics brings economic benefits, such as:

- more effective use of the existing infrastructure,
- reduction in the number of accidents,
- shortening the time of transport and handling operations,

- decrease in the operating costs of vehicles (higher average speed of transport, increased frequency of traffic),
- decreased emission of gases and particulates into the atmosphere.

3. Logistics multimodality and intermodality from the viewpoint of object simulation

The advantages of multimodal and intermodal solutions undoubtedly result from transport integration, which is observed at a few levels [12]:

- technical and technological – related with adjusting various modes of transport, transporters and handling equipment to operating the same unified load unit,
- organizational – where one operator takes responsibility for the whole transport process,
- documentation – related with using only one transport document for the whole freight line,
- price – related with applying identical rules for price quotation for conveying freight with various modes of transport until one rate, that covers the whole delivery process, is suggested to a customer,
- legal – where one contract comprises the whole transport process along with a unified regulation and responsibility system.

From the perspective of logistics network optimization and using simulation as a tool for this optimization, the most important level is the technical and technological one. The optimization of the function of adapting and adjusting modes of transport along with loading and handling infrastructure has become a significant challenge for engineers. They will need to design and carry out experiments with use of various values of model variables until set or expected values of the objective function are obtained.

In order to achieve the objectives of the multimodal transport system it is necessary to use in the transport nodes both unified load units and modes of transport. Standardization is also crucial for the equipment of transport nodes and, most importantly, loading equipment. That is why, the simulation method obviously seems to be a useful tool for designing and analyzing the cost and service features characterizing different modes of transport and elements of logistics infrastructure, especially taking into consideration logistics and loading centers. What is more, simulation indicates the optimum structural solutions for all elements of the system, as it creates a logistics model of a multimodal or intermodal network of a supply chain.

The idea behind the multimodal and intermodal networks optimization is to provide appropriate product to the appropriate place in the appropriate time at the lowest possible cost. The same assumption is made for the simulation modeling and optimization. The most frequently achieved effects of simulation that are related to logistics and transport issues are as follows:

- optimization of the equipment and machinery use,
- minimization of waiting time and queues,
- effective allocation of resources,
- elimination of problems with goods leaving a warehouse,
- minimization of negative effects of breakdowns,
- minimization of negative effects of refusals and loses – reverse logistics,
- analysis of alternative investment ideas,
- optimization of capacity times,
- analysis of cost reduction plans,
- optimization of problems with transport of raw materials,
- optimization of priorities and logic of forwarding goods and services.

When simulation is considered as a method optimizing logistics problems, the basic issue is the possibility of modeling various objects of logistics infrastructure along with the logic of functioning that characterizes each of them. Therefore, the key question is whether the simulation models can reflect the real multimodal or intermodal logistics processes, when the above-mentioned features of these solutions in supply chains are taken into consideration. The question therefore refers to the object representation of logistics infrastructure and proper designing (in case of new investments) or reflecting the state of real links and flow (of load, goods, materials and people).

Logistics infrastructure necessary to implement the functions of multi- and intermodal logistics consists mainly of terminals (such as container and road-rail terminals) and logistics centers.

The infrastructure of a container base consists of the following:

A. Elements of a container base in a seaport:
- wharf,
- loading and storage yard,
- gates for motor vehicles,
- rail loading docks,
- collection and distribution warehouses,
- dispatch and control center,
- container washing stand and workshop.

B. Loading and handling equipment of a seaport container base:
- wharf gantry cranes,
- self-propelled rail-mounted cranes,
- rail-mounted gantry cranes,
- forklift trucks,
- pull shovels,
- container cranes.

C. Loading and handling equipment in land terminals:
- self-propelled rail-mounted gantry cranes,
- road gantry cranes,
- self-propelled cranes,
- universal forklifts for handling swap bodies, semitrailers and containers.

The basic characteristics of logistics centers infrastructure include the following objects and functions:

- centers are mainly used for servicing the goods traffic;
- they are located on the outskirts of urban agglomerations near seaports or large rail junctions;
- they are used to form optimal chains of supply and sales;
- they consist of warehouses, storage areas as well as loading and manipulation equipment;

- they are used for storage and distribution of raw materials and ready products and also for additional services such as packing and labeling, and so on;
- the properly prepared batches of goods are delivered to production plants or to retailers or wholesalers.

