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Evaluation of the efficiency of the delivery process in the technical object of transport infrastructure with the application of a simulation model

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Highlights

- Queue theory can be used to model and analyze elements of Logistics systems,
- Cargo delivery handling in the object is important process influencing its reliability,
- Computer support allows to run of simulations and analysis of the process reliability,
- The process is defining the aim of model, the selection of parameters and design variants,
- A properly structured model allows for the verification of the system and its operation.

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Abstract

The article presents the issue of assessing the effectiveness of the implementation of a logistics process with the use of a simulation model and queue theory. The process that has been analyzed is the process of goods' delivery at the technical object. Firstly, a literature review was carried out. Next, the authors described the process using the QT (Queueing Theory). This was possible due to the fact that QT is widely used in the analysis of systems as well as the assessment of their effectiveness, maintenance, and reliability. The description, characteristics and graphic presentation of the system in which the process is carried out have been included in the study too. Then the process was implemented in the computer simulation environment. Simulations were carried out and four variants of the system operation were analyzed. The comparison of the operating parameters of the system for each variant allowed for a detailed analysis of its operation and the influence of selected factors on the implementation of the process as well as it effectiveness or reliability.

Keywords
process efficiency, mass service system, technical object reliability,multi-element systems simulation, FlexSim simulation

1. Introduction

One of the main tasks of engineering logistics is to ensure the availability of goods in a place where there is a demand for them at a specific time and under given conditions. Moving cargo would not be possible without properly organized transport system and transport processes carried out in them. Among the key elements of the infrastructure involved in the implementation of transport processes, a technical object for delivering and collecting of goods can be distinguished, which is responsible for several important functions and operations 28. A properly functioning technical object of transport infrastructure (for example warehouse) allows to regulate the flow of goods between consecutive points of the logistics infrastructure. In addition to the operation of the system itself, its efficiency and reliability are also important. The importance of this issue is evidenced by numerous methods of assessing logistics systems and a set of indicators developed for their validation 12. An important stage in the implementation of transport processes in the movement of loads is the process of loads delivery by means of external transport (e.g. from the manufacturer) to the internal transport system of the technical object for delivering and collecting of goods 29. The cargo delivery handling process takes place on the border of the external transport environment and the internal transport system of the technical object. Most often, loads are reloaded from delivery vehicles to buffers at the entrance to the technical object for delivering and collecting of goods. This process is accompanied by the control of the delivered loads (quantitative and qualitative) 3. The efficiency and reliability of the process is of key importance for cargo handling. The implementation of this process can be described using the Queue Theory (QT). QT is widely used in a variety of fields. As the name suggest the Queue Theory deals with the problem of queues and their

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operation/ functioning. It focuses on building mathematical models that are based on the theory of stochastic processes. They can be used in the management of operating systems, i.e. Mass Service Systems (MSS) 1. It can be used, as further in the study, in the analysis of selected processes and the assessment of the effectiveness of their implementation. Nowadays, the dynamics of logistic processes implies the need to optimize at almost every stage of transport system. An attempt to optimize such complex systems without the use of modern support tools would be excessively laborious or even impossible 1022. Therefore, the use of computer techniques has become a standard. The FlexSim program used in the publication is a comprehensive simulation environment. It was used to build a model of cargo delivery to the technical object, to obtain its characteristics and to evaluate it. The assessment was possible thanks to the development of four variants of the system operation and the comparison of their key parameters, such as the length of the observed queues, waiting times or the workload on the elements.

Bearing in mind the above, the authors of the article conducted a literature review (chapter 2).It has been divided into three main sections. Each section consider different study area. Further in the chapter 3 studied process has been analyzed with the usage of the Queue Theory. The assumptions used in the construction of the model are described. Description and graphic presentation were made. The QT model became the starting point for model building in the FlexSim computer simulation environment (chapter **Błąd! Nie można odnaleźć źródła odwołania.**). Not only the modeling result itself was presented, but also the performance characteristics of the elements of the mapped system were discussed in detail. In Chapter 5 computer simulation results for four variants of the system are presented. The article ends with conclusions and a summary (chapter **Błąd! Nie można odnaleźć źródła odwołania.**).

2. Literature review

2.1. Efficiency and reliability of the implementation of the processes in the system

Before starting the analysis of the process of receiving loads in the technical object and its modeling, a review of the literature relating to the analyzed issues was performed. There are three main thematic areas of the publication: Mass Service Systems and Queue Theory, efficiency of processes in transport systems and computer simulation with the use of specialized simulation tools (in particular FlexSim).

Many of the available publications relate to processes taking place in transport systems. The results emphasize their importance for the functioning of the market. Modeling is a popular tool for studying processes. Referring to work 3415 this method can be used at various stages of the transport system (processes stages) or for assessment of e.g. system reliability. Often the basis of research is the construction of an appropriate mathematical model, which can be seen in many publications (2534). Modeling can also be used to assess the risk for selected processes in transport 31 or the prevention of undesirable events during their implementation 30. In such analyzes, apart from classical mathematical models, appropriate computer techniques, which are referred to later in chapter 0. Considerations based on a mathematical model are related to the popular problem of allocating resources to tasks. There is a similar issue here as in the Queue Theory, i.e. how to organize the way of handling orders to reduce downtime and maximize the use of available service stations?

The processes in the technical object are referred in elaboration 35. The publication itself focuses its attention on creating a management strategy of processes taking place in a technical facility. It also addresses the material delivery handling process. The process is also partially characterized and strategies for its management are presented. An important topic related to the design and simulation of processes taking place in a technical object has been widely discussed in 6. The authors referred to the importance of the database and its selected elements when simulating processes taking place in a technical facility (including cargo delivery). These processes can be analyzed in various ways and depending on the type of research, other system parameters may turn out to be of key importance. In 18 authors focused their attention on an important parameter, which is the energy consumption of processes in the technical object for delivering and collecting of goods. This resulted in comparing the different technologies used in the technical object for delivering and collecting of goods to determine the cost for each labor. This directs attention to an important issue, which is the selection of parameters that will be analyzed 521. Often a multi-criteria analysis may be required 23. In the system operation analysis, various indicators can be used, on the basis of which design variants can be assessed and the best one can be selected 16. In connection with the pro-consumer orientation of the market, one of the important factors may be, among others efficient and accurate processing of orders in accordance with the client's requirements 12. Selected publications refer directly to the algorithms of procedure for modeling and then the evaluation of the constructed model. The authors dealt with this problem 16.

