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SIMULATION INVESTIGATIONAL METHOD FOR DETERMINING THE PERFORMANCE CHARACTERISTICS OF LOGISTICS SYSTEMS

Abstract. *Complexity of the logistics processes implemented is increasing as a result of striving to satisfy individual custom-er needs regarding the companies. Defining the operational characteristics of these processes is a growing challenge for logistics experts. Incorrectly defined operating characteristics can result in significant losses (e.g. unjustified investment, unsatisfied customer requirements, etc.). A simulation investigational method for the determination of operating characteristics has been developed on the basis of experience gained in industrial research con-ducted in the last years. I believe that the investigational process that will be presented will be useful to many professionals in implementing a simulation examinational process.*
Keywords: *simulation investigational method; logistics systems; logistic indicators; operational characteristics.*

1. INTRODUCTION

Nowadays, there is a clear trend towards diversification of customer needs, with the result that only companies that are able to produce customized products that are often required by customers at a low cost and/or high-quality level can remain competitive. If we want to translate this into the language of logistics means that the number of product types to be handled and the complexity of logistics systems are constantly increasing [1-3]. Concerning the complex material flow systems, simultaneous production and logistics management of products of several product lines is carried out. As the complexity increases, the application of new industry 4.0 technologies [4-5] becomes more and more important, including simulation examination of the investigated logistics systems.

I have been participated in several industrial research projects in recent years [6] at the Institute of Logistics, University of Miskolc, the most important of which are the following:

- Innovative design of simulation methods for installing the objects of technological processes related to small-scale production of parts of the tool factory at the Audi Hungaria Motor Ltd (Participants: Dr. Péter Tamás, Dr. Béla Illés, Sándor Tollár).
- Development of a parameterizable simulation model of maintenance activities for MÁV-TISZAVAS Miskolci Járműjavító Ltd. (Participants: Dr. Béla Illés, Dr. Péter Tamás).

One of the objectives of these research projects was to determine the operational characteristics of an limited logistics system, which allowed minimizing the risks inherent in the design/development decisions of the company under the examination. In the following, the steps of the simulation test method developed to determine the operational characteristics based on practical experience are presented.

2. SIMULATION INVESTIGATIONAL METHOD FOR DETERMINATION OF THE OPERATIONAL CHARACTERISTICS

The steps of the simulation investigational method for determining the operating characteristics are illustrated in Figure 1.

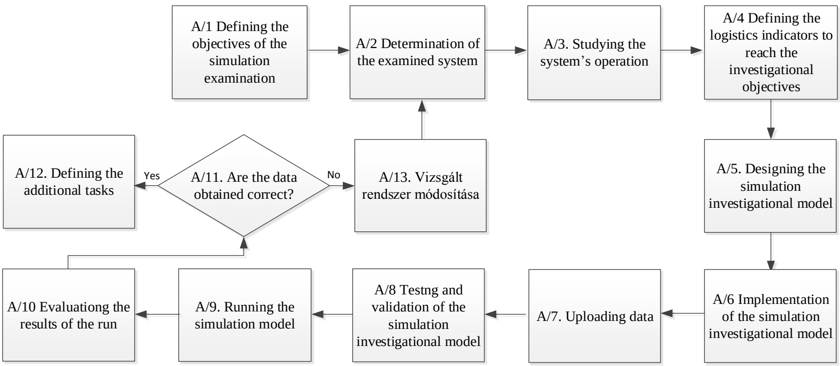

Figure 1 – Simulation investigational method for determining the operational characteristics [edited by the author]

A/1 Defining the objectives of the simulation examination: The basic objectives of defining operational characteristics in a current or planned system are to avoid design failures and to identify directions for improvement regarding the:

- developing storage capacities,
- operation of material handling machines,
- operation of technological equipment,
- human resource management.

During the exploration of design failures, we examine which parameter of the system under investigation does not meet the requirements (eg storage capacity, handling capacity, etc.). The development areas are basically determined through the evaluation of the examined system, which requires the determination of the selected operational characteristics (e.g., warehouse expansion, equipment acquisition, route planning efficiency increase, etc.).

A/2 Determination of the examined system: The logistics system under consideration (e. g. a given production line, complete production system, storage system, etc.) should be clearly delimited on the basis of the investigational objectives.

A/3 Studying the system's operation: After defining the system under investigation, the person who makes the simulation model have to understand the material and information flow of the examined system.

A/4. Defining the logistics indicators to reach the ivestigational objectives: In this step, the operational characteristics (e. g. maximum inventory level, utilization of the equipment, etc.) that define the investigational objectives (see Step A/1) have to be defined.

Key logistics indicator [6]:

1. Decision support for determination of the storage capacity to be created: Precise determination of the storage capacity needed for a system to be realized can cause significant difficulty because of the complexity of the processes. In such cases the necessary controls and alterations can be executed by the elaborated simulation method.