In its conclusions the decree of the European Parliament on the guidelines for the trans-European transport network evaluates the existing logistics infrastructure and recommends its modernization and adjustment to multimodal solutions.

“Transport infrastructure between the transport modes is fragmented. As regards making multi-modal connections, many of Europe’s freight terminals, passenger stations, inland ports, maritime ports, airports and urban nodes are not up to the task. Since these nodes lack multi-modal capacity, the potential of multi-modal transport and its ability to remove infrastructure bottlenecks and to bridge missing links is insufficiently exploited. (…) The core network should be identified and implemented as a priority within the framework provided by the comprehensive network by 2030. It should constitute the backbone of the development of a multi-modal transport network and stimulate the development of the entire comprehensive network. It should enable Union action to concentrate on those components of the trans-European transport network with the highest European added value, in particular cross-border sections, missing links, multi-modal connecting points and major bottlenecks.” [14]

The quoted fragment leads to the conclusion that the present state of transport infrastructure, in terms of multi- and intermodal logistics, is generally insufficient. Another reason for using simulation techniques of designing and optimization is the fact that it is necessary to determine the adjusting method as well as the amount and quality of investments, which are crucial from the perspective of the criteria of network spatiality and solutions economy.

“Recently, the role and importance of methods and techniques that make it possible to design and optimize the existing infrastructure have been growing steadily. This situation results mainly from market tendencies and changes in the character of logistics functions as well as strategic and administrative decisions. A good example here is the White Paper which provides a plan for establishing a uniform European transport area. The publication contains the following priorities concerning the development and optimization of multimodality: New transport patterns must emerge, according to which larger volumes of freight and greater numbers of travelers are carried jointly to their destination by the most efficient (combination of) modes. (…) Information technology provides for simpler and more reliable transfers (…).Future development must rely on a number of strands. (…) Optimizing the performance of multimodal logistics chains, including by making greater use of inherently more resource-efficient modes, where other technological innovations may be insufficient (e.g. long distance freight).”[11]

It is impossible, or at least very difficult, to meet those requirements without applying the most modern methods of optimization design and analysis.

4. Requirements for simulation in the area of “logistics multimodal networks”

To simulate means to imitate the real system with use of experiments made on a model representing the system. However, simulation is not only imitating and experimenting. It consists of activities such as defining, designing and building a model, i.e. defining experiments which will be carried out, collecting and analyzing data needed to launch a model, analyzing and interpreting results obtained from experiments. [2].

“In the course of exploring complex systems (detail complexity and dynamic complexity), simulation is the only tool that makes it possible to express and understand the cause-and-result relations that are distant in time and space and linked by numerous feedbacks (dynamic complexity). That is because simulation has the ability to manipulate the space-time.” [4]. The multimodal transport systems are complex. The difficulties in investigations on flows in multimodal networks result from the need to construct structural and functional models with known parameters, obtained from model identification procedures, the method of defining these parameters and the necessity of making measurements and evaluations. “Such models are then the basis for simulation, i.e. the virtual investigations and transformations of reality” [4].

Simulation is an effective alternative for analytical methods. Table 1 shows the comparison of the two alternative solutions.

Researchers work on expanding the use of simulation upon new problem categories [6]. The question is why it is so. As a matter of fact, simulation is based on modeling the reality. In his classic work, J. Forester [8] presented the classification of models used in the management and economical sciences. Forester noticed that most of the models used in the discussed area, were stable-steady state models. The models of stable-steady state category can be successfully used for describing certain management problems, i.e. mainly layout planning and modeling problems and, to a wider extent, problems with changes in an organization [5]. Computer simulation and simulation models can be used to model intricate supply/multimodal networks close to real systems, execute those models, and observe system behavior. Simulation enables supply/multimodal network managers to study and evaluate alternative solutions, and to analyze the effect of process or operation modification [3]. Discrete event simulation can be particularly useful in non-stable environments such as supply/multimodal networks that are characterized by a high degree of interdependences and where logistics processes play an important role, and also there is a need for process optimization [1].