2.2. Using the Queue Theory for evaluation of the processes

The foundations of Queue Theory have been discussed and used in publications over the past few years 67. They present the main dependencies occurring in Mass Service Systems, the types of their elements and their parameters. They also refer to the method of mathematical description of MSS. In Chapter 0 it was emphasized that the starting point for modeling is often the construction of a mathematical model. Mathematical models will be of particular importance for the queue theory. A model that simultaneously uses QT can be constructed to optimize production and other logistic processes in the enterprise 25. Some models based on the queue theory are very complex and take into account many factors 9 or use algorithms to find favorable solutions for the system (e.g. a classic three-stage supply chain) 26.

For further considerations, however, their limited area of use will be of key importance. The application of the Queue Theory in the analysis of logistics processes has been presented in the publication 11. The publications themselves refer to the processes related to the organization of rail traffic as a logistics process. An analogous system for presenting mass service systems and their description will also apply to the analyzed warehouse process, which is the acceptance of loads. The subject of the functioning of logistics facilities and the theory of mass service was also raised by 37. A classic notation was used to characterize the queuing systems in relation to the functioning of the logistics center model. The whole is completed by a mathematical model. It is worth paying attention to the wide application of the queue theory. Even by limiting its use to the logistics industry, it can be noticed that its use is not limited to road or internal (warehouse) transport, but its elements can also be found in publications related to, inter alia, aviation (8) or railway (19).

2.3. Computer techniques and their importance for the study of Mass Service Systems

The publication combining the issue of computer simulation and warehouse processes is 1320. Software other than FlexSim was used for modeling and simulation, but there is an analogy with the model construction and elements of the queue system in the presented warehouse processes. The FlexSim program is currently one of the most popular and the most comprehensive computer simulation tools for building models and researching logistics processes. It was used, inter alia, in 22, 17 or 10. The above-mentioned publications show the method of modeling logistics processes and the possibilities of the simulation environment. At the same time, it is worth noting that even in the case of a computer simulation, the model has the features of a queuing system with service stations and queues with specific parameters. In case of 22 these are, for example, elements of an intermodal terminal and devices implementing the cargo handling process. A good example of the use of computer simulation in the analysis of the effectiveness of the implemented processes are the considerations presented in 2. We are dealing here with a classic analysis of the operation of a system with given parameters for various variants (in this case, a comparison of the work of a production line operated by robots or a human).

Basic issues related to the design of logistics systems and their modeling can be found in holistic studies (e.g. 102734) or scripts (244). Authors of 10 more generally referred to modeling and optimization in FlexSim. However, their attention was also focused on internal warehouse processes. Finally, when modeling, regardless of whether we are talking about a classic QT record or an advanced computer simulation, it is also necessary to know the process under study and to select the appropriate data set. This topic was discussed in the publication 30 and 33. From the publication, it is possible to conclude what data and why are important for the analyzed process, and how their lack may affect the research results. Due to the factors mentioned above, many authors decide to use the FlexSim simulation environment to present the processes that are analyzed further in this article. In the publication 36 the authors analyzed the operation of the system consisting of service stations (of various types), queues, as well as entry and exit from the system. This is a structure that is characteristic of e.g. production lines, but also of the acceptance process analyzed below.

It is also worth paying attention to the fact that so far the process of loads delivery handling in the technical object for delivering and collecting of goods has not been thoroughly analyzed both in terms of QT or the use of modern simulation tools.

3. Model for assessing the effectiveness of cargo delivery handling process in a technical object for delivering and collecting of goods with the use of the queue theory

3.1 Assumptions adopted for the description of the process using the queue theory

Before starting the description of the process of goods receipt in the technical object for delivering and collecting of goods with the use of QT, three parameters necessary for proper characterization shall be defined MSS 32:

The requests inflow intensity λ can be represented as: $\lambda = \frac{1}{t_\lambda}$;

where:

$t_\lambda -$ average time interval between requests flowing to the system.

1. The handling intensity μ is defined by the following formula:

$\mu = \frac{1}{t_\mu}$;

where:

$t_\mu -$ average time interval between requests flowing to the system .

2. Queue regulations. The queue is FIFO (First In First Out). Accordingly, the functioning of the system is expressed in terms of the degree of system utilization ρ:

$\rho = \frac{\lambda}{\mu}$;

In the analyzed logistics process, the variables describing declarations and service in each of the subsystems are random variables with an exponential distribution. In the case when $\rho > 1$ with $t \to \infty$ the queue increases to infinity, the system is unstable, otherwise, at $\rho < 1$ the queue problem does not occur and the system is stable. Analyzing the above rules, the case of $\rho = 1$ is mostly at the limit of stability. The parameter ρ derives many dependencies such as the average number of objects in the queue, the average time spent in the queue, the wait probability, the probability that there are n objects in the system, the probability that the system is empty, and the wait probability. The described dependencies are presented in the subsection 0.

Parameters characterizing the service system according to the so-called Kendall notation. It takes the following form 732:

$$X/Y/s$$

where:

$X -$ distribution of the input stream of requests in the system,

$Y -$ distribution of times characterizing the handling of requests,

$s -$ number of handling stations.

The process under study is the adoption of specialized medical tools for laparoscopic surgery from an independent supplier to the main technical object for delivering and collecting of goods. The described process is divided into four basic stages defined as collecting the delivery from a courier or other transport company, handling of the delivery in the technical object of transport infrastructure, detailed control of the delivery and handling of returns.

Pickup from a courier or other transport company is a stage devoted mainly to the initial inspection of the delivery in order to determine its compliance with the documentation and to verify its condition for damage. During this stage, an employee of the Logistics Department is required to carry out an entry check, which is devoted to the verification of packages with CRM / bill of lading and shipping documents of the supplier. After confirming compliance, individual packages are then visually inspected in order to find any mechanical damage. In the course of performing each of the above-mentioned activities, the package may be rejected and handed over for service by an employee of the Returns Department. If there is no inconsistency with the order in the package or visible damage, it is moved by a pallet truck (lifting truck) to the reception area, which serves as an input buffer.The stage of accepting a delivery is relatively short and consists of just two steps for each package. The first is to send a notification to the Procurement Department about the receipt of the shipment and prepare copies of the complete set of documents for the Procurement Department, Logistics Department and Control Department. After its completion, the shipment is moved to the control zone by a lifting pallet truck. The activities are performed by an employee of the Logistics Department.