- Maximum stock level: This is how to determine the maximum storage capacity need(s) regarding one or more storage systems. The maximum stock level of the storage system s can be calculated as follows

$$Q_s^{Max} = \max_{t \in \Theta^S} \left\{ q_{So} + q_{sbz} - q_{skt} \right\} \quad (1)$$

where Θ^s is the date when stock movements were executed, q_{So} is the starting stock level, q_{sbt} contains the stocked in amounts, q_{skt} the stocked out product quantities regarding date *t*.

2. Decision support for determination of the material handling equipment's efficient utilization: The working strategy and efficiency of the material handling equipment can be difficult to evaluate before the realization of the examined system regarding the intermittent production systems, but the necessary controls and alterations can be executed by using elaborated simulation investigational method [7].

Most important indicators:

- Rate of the effective route length: This expresses what percentage of the material handling equipment's total traveled route length was executed without unladen vehicle. The rate of the effective route length in case of the material handling equipment m can be calculated as follows:

$$R_m^U = \sum\nolimits_{d \in \Theta_m^U} \left(l_d \right) / \sum\nolimits_{d \in \Theta_m} \left(l_d \right) \tag{2}$$

where Θ_m is a set containing the identification of the traveled route sections for the material handling equipment *m*, Θ_m^U includes the identification of the effective route sections, and l_d indicates the length of the route section *d* according to equation (2).

- Capacity utilization of the material handling equipment: This introduces what percentages of the material handling equipment's transportation capacity is utilized during the examinational period. The transportation capacity of the material handling equipment m can be defined as follows:

$$C_m^U = \sum\nolimits_{d \in \Theta_m^U} \left(l_d \cdot c_{m,d}^U \right) / \sum\nolimits_{d \in \Theta_m} \left(l_d \cdot c_{m,d}^{max} \right) \tag{3}$$

where $c_{m,d}^U$ indicates the delivered products' quantity regarding route section *d* of material handling equipment m and $c_{m,d}^{max}$ contains the transportable maximum quantity regarding route section *d*.

- Stock in, stock out and commission efficiency of the material handling equipment: This introduces the material handling equipment's average stock in, stock out and commission quantities per unit time. The average stock in, stock out and commission efficiency of material handling equipment m can be calculated as follows:

$$P_m^i = N_m^i / T_m^i \tag{4}$$

where $i \in \{SI, SO, CA\}$ can contain 3 kinds of values depend on the type of the examined operation (Stock In, Stock Out, Commission Activity). N_m^i indicates the number of operations in case of operation type *i* of the material handling equipment *m*, while T_m^i shows the length of the examinational period regarding operation type *i* of material handling equipment *m*.

3. Decision support for determining the actuation of the technological machines: The working properties and efficiency of technological machines to be applied can be difficult to evaluate for intermittent production systems; however, the necessary controls and alterations can be realized using the elaborated simulation investigational method.

Most important indicators:

- The rate of value added activities: This introduces that what percentage of the assigned technological machine's examinational period is spent on value added activities.
- The rate of waiting activities: This indicator shows what percentage of the assigned technological machine's examination period is spent on waiting activities.
- The rate of changeover activities: This indicator introduces what percentage of the assigned technological machine's examination period is spent on changeover activities.
- The rate of blocking activities: This indicator shows what percentage of the assigned technological machine's examination period is spent on blocking activities (the machine is not able to move the parts to the following station because the station is occupied).
- Amount of completed products: This shows how many products were completed during the investigational period by the assigned technological machine.

The rate of the value added, waiting, changeover and blocking activities can be calculated as follows:

$$R_e^j = \sum\nolimits_{o \in \Theta_e^j} \left(t_o\right) / T_e \tag{5}$$

where $j \in \{VA, WT, CO, B\}$ indicates the type of examined operation and Θ_e^j contains the operations of technological machine e regarding operation type *j*. In addition, T_e is the length of the examinational period in case of technological machine *e*.

4. Decision support for determining the application of the human resources

Most important indicators:

- The rate of value added activities: This introduces what percentage of the assigned worker's xamination period is spent on value added activities.
- The rate of waiting activities: This indicator shows that what percentage of the assigned operator's examination period is spent on waiting activities.
- The rate of changeover activities: This indicator introduces the percentage of the assigned operator's examination period spent on changeover activities.
- The rate of blocking activities: This indicator shows the percentage of the assigned operator's examination period spent idle due to blocking activities (the person is not able to move the parts to the following station because of the station's occupation).
- Amount of completed products: This shows the number of products were completed during the investigational period by the assigned operator.

The rate of the value added, waiting, changeover and blocking activities can be calculated as follows:

$$R_h^k = \sum_{o \in \Theta_h^k} (t_0) / T_h \qquad (6)$$

where $k \in \{VA, WT, CO, B\}$ indicates the type of examined operation and Θ_h^k contains the operations of the human resource h regarding the operation type k. In addition, T_h is the length of the examinational period in case of the human resource *h*.

In most cases, the indicators described above will provide sufficient support to make the necessary decisions, but in specific cases other indicators may need to be defined. Most simulation frameworks used in practice are capable of graphically displaying the values of predefined indicators (plotter, frequency function, distribution function, etc.), providing additional information for more efficient decision support.