The main advantages of the supply/multimodal network computer simulation are as follows [13]:

- The simulation is relatively clear and flexible.
- It can be used for the analysis of complex real systems such as supply networks.
- With the simulation, it is possible to include real-world influences, for example uncertainty factor in demand or lead time.

Analytical methods	Simulation methods
Their idea is to indirectly describe the modeling object with use of the system of mathematical dependencies. The language of analytical description contains the following groups of semantic criteria: criterion, unknown, data, mathematical operations, constraints. The structure of analytical models does not reflect the structure of the modeled object (structural similarity is understood as one-to-one correspondence between elements and feedbacks in the model and object). Analytical models are those built with use of mathematical programming methods and the analysis of regression and correlation. An analytical model is always a formal structure which can be analyzed and solved with mathematical methods. With use of mathematical programming, the model is made from an objective function and a system of constraints, which must be satisfied by the introduced variables. An objective function describes the characteristics of the system which must be calculated or analyzed. Analytical models are an effective tool for solving optimization tasks or calculating system characteristics. In numerous practical cases, the use of analytical model is difficult, mainly because of their large size – obtaining the optimum solution creates a huge computational problem. Increasing efficiency: Dividing a complex problem into a number of simpler ones – the problem of interrelations between sub-problems – not always easy to solve; Decrease in the accuracy of calculations – time for solving a problem is shortened.	Their idea is to directly describe the modeled object. Their main feature is the similarity between the model and object structures – it means that each element important for the problem which is being solved, is reflected by an element of the model. In the course of creating a simulation model, the functioning rules for each element of the object and the relations between them are described. The idea of working with a simulation model is to carry out a simulation experiment. A process occurring in the course of experiment is similar to that which occurs in the real object. That is why, investigating an object with use of its simulation model means investigating the characteristics of the process observed in the experiment. The idea of formalization of the system presentation is to accept a scheme with discrete events. The process of system functioning in time is treated as a sequence of events occurring in the system according to its functioning rules. The notion of "event" is ascribed to a specific meaning depending on the modeling objective.

Tab. 1. Comparison of characteristic features of analytical and simulation methods

- ‘‘Time compression” is possible. Effects of a certain business policy over a long period of time (months, years), can be obtained in a short time.
- The simulation enables ‘‘what-if” analysis. Managers can test the results of different decisions.
- The simulation does not interrupt real systems. For example, experimenting with different supply/multimodal network configurations can be done without disruptions and significant investment.
- With the simulation, the effects of the individual components, parameters and variables can be studied at the global level.

The main disadvantages of the supply network computer simulation can be summarized as:

- Quality simulation models can be expensive and time consuming to develop and validate.
- This is a ‘‘modify-try” approach. Typically, it does not generate optimal solutions.
- It is necessary to model and define all relevant data in order to produce valid results which can be very difficult in complex supply network scenarios.

5. Conclusions

Based on his own experience as well as relevant literature, the author has defined the following requirements which must be fulfilled by simulations tools in respect to the peculiarity of multimodal networks:

- Task Driven as well as Process Driven Functionality,
- Movement of Parts between Processes Using Resources,
- Message Passing Functionality,
- New technologies,
- Library of objects.

Task Driven as well as Process Driven Functionality – Typically simulation tools use a process driven approach where the flow of the parts between processes cause the demands on resources, i.e. a part moves to a machine and demands a resource to complete the operation. Whilst this methodology is fine for some applications it does not allow for situations where the resources have tasks to complete which are not flow related. In these situations a task driven approach ensures that jobs can be undertaken in a realistic manner, e.g. an operator/transporter (mobile resource) has the job of performing a set of inspections of idle equipment when not otherwise engaged in process work. The task based approach allows for the creation of activities for an operator/transporter (mobile resource) which are totally independent of any processing activities and allows him to become engaged in a set of tasks which may require him to travel, acquire tools and remain "busy" for a period of time. Furthermore, using a task driven approach, resources can incorporate their own 'intelligence' to decide what jobs to do and when.