In a detailed inspection, trained employees of the Control Department analyze the documents received from the supplier regarding each received package and compare them with the previously received notification. After determining the compliance of 6 documents, each package is subjected to a very thorough control of the contents, each of them is unpacked, then all individual products are subjected to a thorough verification consisting in determining the compliance of the serial numbers of the tool with the numbers given in the package documentation. The end of the activity is repacking the package. If, during the performance of any of the mentioned activities, inconsistencies are found in the documentation, it is handed over to an employee of the Returns Department. Otherwise, the package is marked in accordance with its intended use, i.e. it may be marked as a package intended for the immediate execution of contracts, a package for storage in the general technical object area or a package intended for handling by the Service Department. After the package is properly marked, an employee of the Logistics Department moves the package to the appropriate storage area using forklift. The parcels then wait for handling before being shipped to the appropriate customers.

The last stage of activities performed on parcels for which non-conformities have been found, at the stage of receipt of the parcel or during a detailed inspection, is the handling of returns. Activities during this stage are performed by employees of the Returns Department. First, the package is moved to the returns area. Then, an employee of the Returns Department starts preparing a report on non-conformities in the package. After all necessary documents are prepared, they are forwarded to the Procurement Department. Additionally, it is assumed that in the process of entering the parcels to the warehouse, 20 parcels are delivered with an interval of 3 minutes. 5% of parcels are rejected during initial control, while only 2% during in-depth control process.

3.2. Graphical presentation of the process using the queue theory

On the basis of the description of the cargo receipt process in the technical object for delivering and collecting of goods, included in chapter 2, the graph presented in the Fig. 3.1 has been created. It illustrates the sequence and dependencies of individual activities among themselves. The process diagram is supplemented by Table 3.1, which presents the characteristics of individual steps in the process. The mapping of the process in the form of a mass service system was performed in two stages. The first was to correctly identify elements such as queues and service stations. Thanks to this, based mainly on the scheme and data about individual processes contained in Table 3.1. we were able to define the characteristics of activities. The second stage was to determine the characteristics of individual, smaller queuing systems that make up the full logistics process. It was determined on the basis of the average service times selected on the basis of the Kendall notation, which determines the distribution of the random variable being the time between reports, the distribution of the random variable referring to the time of handling a single report, the number of stands in each of the subsystems and the size of the waiting room for each of the subsystems.

Table 3.1. Characteristics of activities observed during the process.

ID	Process stage	Action	Involved dept.	Number of workers p/ devices u	Avg. handling time [min]
1	Receipt of delivery	Input inspection (verification with CRM / bill of lading and supplier's shipping documents)	Logistics	1 / -	3
2		Visual inspection for damage		1 / -	1
3		Moving the parcel to the reception area		1 / pallet truck (lifting)	2
4	Returns handling	Moving the package to the returns area (from receipt)	Returns	1 / pallet truck (lifting)	2
5		Moving the package to the returns area (from control zone)		1 / pallet truck (lifting)	4
6		Preparation of documents and notification of inconsistencies with the Procurement Department		2 / -	40
7	Delivery handling process	Sending a notification to the Procurement Department about the receipt of the shipment and preparing copies of a set of documents for the Procurement Department, Logistics Department and Control Department	Logistics	2 / -	5
8		Moving the shipment to the control zone		1 / pallet truck (lifting)	3
9	Detailed delivery control	Analysis of documents received from the supplier and comparison with the previously received notification	Control	3 / -	10
10		Detailed control (unpacking, thorough verification of individual products, re-packing)		3 / -	15
11		Appropriate package marking		1 / -	2
12		Move the package to the appropriate storage area	Logistics	1 / forklift	5

Authors' own elaboration.

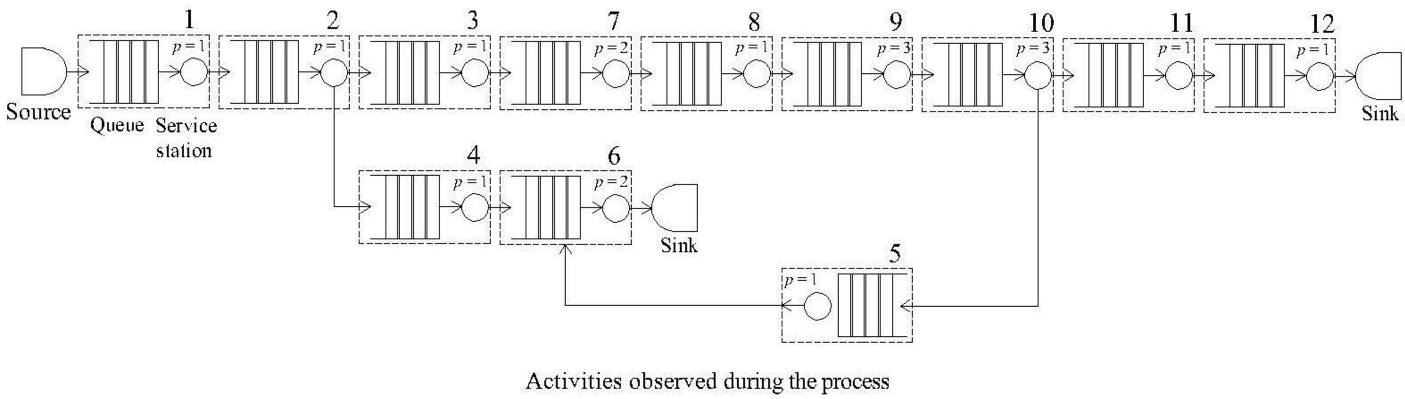

Fig. 3.1. Diagram of activities observed during the process. Authors' own elaboration based on https://app.diagrams.net/.