A/5 Designing the simulation investigational model: After defining the investigated logistic system and defining the logistic indicators to be created, the material flow processes of the simulation investigational model, as well as its data structures and operating algorithms are defined. In order to increase the clarity of the simulation model, the way in which the model is structured (eg, the selected subsystem is placed on a separate modeling surface) is also determined at this step. In practice, there are several simulation frameworks (e. g. Arena, Simul8, Plant Simulation, etc.) which differ only slightly in their operational concept.

A/6. Implementation of the simulation investigational model: Based on the prepared plans, the simulation investigational model shall be prepared by creating a custom application or applying a simulation framework. The use of simulation frameworks enables the use of predefined objects, evaluation and optimization functions, which significantly increases the efficiency of realizing the required examinations.

A/7. Uploading A/9 data: You can upload specific data structures by manually uploading data and/or creating the data connections. Data can be uploaded using data generated by on-site measurements and/or provided by information systems.

A/8 Testing and validation of the simulation investigaional model: The operation of the prepared simulation model, which is filled with the defined data, have to be tested and validated. The implementation of this phase should be carried out in close cooperation between the simulation study designers and the contractor company. When testing the simulation model, the following types of failures that can be corrected can occur:

- incorrect data recording,
- inadequate data communication,
- inappropriate material flow route,
- bug.

After the necessary tests and corrections have been made, the validation of the investigational model can be realized by checking the processes of the simulation investigational model and/or comparing the data obtained from the simulation investigational model and the real system.

A/9 Running the simulation model: After validation, the simulation test model have tot be run and the logistic indicators defined.

A/10 Evaluating the results of the run: Based on the logistics indicators defined, the results of the examination have to be evaluated, which results in:

- detection of design failures,
- identification of the improvement fields ,

can be realized.

A/11. Verifying the acceptance of results obtained [7,8]: If the results obtained are acceptable, then additional tasks are defined that may be directed to conducting further investigations or implementing the approved plan (Step A/12). If the results obtained do not make a decision in relation to the objective of the examination, the defined system may need to be modified and a simulation examination repeated (Step A/13).

The study of the adaptation possibilities of the developed investigational method in the field of machining [9] is the subject of further research.

3. SUMMARY

The paper describes the processes that significantly contribute to the increase of the complexity of logistics systems. It can be stated that as the complexity increases, the determination of the operational characteristics of the logistics systems investigated - with sufficient reliability - is an increasing challenge for the logistics professionals. This may require the use of simulation investigational methods in many cases. Using the experience gained in solving industrial research tasks, I described in detail the characteristic process of defining operational characteristics, which can serve as a help for the logistics professionals performing simulation testing. Using the experience gained in solving industrial research tasks, I described in detail the simulation investigational process of the determination of operational characteristics, which can be helpful for the logistics professionals performing the simulation examination.

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ВИКОРИСТАННЯ МЕТОДУ ІМІТАЦІЙНОГО МОДЕЛЮВАННЯ ДЛЯ ВИЗНАЧЕННЯ РОБОЧИХ ХАРАКТЕРИСТИК ЛОГІСТИЧНИХ СИСТЕМ

Анотація. *Складність впроваджуваних логістичних процесів зростає в результаті прагнення компаній задовольнити індивідуальні потреби замовників. Визначення експлуатаційних характеристик цих процесів є зростаючою проблемою для фахівців з логістики. Неправильно визначені експлуатаційні характеристики можуть привести до значних втрат (наприклад, необґрунтовані інвестиції, незадоволені вимоги клієнтів і т.п.). Метод імітаційного дослідження для визначення експлуатаційних характеристик був розроблений на основі досвіду, накопиченого в останні роки в промислових дослідженнях. В даний час спостерігається чітка тенденція щодо диверсифікації потреб клієнтів, в результаті чого конкурентоспроможними можуть залишатися тільки компанії, здатні виробляти індивідуальні продукти, які часто потрібні споживачам за низькими цінами і на високому рівні якості. Якщо перевести це на мову логістики, це означає, що кількість оброблюваних типів продуктів і складність систем логістики постійно зростають. Основні цілі визначення експлуатаційних характеристик в поточній або запланованій системі полягають у тому, щоб уникнути збоїв проектування і визначити напрямки для поліпшення розвитку складських потужностей, експлуатації вантажно-розвантажувальних машин, експлуатації технологічного обладнання, управління персоналом. У більшості випадків логістичні індикатори забезпечать достатню підтримку для прийняття необхідних рішень, але в окремих випадках може знадобитися визначення інших індикаторів. Використовуючи досвід, отриманий при вирішенні задач промислових досліджень, в статті представлений характерний процес визначення експлуатаційних характеристик, а також, детально описано процес дослідження моделювання для визначення експлуатаційних характеристик, який може бути корисний для фахівців з логістики, що виконують моделювання та його перевірку.*

Ключові слова: *імітаційна модель; система логістики; логістичні індикатори; експлуатаційні характеристики.*