NONDETERMINISTIC FACTORS IN SIMULATION MODELS OF LOGISTICS PROCESSES

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Abstract
A characteristic feature of many real logistics systems and processes is an influence on them of non-deterministic factors. It is necessary to take into consideration those factors within analyzing logistics processes using modeling and simulation methods. In the paper the problems of using nondeterministic elements and parameters in example logistics systems were introduced. The literature review was prepared and discussed. The concept of incorporating non-deterministic factors and data into models developed with selected discrete event oriented simulation package was presented.

Keywords: logistics process, simulation model, nondeterministic factors, uncertainty

1. INTRODUCTION
Dynamical market situation, growing competition for customers urge businesses to look for newer and more efficient management methods, which are designed to assist in maintaining or winning competitive edge, and sometimes in an organization’s surviving in the market.
Contemporary enterprises have to operate in a highly complex, dynamic and competitive environment. In order to survive in such circumstances, they have to monitor the developments in the environment and plan their activity flexibly, but also creatively. Pressure from international organizations, increasing global communications and, quite recently, the technological leap all contribute to growth of international competition. Each enterprise has to continuously improve a customer’s satisfaction and look for new ways to reduce its cost of activity.
In recent years, logistics has been playing a key role in the rationalization of operations and processes ongoing at enterprises, as it proposes systemic organizational and technical solutions for processes along the entire chain from suppliers to production, to customers. When the increase in economic performance and maintenance of an enterprise’s market position can no longer be supported with production cost reduction, the efficiency of chains and networks, as well as logistics processes may prove a decisive factor of successful competition.
Efficient management and improvement of logistics processes ongoing at enterprises both require that the processes should be understood first. Modeling and simulation methods, using discrete event mechanisms, play a special role among methods applied to analyses logistics processes. Their usefulness is primarily evident where the processes considered are complex and dynamic.
In the paper the initial assumptions and the analysis of non-deterministic factors considered in the models of logistic processes were presented. In particular, authors of the paper discussed the problem of the use of uncertain and fuzzy data and information.

2. UNCERTAINTY IN MODELS OF LOGISTICS SYSTEMS AND PROCESSES - LITERATURE REVIEW
A characteristic feature of many real logistics systems and processes is an influence on them of nondeterministic factors. Companies have to deal with autonomous customers decisions on which products, where and when to buy. In the same time, they have to place their individual replenishment orders taking into
consideration such factors as costs and delivery times. Those factors can vary randomly so it is important to find a way how to allow for this uncertainty in production and logistics management.

Basic step in sales and production planning and in inventory management is demand (supply) forecasting. We can divide forecasting methods into two main categories: a) classical – based on econometrics equations, and b) non-conventional – complex metaheuristics such as neural networks, genetic algorithms and especially fuzzy logic, which in better way allow for the inclusion of uncertainties and imperfect information [Kahraman et al. 2010]. Padmakumari et al. (1999) proposes long term distribution demand forecasting using neuro fuzzy computations. In other works, we can find fuzzy logic-based forecasting model [Frantti and Mahonen 2001] and fuzzy decision support system for demand forecasting with a learning mechanism [Petrovic et al. 2006].

An inventory control problem is one of the very common problems in industrial engineering. As it was mentioned earlier, enterprises and production plants have to deal with demand fluctuations, so it is clear that preparing credible demand forecasts can have an important influence on order policy. An inventory control model based on fuzzy logic was presented by Samanta and Al-Araimi (2001). The problem applied to inventory level control in a medium-scale production system. The basic assumption was to maintain desired inventory level in spite of variations in demand. The simulation model was prepared using fuzzy logic controller (FLC) coupled with a conventional proportional-integral-derivative (PID) controller. In other work [Gen et al. 1997], a model in which input data are described by triangular fuzzy numbers was presented. Since the demand, lead time and safety stock level may not be known with certainty, they should be represented by fuzzy numbers. If those factors are considered as fuzzy numbers, they lead to obtaining fuzzy reorder level, what was presented in the paper.

Inventory management is directly connected with material requirements planning (MRP) systems. Classical procedures applied in MRP environments assume a deterministic structure of the system [Orlicky 1975], although in the real world such difficulties as uncertainty in market demand, resources with limited available capacities, uncertainties in capacity data or uncertain costs arise [Mula et al. 2006]. The first publication of MRP systems under uncertainty was prepared by Whybark and Williams (1976). Their paper contains a description of two basic forms of uncertainty that can affect an article in an MRP environment – demand fluctuations and supply instability. Dolgui end Prodhon (2007) study specifically supply planning under uncertainties in MRP environments. Their survey focused on the parameterization of MRP systems under demand and lead time (which has been ignored in the past, in spite of their significant importance) uncertainties. Mula et al. (2007) propose a fuzzy mathematical programming model for production under uncertainty in an industrial environment. The described model with fuzzy constrains is implemented and tested on real data from an automobile seat assembler, what once more proves that fuzzy set theory approach enables to model uncertainty and randomness effectively.