The mapping of the process using MSS was made based on the assumption that the application to the system is delivery of a package by a courier or another, independent transport company. After its delivery, it goes to the first mass handling subsystem, consisting of a queue and a single handling station, dedicated to the inspection of the package and its documents at the exit. From there, the package can go to one of two queues. If parcel is accepted, then it is directed to subsystem 2, which describes its movement to the reception area. Then, the compliant package goes to the subsystem imaging the performance of activities related to the receipt of the package, i.e. sending notifications to the appropriate departments. This operation is performed simultaneously by two employees, so there are two service stations in this subsystem.

After sending the notifications, the package is moved to the control zone, which is the next MSS described with the number 5 and consisting of a single queue and a single handling station. Subsequently, the package goes to the most extensive subsystem, which is devoted to its detailed control. This subsystem consists of one queue and three service stations operating in parallel. After exiting the subsystem 6 devoted to control, the package can once again move to one of the two queues. If no irregularities are found, the package goes to the queue of subsystem 7, where it is appropriately marked at a single service station, and then in subsystem 10 it is moved to the appropriate storage location using one forklift operating in the technical object for delivering and collecting of goods.

If the package is marked as inconsistent with the order or defective, it will be directed to an alternative service path. Due to the different handling times during the movement from different zones, the movement to the return zone has been presented as two different MSS 3 and 8 corresponding to the movement from the delivery (3) and the movement from the control zone (8). After the package passes through one of these subsystems, it goes to the last subsystem (no. 9), symbolizing the preparation of a report on non-conformities and sending it to the appropriate entities. The activity is performed by two employees in parallel. The way the system works and the possible routes for parcels to pass through the system are presented on Fig. 3.2. Each subsystem is described in Kendall notation. It was assumed that the variables describing the reporting process and the service process are random variables with an exponential distribution in each of the subsystems

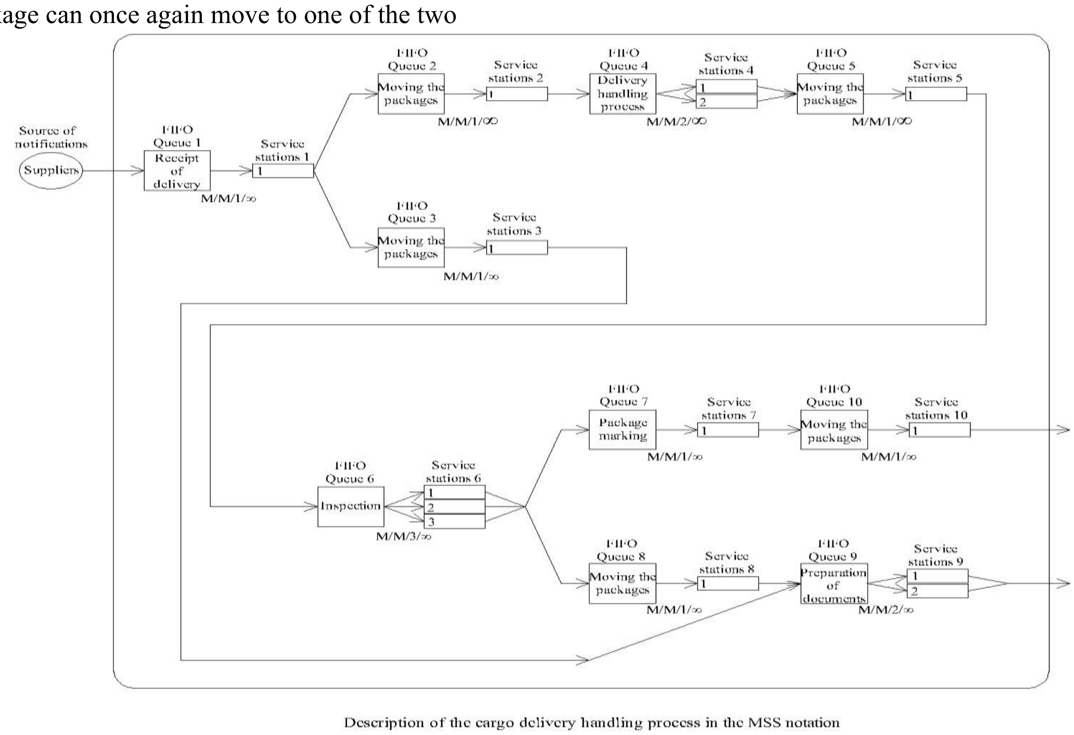

Fig. 3.2. Description of the cargo delivery handling process in the MSS notation.

4. Construction of a simulation model to assess the effectiveness of the delivery handling process

4.1. Process implementation in the FlexSim simulation environment

The FlexSim program is based on the QT and allows you to simulate complex multi-element systems 14. This chapter presents the way in which the studied process was modeled in the FlexSim tool using the QT, based on the system presented in Fig. 4.1. In the next steps, the results of several model simulations are presented. The first simulation was created on the basis of the previously presented data on the number of stations and the distribution of packages in terms of their compliance with the order. The next three simulations assume a reduction in the number of service stations, an increase in the number of service stations and a change in the probability distribution regarding the compliance of packages with the order.

The model created in FlexSim was built on the basis of the Mass Service Theory diagram presented in the subsection 3. The layout starts with a source that creates a package (cargo input to the system). Due to the characteristics of deliveries, it was necessary to carry out a parametrization of the source, which allowed for the admission of 20 parcels to the system in a predetermined number.

Queues have not been limited in terms of the number of items that can be stored at one time. In addition, in two places, the processors are nodes where the packages separate with a certain probability, which was determined on the basis of the data provided in the first chapters of the study. After selecting one of two possible paths, the appropriate parameters determining the probability of compliant and non-compliant packages coming out of subprocess 1 have also been edited.

Parameters for parcels coming out of subprocess no. 6 were defined in a similar way. At the stage of distributing parcels between two parallel traffic flows, one should remember about the order in which connections are created. The connection created first will always be specified as port 1. Due to the fact that the rules of each queue were established as a FIFO, it was possible to determine the number of available positions in each sub-process by using the basic functionalities of the processor. By setting the value of the processor parameter to the assumed value equal to the number of parallel service stations, it was possible to exclude the need to use parallel processors and accumulate them into a single station handling three packages at the service stations in subprocess 6.