Movement of Parts between Processes Using Resources – The ability to tie parts and resources together to simulate the movement between processes. The simulation tool should assure possibilities to allow for the pickup, move (with acceleration and deceleration) and drop off of parts either using a direct straight line connection or via a complex network using a variety of resource types. The flexibility of these possibilities should allow the user to easily model scenarios, such as Crane A unloading directly to Forklift truck B or Crane C picking from a specific location in a store and transferring to a AGV system without the need for "dummy" interim buffers or tying up the Crane if the AGV is not available.

Message Passing Functionality – Message passing is a facility which allows direct communication between simulation elements; its use can simplify the development of simulation models. For example, when developing a model, variables are often used as a common method not only for storing data but also as an acceptable method for controlling routing and flow. For instance, if a process accepts parts only when the gate is "open" then the modeler would usually model this using a variable which is set on another process, and where the process of opening the gate is delayed due to a time shift then a further "dummy" operation is put in place to model the delay event. The receiving operation will then continually check the state of this variable before accepting any parts. Additionally, a simulation tool should offer the use of message passing which allows one operation to send a message to another operation (this can be time delayed if the modeler wishes). Furthermore, on receipt of the message, the receiving process can chose to act on, ignore or further delay the message until more appropriate time. This functionality is commonly used as it is a more natural way to model control logic but also makes the model more understandable for someone reviewing the model code and therefore improves the maintainability of the model. An important factor of message passing is that the receiving object can act on the message irrespective of its state, i.e. it can close a connection to another element at the time the message arrived, even if the process is currently idle.

New technologies – simulation tool should use new information technologies: object orientation (C++), internet technologies (Google sketchup, clouding), SQL Database for saving all information generated during simulation experiment, interface to Autocad (DWG/dxf formats), OpenGL graphics. Object orientation od simulation packages (concretely the feature – heritage of properties) is important because it enables reuse of created simulation models (their parts and elements) especially in modeling intermodal transport systems. SQL Database technology for saving all information opens new possibilities to form reports and statistics. Next OpenGL graphics opens new possibilities in visualization 3D and in using virtual reality during simulation animation.

Library of objects – a large library of typical mobile objects that make it possible to implement transport operations as well as easily create new specific objects.
The first, second and third requirements concern the scope of functionality above all. Fourth requirement demands using newest technologies (high-tech) and the last concerns the variety of available objects and simple possibilities to extend this library.
The market offers many simulation systems which enable, partially to fulfill defined requirements. Task driven functionality is contained in new simulation packages like FlexSim and Simio. The feature – movement of parts between processes using resources, is contained in Arena, Plant Simulation and FlexSim. Message passing functionality is fulfilled by Arena and FlexSim. Library of objects is possible to build in Witness, ProModel and ExtendSim.

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Key words:
simulation, modeling, multimodal networks.

Abstract:
The author focuses his research mainly on the area of logistics, especially on problems related with logistics multimodal networks. In the paper the basic characteristics and benefits from using multimodality and intermodality is presented. The author describes the multimodal and intermodal applications from the viewpoint of object simulation. The main Research Highlight of performed works is: definition of requirements for simulation in multimodal logistics networks. One of the main paper's finding is distinction of characteristics features of multimodal networks, which enable the definition of requirements. These requirements are necessary for proper selection of tool for modeling and simulation logistics multimodal networks.

WYMAGANIA DLA SYMULACJI LOGISTYCZNYCH SIECI MULTIMODALNYCH

Słowa kluczowe: symulacja, modelowanie, sieci multimodalne.

Streszczenie:
Główny obszar badań autora obejmuje logistykę, a szczególnie problemy związane z logistycznymi sieciami multimodalnymi. W prezentowanej pracy zostały przedstawione charakterystyki podejścia multimodalnego i intermodalnego oraz korzyści wynikające z ich wykorzystania. Najważniejszym punktem realizowanych prac jest definicja wymagań stawianych budowaniu modeli symulacyjnych i realizacji symulacji w logistycznych sieciach multimodalnych. Jednym z najważniejszych efektów prezentowanej pracy jest wyróżnienie charakterystycznych cech sieci multimodalnych, umożliwiające definicję wymagań, które są niezbędne do poprawnego wyboru narzędzia, które będzie używane do modelowania i symulacji omawianych sieci.

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