As the opposite of the classical MRP philosophy, just-in-time (JIT) approach is generally accepted. An algorithm for JIT production planning with a fuzzy due date was developed by Wang et al. (1999). In another work [Mansouri 2005] a multi-objective genetic approach to a just-in-time sequencing problem is presented. Fuzziness in JIT and Lean Production Systems was also introduced later by Yavuz (2010). The author presents a scheduling model for one-of-a-kind production and a discrete scheduling model for repetitive products. In spite of numerous publications about lean manufacturing, the concept still seems to be underdeveloped. One of the reasons of this situation is a lack of generally accepted methods for leanness measuring since lean is considered to be a matter of degree [Bayou and de Korvin 2008].

As it was emphasized lots of times in this work, many parameters of logistic processes can only be estimated without great precision. Supplies’, demands’ and costs’ values can change rapidly and significantly what can have a great influence on a supply/selling/inventory policy. The problem seems to be much more difficult when we do not consider logistic processes separately but try to optimize a whole logistic network. An ambiguous information might cause a phenomenon called “Bullwhip effect” [Lee et al. 1997]. One of the first attempts of using fuzzy logic for reduction of bullwhip effect in supply chain systems were made by Zarandi
et al. (2008). In the model of multi-stage supply chain all demands, lead times and order quantities are considered to be fuzzy numbers. Thanks to implementation of a back propagation neural network and genetic algorithm module, minimization of the total cost and reduction of bullwhip effect were possible. The results of the research were superior than the previous analytical works in this field.

Finally, in the end of this section it is necessary to draw attention directly to fuzzy simulation and its applications in production and logistic systems. Describing the real world uncertainty in a probabilistic sense may not be precise enough, so the development of fuzzy simulation is indispensable. Sevastjanov and Rog (2003) notice, that when we do not have precise information about all necessary input parameters, the simplest and natural way to solve the problem is to replace them by fuzzy intervals. Another research [Dymowa and Sevastjanov 2010] deals with a problems in formulation of basic mathematical operations on fuzzy and interval objects. The authors consider interval and fuzzy objects comparison, what is very significant especially for fuzzy optimization.

Modeling and simulation of real system must be preceded by a system structure analysis. Knowing the system form allows to come to some conclusions of its behavior. The first book, where the basic systems modeling formalisms were presented was prepared by Zeigler (1976). The author distinguished three basic systems formalisms: a) DESS (Differential Equation System Specifications) – the traditional systems, where states and time are considered as continuous elements, b) DTSS (Discrete Time System Specifications) – systems that operate on a discrete time bases, c) DEV (Discrete Event System Specifications) – systems that operate on a continuous time bases, whereas states are represented as a discrete numbers.

In another work [Zeigler et al. 2000], the authors indicate that conventional approach to uncertainty is based on including pseudo-random-number generators into models. They notice, that it might be necessary to discuss extensions of DEV formalism that support dynamic system structure. Four DEV-based extended formalisms are presented: Dynamic Structure DEV, Symbolic DEV, Real Time DEV and Fuzzy DEV. Dynamic Structure DEV (DSDEV) enable a model to transform its structure during a simulation run. Related work, where changing model components and their connections were discussed was prepared by Barros and Zeigler (1997). The DSDEV was used to model an adaptive queuing system. In Symbolic DEV symbolic time base is involved – time base was extended from the real numbers to the field of linear polynomials over the reals [Zeigler and Chi 1992]. In Real Time DEV a model is executed in real time. An example implementation of real-time simulation was presented by Zeigler and Kim (1993). Finally, fuzzy extension of DEV allows to incorporate uncertainty into model in easier way. Time advance values such as small, medium and large are incorporated into model, what enables an less sophisticated approach to discrete event modeling. Related work, where fuzzy discrete-event simulation for modeling uncertain activity duration was introduced was prepared by Zhang et al. (2004).

3. SIMULATION MODELS OF COMPLEX LOGISTICS PROCESSES

Simulation modeling techniques are one of the basic tools used for identification, analysis and optimization of logistic processes and systems. A number of modern logistics process simulation tools use DES approach. This kind of simulation is a very useful and often the only tool supporting the analysis of complex logistics systems, including their dynamics.