The model was completed with two queuing zones, which allowed at later stages to determine the share of compliant and non-compliant packages in a given shipment. Whole model is presented in Fig. 4.1.

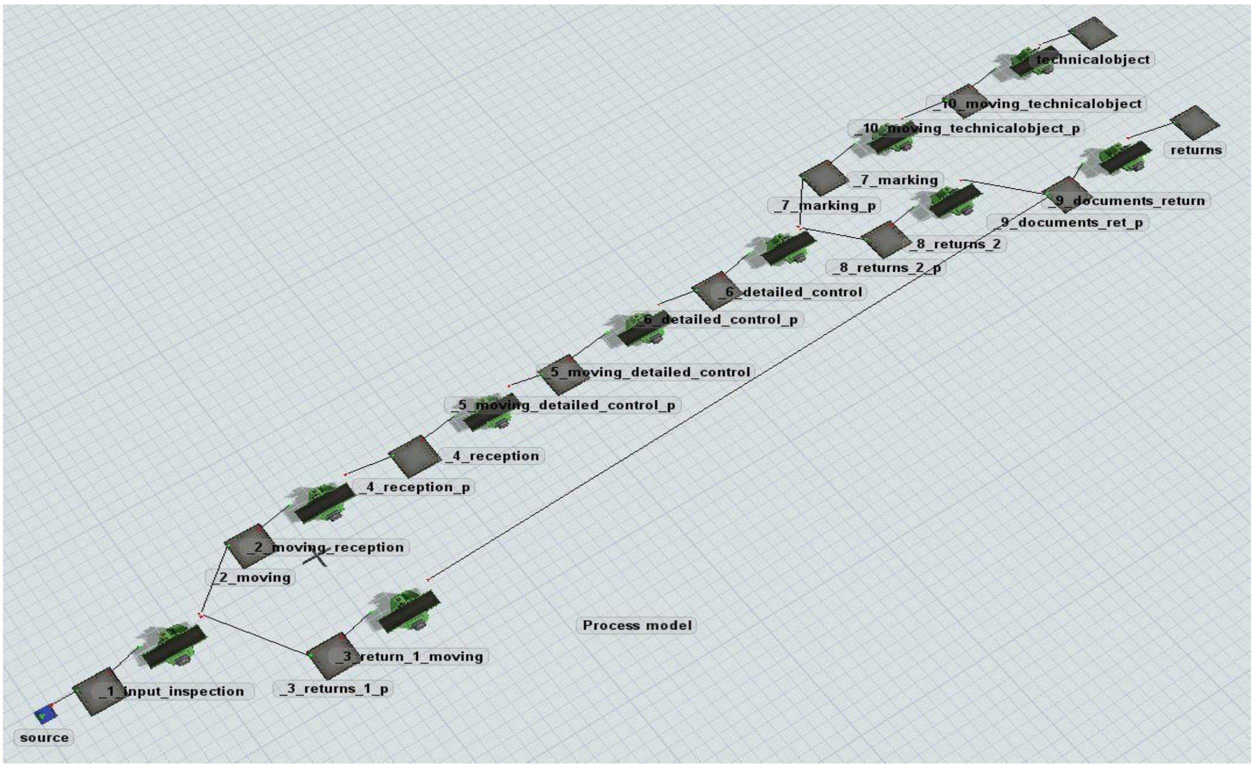

Fig. 4.1. Process model. Authors' own elaboration based on FlexSim 2021.

4.2. Characteristics of the system components

The characteristics of individual elements were tested on the basis of the data specified below Table 4.1. For the first mass service subsystem, i.e. parcel control at the entrance, it was a simple process, as all the necessary data (random variables describing the flow of requests and handling at the stations) were provided. On the other hand, the inflow of requests to subsequent subprocesses is strictly dependent on the previously performed activities on the package. For this reason, a simplification has been adopted in which the flow at the input to individual subsystems is determined directly on the basis of the output from the previous subsystem.

In addition, it is assumed that reports originate from each subsystem with the lower of the service and call intensity of the two. This simplification was made due to the physical operation of the systems and the close relationship between their elements. Additionally, the described process merges streams from two mass service subsystems. For this reason, mathematical operations should be performed on the distributions describing the service intensity processes in order to determine the distribution describing the flow of incoming requests to a given activity.

A possibly pessimistic scenario was adopted, in which from both sources entering subsystem 9, i.e. subsystem 3 and 8, reports come regularly, for 100 minutes, with an intensity equal to, respectively $\lambda_{wy3} = 0{,}25$ and $\lambda_{wy8} = 0{,}12$. It follows that within the next 100 minutes subsystem 9 will receive 25 declarations from subsystem 3 and 12 declarations from subsystem 8. It follows that the intensity of requests incoming to subsystem 9 is $\lambda_9 = 0{,}37$, and expected value of time between the requests is 2,703 minutes. Data describing subsystems are presented in Table 4.1.

For each of the subsystems, numerical characteristics were determined, such as traffic intensity, waiting probability, average number of objects in the queue and average time spent in the queue. The basic FIFO method of handling notifications has been adopted, i.e. handling according to the order of reporting to the system. Individual characteristics were determined for two different types of systems that could be identified, i.e. a system with the number of handling stations s and a system with one handling station. System $M/M/s/\infty$ including s handling stations was constructed based on subsystem no. 4, in which 2 handling stations are used. System $M/M/1/\infty$ including 1 handling station was constructed on the basis of the subsystem 2. Formulas used during the calculations of characteristics for the subsystems are presented in Table 4.2 32.

Table 4.1. Data for MSS subsystems.

Subsystem	**Intensity of:**			**Avarage time between:**			**Number of handling stations s [-]**
	requests λ [request/min]	**handling μ [handle/min]**	**exits from the system λ_{wy} [exit/min]**	**requests t_λ [min]**	**handlings t_μ [min]**	**entry and exit t_λ [min]**	
1	0,333	0,25	0,25	3	4	4	1
2	0,25	0,5	0,25	4	2	4	1
3	0,25	0,5	0,25	4	2	4	1
4	0,25	0,2	0,25	4	5	4	2
5	0,25	0,333	0,25	4	3	4	1
6	0,25	0,04	0,12	4	25	8,333	3
7	0,12	0,5	0,12	8,333	2	8,333	1
8	0,12	0,25	0,12	8,333	4	8,333	1
9	0,37	0,025	0,05	8,333	40	20	2
10	0,05	0,2	0,05	20	5	20	1

Table 4.2. Formulas for MSS subsystem characteristics.

Characteristics of systems	**Type of system**	
	System $M/M/s/\infty$	System $M/M/1/\infty$
Traffic intensity	$\rho = \frac{\lambda}{s \cdot \mu}$	$\rho = \frac{\lambda}{s \cdot \mu}$
Probability of downtime or that the system is empty	$P_0 = \left[\sum_{i=0}^{s-1} \frac{(s\rho)^i}{i!} + \frac{(s\rho)^s}{s!} \cdot \frac{1}{1-\rho}\right]^{-1}$	$P_0 = 1 - \rho$
The probability that there are n objects in the system	$P_s = \frac{\rho^s \cdot s^s}{s!} \cdot P_0$	$P_s = \rho^s \cdot (1 - \rho)$
Probability of waiting	$P(n \geq s) = \sum_{i=s}^{\infty} P_i = \frac{P_s}{1-\rho}$	$P(n \geq s) = \sum_{i=s}^{\infty} P_i = \frac{P_s}{1-\rho}$
Average number of items in the queue	$\bar{v} = \sum_{i=s}^{\infty} (i - s) \cdot P_i = \frac{\rho \cdot P_s}{(1-\rho)^2}$	$\bar{v} = \frac{\rho^2}{1-\rho}$
Average time in the queue [min]	$\bar{\tau_k} = \frac{\bar{v}}{\lambda} = \frac{P_s}{s\rho(1-\rho)^2}$	$\bar{\tau_k} = \frac{\rho}{\mu(1-\rho)}$
Signs	Requests intensity: $\lambda = 0{,}25$, Number of handling stations: $s = 2$ Handling intensity $\mu = 0{,}2$ $i = 0{,}1$	$\lambda = 0{,}25$, $s = 1$, $\mu = 0{,}5$

Analyze of the equations allows to determine the characteristics of a MSS of a given type, it can be seen that the main parameter that determines whether the appropriate characteristics can be determined for the system is the traffic intensity. If it reaches a value below 1, it means that the system is stable and appropriate characteristics can be determined. If the traffic intensity reaches the value of 1, it means that the system is on the verge of stability, while the value above 1 means that the system is unstable and the elements will appear in the queue much more often than they will run out of service. For this reason, it was impossible to determine the characteristics for subsystems 1, 6 and 9. However, it is suspected that due to the limitation of the input source to the average delivery of 20 packages, it will be possible to determine all numerical characteristics at the stage of computer simulation of the system.

Table 4.3 presents all the characteristics of the QT subsystems that can be determined in an analytical manner, which make up the full process of handling the package during the reception process.

Table 4.3. Characteristics of MSS subsystems.

Process	Number of stations s	Requests intensity λ [request/min]	Handling intensity μ [handle/min]	Movement intensity ρ	P_0	P_s	$P(n \geq s)$	Avarage queue lenght $\bar{v}$ [objects]	Avarage wainting time τ_k [min]
1	1	0,333	0,25	1,332	-	-	-	-	-
2	1	0,25	0,50	0,50	0,50	0,25	0,50	0,50	2,00
3	1	0,25	0,50	0,50	0,50	0,25	0,50	0,50	2,00
4	2	0,25	0,20	0,625	0,231	0,181	0,483	0,804	3,216
5	1	0,25	0.333	0,751	0,249	0,187	0,751	2,266	9,057
6	3	0,25	0,04	2,083	-	-	-	-	-
7	1	0,12	0,50	0,24	0,76	0,182	0,24	0,076	0,632
8	1	0,12	0,25	0,48	0,52	0,2496	0,48	0,443	3,692
9	2	0,37	0,025	7,4	-	-	-	-	-
10	1	0,05	0,2	0,25	0,75	0,1875	0,25	0,083	1,667

5. Simulation and evaluation of the effectiveness and reliability of the process

5.1. Variant 0 (starting variant)

After the appropriate mapping of the system in the FlexSim, it was simulated in several variants. In the next steps, the changes introduced in each variant are presented. The results obtained, in the form of the maximum number of parcels simultaneously in each queue, the average waiting time in the queue and the processing time, first read directly from the output data from the program and expressed as a percentage, and after the overall simulation time expressed in minutes, were presented in the last section summarizing the results of all simulations.

The basic variant (Variant 0) is based on the data presented in the subsection 0. Due to the introduction of simplifications and consolidation of some processes, it is presented Table 5.1. Table 5.1 contain basic parameters: the time expected between requests to the system, expected service times in each subsystem and the number of handling stations in each of the subsystems. The basic variant of the process is a reference point for the rest of the variants simulations. Basic simulation had a total time of 176 minutes. 17 out of 20 parcels generated at the exit were sent to the warehouse area, and 3 to the returns area.

Table 5.1. Model parameters in the basic variant (variant 0).

Avarage time between the requestes [min]:		**3**
Subsystem number	**Expected handling time [min]**	**Number of handling stations [-]**
1	4	1
2	2	1
3	2	1
4	5	2
5	3	1
6	25	3
7	2	1
8	4	1
9	40	2
10	5	1

5.2. Variant I - reduction of the number of service stations

Observing the results of the basic simulation, a decision was made to reduce the number of service stations for processes with more than one service station. Thus, in subsystems 4 and 9, the number of positions was reduced to 2, and in the system of 6 to 3 control stations. The full simulation time of the variant with the reduced number of stations was 271 minutes. Only one of the 20 parcels generated at the source went to the returns area.

5.3. Variant II - increasing the number of service stations

As a supplement to the previous simulation (Variant I), a decision was made to implement a simulation with an increased number of stations. In subsystem no. 1, the number of service stations was increased from 1 to 2. The most loaded processor no. 6 was also given an additional control station, which meant that in the analyzed variant, 4 detailed control stations operated simultaneously. The simulation of the variant with an increased number of stations lasted a total of 156 minutes. 19 out of 20 generated parcels were deemed compliant with the order and were sent to the storage area.