However, this tool requires precise data of the processes under study, which not always are available in the form in which they could be directly used in the process of building a model. The actual conditions observed in the industrial practice often go beyond the limits defined by boundary conditions or the models used. This principally applies to all available information on processes, such information being, as a rule, incomplete and uncertain, as well as to the nature of the processes, which are usually stochastic and reveal strong nonlinear relations. For this reason, there has been a growing interest in hybrid methods using the traditional approach supported by computational intelligence models, exploiting modern methods of information analysis and processing.
Among the techniques of computational intelligence, broadly used in modeling events whose nature is non-linear, multi-dimensional with elements of uncertainty and incompleteness of information, there are artificial neural networks and fuzzy sets and fuzzy logic [Babuska et al. 1998; Kudlich 2000; Marquardt and Schulze 2000; Panayiotou et al. 2000; Zeigler et al. 2000; Ostermann 2001; Rabelo et al. 2003; Rog and Sevastjanov 2003; Nucci and Grieco 2006].

4. NON-DETERMINISTIC DATA AND SIMULATION PACKAGES

There are many simulation packages available in the market. Most of these packages offer wide range of tools supporting modeling of randomness occurring in real logistics processes. However, it is still not possible to take into account the uncertain, fuzzy and incomplete data or information, which refers, inter alia, to the operation, transport or setup times.

An example of such a discrete event tool can be DOSIMIS-3 package. This package is a module-oriented simulation tool, adapted to, inter alia, designing and creating models of logistics systems. Owing to its module-oriented approach to a modeling problem, DOSIMIS-3 quickly delivers reliable results and can be an excellent tool supporting decision making, even in minor projects. The DOSIMIS-3 package is an interactive graphic simulator. The operation of the simulator is modeled in event controlled discrete processes and is able to simulate various systems, including complex logistics systems. Computations performed by the simulator use inputs from procedures handling events notified in the system and procedures monitoring the passage of time. DOSIMIS-3 has several dozen of predefined components which cover several modelling levels: material flow level, organisational level and control level. In order to understand and analyse logistics systems and processes, one should be familiarised with essential simulation components. The significant components of discrete-event simulation models are:

- **modules (entities):**
  - they represent behaviour of static elements or resources of a system,
  - module has a specified process logic,
  - modules may represent, e.g., buffers, workstations, loading or unloading stations, assembly and disassembly places and many others.
- **(movable) objects or transfer entities:**
  - they are used to describe movable parts, products, vehicles, people or a piece of information.
- **junctions:**
  - they transmit information from one module to the adjacent one.

For the modelling of logistics systems and processes, DOSIMIS-3 uses components which can perform the following functionalities:

- at the material flow level – accumulate paths, distribution cars, workstations, buffer capacities, assembly and disassembly stations,
- at the control level – decision tables, bottleneck controls, signals, monitoring components,
- at the organisational level – disturbances, maintenances, set-ups, breaks and labour organisation.

Simulation package provides several distribution functions to model processes with probabilistic nature: uniformly distributed, normally distributed, exponentially distributed or empirical distribution functions may be considered in simulation model. However, there is impossible to model the processes for which we have to deal with uncertain or fuzzy data or structure. The solution to this disadvantage may be to use the programming interface and some external tools dedicated for prototyping models.

The DOSIMIS-3 package offers the interface (API, Application Programming Interface) supporting communication with external DLL libraries (Dynamic Linked Libraries), which may be developed by the modeler. A general concept of data exchange between the discrete event simulator (DOSIMIS-3) and
models developed is shown in Figure 1. The DLL libraries developed in the case considered exchange information with the discrete event simulation software, collecting input data from it and returning responses generated by the partial model.

Fig. 1 The interface between the discrete event simulator (DOSIMIS-3) and an external model

The modeller has the ability to implement any model inside the runtime DLL library and integrate it with data structures of the simulation package. It is relatively easy to integrate discrete model with fuzzy model developed in the external environment, such as MATLAB Fuzzy Toolbox, which provides tools for prototyping fuzzy systems and models. There is a possibility of the data exchange between the simulator and external functions developed in.

5. SUMMARY

The use of tools described leads to a greater accuracy and completeness in problem formulation and model development. The comprehensive approach to the analysis of key logistics processes enables a broad range of phenomena occurring in logistics systems to be taken into consideration in the course of such analysis: from those both of deterministic and stochastic nature, to phenomena the knowledge of and data on are incomplete and uncertain.

LITERATURE