5.4. Variant III - changed the probability of detecting a non-compliant package

The third variant introduced the smallest changes in relation to the base model. The only change was the increase in the percentage of parcels identified as non-compliant at the second control (‘in-depth’ control). In the analyzed variant, it was determined that as much as 5% of parcels will be rejected because they are determined to be inconsistent with the order.The simulation of this variant lasted 191 minutes, 4 out of 20 parcels generated at the entrance were transferred to the returns area.

5.5. Simulation results comparison for variants

The results of simulation obtained on the basis of the described simulation variants are presented in Table 5.2. (Variant 0 and Variant I) and Table 5.3 (Variant II and Variant III).

It should be noted that due to the very low percentage of packages identified in the in-depth control as non-compliant with the order, no flows through subsystem 8 occurred in the first three simulation variants. For this reason, FlexSim was not able to provide numerical characteristics for this subprocess. The easiest way to perform a comparative analysis between individual simulation variants is to observe the graphs with the values recorded on them, obtained in different iterations. Comparing the results on the size of queues, it can be easily observed that in the warehouse where the process under study takes place, the largest queuing space should be provided for the subsystem 6.

Table 5.2. Simulation results of the parcel delivery handling process (variant 0 and I).

	Variant 0				Variant I			
Differences comparing to Variant 0:	---				1 handling station in the subsystem 4 2 handling stations in the subsystem 6 1 handling station in the subsystem 9			
Simulation time [min]	176				271			
Distribution of parcels at the end of the process	3 parcels queued in the returns area				1 parcel queued in the return area			
	17 parcels in queue in the technical object				19 parcels in queue in the technical object			
Queue/ station no.	**Max. number of items in the queue**	**Average waiting time [min]**	**Processors working time [%]**	**Processor uptime [min]**	**Max. number of items in the queue**	**Average waiting time [min]**	**Processors working time [%]**	**Processor uptime [min]**
1	5	9	45,5	80,08	5	9	29,6	80,22
2	1	0	19,4	34,14	1	0	14,1	38,21
3	1	0	3,5	6,16	1	0	0,7	1,90
4	1	0	39,8	70,05	4	8,4	35,1	95,12
5	1	0	29	51,04	1	0	21,1	57,18
6	8	30,1	87,6	154,18	11	63,9	92,3	250,15
7	1	0	19,4	34,14	1	0	14	37,94
8	X	X	X	X	X	X	X	X
9	1	8	45,5	80,08	1	0	14,8	40,11
10	1	0,9	48,2	84,83	1	0	35	94,85
Avarage value:	**2,22**	**5,33**	**37,54**	**66,08**	**2,89**	**9,03**	**28,52**	**77,30**

Authors' own elaboration.

Table 5.3. Simulation results of the parcel delivery handling process (variant II and III).

	Variant II				Variant III			
Differences comparing to Variant 0:	4 handling station in the subsystem 6 2 handling station in the subsystem 1				95% and 5% at the exit of the subsystem 6			
Simulation time [min]	156				191			
Distribution of parcels at the end of the process	1 parcels queued in the returns area				4 parcel queued in the return area			
	19 parcels in queue in the technical object				16 parcels in queue in the technical object			
Queue/ station no.	**Max. number of items in the queue**	**Average waiting time [min]**	**Processors working time [%]**	**Processor uptime [min]**	**Max. number of items in the queue**	**Average waiting time [min]**	**Processors working time [%]**	**Processor uptime [min]**
1	1	0	38,9	60,68	5	9	41,9	80,3
2	1	0	24,4	38,06	1	0	17,9	34,9
3	1	0	1,3	2,03	1	0	3,2	6,11
4	1	0	38,7	60,37	1	0	36,7	70,1
5	1	1,1	36,6	57,10	1	0	26,8	51,19
6	9	23,9	84,4	131,66	8	30,1	80,6	153,95
7	1	0	24,4	38,06	1	0	16,8	32,09
8	X	X	X	X	1	0	2,2	4,20
9	1	0	25,7	40,09	1	6	62,8	119,95
10	1	2,4	60,8	94,85	1	0,9	41,9	80,3
Avarage value:	**1,89**	**3,04**	**37,24**	**58,10**	**2,1**	**4,6**	**33,08**	**63,18**

Authors' own elaboration.

Regardless of changes in the characteristics describing the process, the system input is always the place with the highest queue load. It is worth noting that the minimum queue has been reached for the base variant (Variant 0). Despite testing the variant in which the number of positions in detailed control was increased, the queue increased by one packet at the most loaded moment. This was due to the faster passage of parcels through subprocess 1, in which there was almost no queue. The simulation results for variants 0-III are presented further with the use of graphs:

– Maximum number of packages waiting in the queue (Fig. 5.1.),
– Average waiting time in the queue QT (Fig. 5.2.),
– Processors performance in relation to simulation time (Fig 5.3.).

Definitely the greatest differences between the simulation variants can be observed when analyzing the average waiting time in the queue. For the variant with a reduced number of service stations in subprocesses 4, 6 and 9, a double increase in the average waiting time in the queue in subsystem 6 can be observed. It is worth noting, however, that in this variant, the average waiting time in the queue to subsystem no. 9 causing the bottleneck in subsystem 6 to narrow. Packages are blocked in it and leave it with an intensity that is less than the capacity of subsequent subsystems, which therefore no longer accumulate loads.

The load of processors in individual subsystems shows the extent to which a given processor is used during the entire process of delivery handling. By analyzing the results, it can be observed that the subprocess 6 is the most loaded and laborious in all simulations. It can also be noticed that by slightly changing the probability distribution of determining the package as inconsistent with the order, the subprocess 9 load significantly increased.

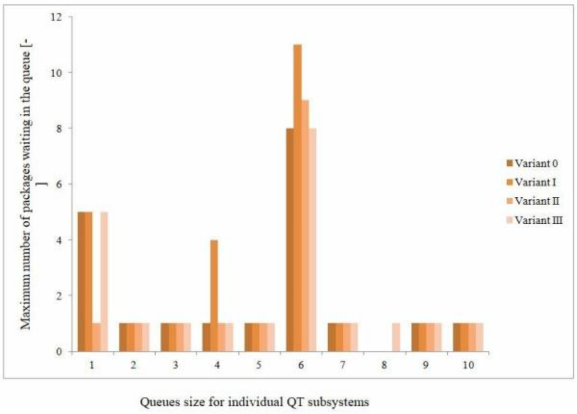

Fig. 5.1. Queues size for individual QT subsystems. Authors' own elaboration.

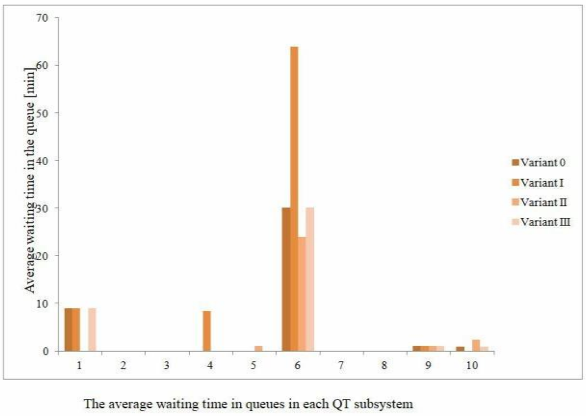

Fig. 5.2. The average waiting time in queues in each QT subsystem. Authors' own elaboration.

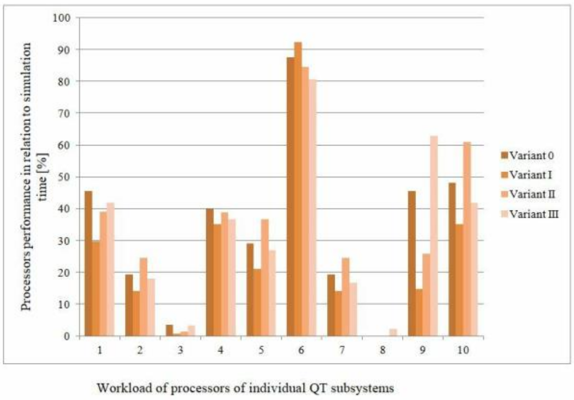

Fig. 5.3. Workload of processors of individual QT subsystems. Authors' own elaboration.

6. Summary and conclusions

Analyzing the examined process of cargo delivery handling process in the technical object, it was possible to notice a division into four main sub-processes, i.e. pickup of delivery from a courier, delivery handling, detailed control and handling of returns. During the analysis, 12 minor activities were also specified. Due to the fact that some of them are served by the same number of employees, they have been consolidated at further stages, allowing for a slight simplification without adversely affecting the description of the process. Due to the handling of specialized equipment, during the full delivery handling process, particular attention is paid to checking individual packages and reporting on their condition and non-compliance with the order.

The logistic process was mapped in the form of a Mass Service System (MSS) with the use of Queue Theory (QT). Firstly,
a simplified process was used, containing 10 smaller MSS subsystems. For each subsystem, its characteristics were defined and it was described using Kendall's notation. Characteristics describing its operation were also determined for each system, focusing mainly on queues. The characteristics were determined on the basis of defined average service times, average times between reports and the number of service stations.

A simplification has been adopted for the systems behind system 1 (not in the input) on the entry of declarations into the system with the intensity equal to the intensity of outputs from the subsystems preceding it. The parameters that were determined included the traffic intensity, waiting probability, the average number of objects in the queue and the average time spent in the queue. Due to the fact that the systems 1, 6 and 9 exceeded the value 1 for the traffic intensity, it was not possible to determine other characteristics. However, it was suspected that due to the reduction in the size of the delivery to 20 packages, it would be possible to determine the characteristics at the stage of computer simulation in the selected tool.

The last stage during the process study was the simulation of the chosen process in the FlexSim computer tool, which also uses the QT and enables the simulation of complex systems composed of many elements with different characteristics. Nowadays, profit-oriented and successful companies can use computer tools for simulation and process modeling. This carries with it a great many advantages. One of them is that one can follow the process in depth while speeding up and slowing down time. It is possible to go deep into the system, introducing new solutions and observe the effects. With computer tools that are used for simulation, companies can detect limitations and obstacles. The data that is obtained from simulations allows to determine the reasons for delays. Undoubtedly, an important plus of computer simulations is the visualization of processes, using graphics. Next, it is also important to note the reduction of the company's costs in connection with carrying out computer simulations. This involves the ability to implement and analyze various solutions in a computer tool, rather than in reality. Enterprises can create multiple configurations and choose the optimal option. Carrying out many different solutions and choosing the best one is associated with better enterprise performance.

In the article, analyzing the results of several simulations, it can be concluded that in real conditions a system based on the principles of QT will operate diametrically differently than it could result from the theoretically determined characteristics based on real data.

Comparing the simulation results obtained with the FlexSim software with the results determined in an analytical way, it can be seen that significantly different results are obtained. Despite the theoretical definition of some of the subsystems as unstable, i.e. those that cannot function properly and the queue in them will grow much faster than it is possible to handle requests, due to the source limitations at the entrance to a certain number of subsystems, they are still capable of operation.

The simulation results also show that the full process of delivery handling in the worst case (variant 2) slightly exceeds 4.5 hours. In other variants, it takes about 2.5 up to 3.0 hours. This proves that the process has been designed quite well. Attempts to optimize it ended with reducing the time of accepting a full delivery by about half an hour in the variant assuming an increase in the number of positions in sub-processes 1 and 6. However, it is suspected that this activity may not be appropriate when optimizing the process, as it could entail significant outlays and costs only slightly increasing the throughput of the technical object at the entrance.

The subsystem that was most loaded over all simulations is subsystem no. 6. Due to its long duration, on average 25 minutes, and a large number of parcels passing through it, it is characterized by the largest queues and waiting times. When starting to optimize the admission process, the main focus should be on this sub-process. However, it should be noted that the changes introduced in this sub-process in one of the simulation variants negatively influenced the results of other sub-processes on the further path that the parcel takes when it is admitted to the technical object.

Although some subprocesses are characterized by quite a high load, it should be noted that this is the value that relates to the duration of the simulation. This means that the most loaded process, in the most loaded simulation, took place for just over 4 hours. To sum up, the examined process can be considered as designed correctly, and possible actions aimed at its improvement should be carried out very carefully, also based on data on costs and expenditures that could be caused by improvements.

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