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PRODUCT-SERVICE SYSTEM DESIGN: AN EXAMPLE OF THE LOGISTICS INDUSTRY

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Abstract:

Product-Service System (PSS) has been perceived since the 90s as a concept supporting enterprises of various industries in creating a competitive advantage and generating new value for customers by expanding the offer with additional services related to the product. Product-Service System (PSS) draws attention to the life cycle of products and services and the circular economy, which supports sustainable development. All the time, practitioners and theorists report the need to develop new Product-Service System (PSS) for other industries. Until now, a number of practical and methodological aspects related to design remain unresolved. The paper presents issues related to the Product-Service System (PSS) and PSS design. A literature review and gaps in available methods are presented. A conceptual framework for Product-Service System (PSS) design that has been used in the logistics industry is presented. By referring to the design of a selected process from the logistics industry, it was presented how to analyze the process during design and what methods of design support to use. Reference is made to mathematical modeling based on the optimization function and computer modeling with the use of a simulation model. Attention was also paid to the importance of knowledge of the industry and having expert knowledge about the designed processes in the systems. It is also extremely important to have the appropriate data set for a given case. In addition to the general mathematical and computer model, reference was also made to a chosen element of Product-Service System (PSS). The mathematical and simulation model included in the study refer to the process of completing customer orders in a logistics company. It is one of the most laborious and time-consuming processes. The FlexSim simulation environment was used to perform the computer simulation. A total of 15 variants were considered, which differ in terms of the scope of services provided during the process. The scope of services significantly affects the cost, time and profit. The purpose of the constructed model is to find a variant for the adopted data in which the profits will be maximized while maintaining the constraints imposed on the system.

Keywords: *product-service system (PSS), product-service system design, logistic industry, order picking, supply-chain*

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1. Introduction

Recent decades have been associated with a change in the importance of the share of individual sectors in GDP in the economies of individual countries. The service sector is starting to play the most important role. In 2018, he was responsible for 61.2% of the global GDP and 58.37% of the Polish GDP (SDoGDP), 2019. The increase in the share of the services sector in GDP is related to the servicisation trend. A special example of servicisation is Product-Service System (PSS), which are a combination of a product and many related service (Kusumaningdyah et al., 2021; Salwin et al., 2020A; Baines et al., 2007; Salwin et al., 2018).

Currently, manufacturing companies focus on providing tailor-made and ready-made solutions to their customers. In these solutions, the product is only the material core, while the services become responsible for the value delivered to the customer (Tukker, 2015; Reim et al., 2015; Salwin et al., 2020B). Therefore, an important activity is the design and development of Product-Service System. This requires manufacturing companies to change the way they function and expand the department responsible for designing and delivering such solutions. For this reason, it seems necessary to support enterprises in these activities. Designing PSS is extremely difficult in companies that so far have focused on production activities and this activity is being carried out there for the first time. It is an action that relies on the material element (product) and the non-material element (service) and on determining such relations and dependencies between them that the developed product-service system in market conditions gives specific effects and meets the assumed goals (Gaiardelli et al., 2021; Mont, 2002; Marques et al., 2013). Design is one of the main areas of research on PSS. Literature provides several methods, but they do not meet the requirements of enterprises. They are usually too general and untested. Additionally, they do not consider the specific characteristics of the industry, customer needs and the market situation (Beuren et al., 2013; Baines et al., 2009; Khan and Wuest, 2018; Vasantha et al., 2012).

Further in the paper a mathematical model aimed at designing selected stage of PSS is presented. It aims is to present the relationship between the number of services offered in the system, and their impact on the possibility of executing customer orders by the system. The limitations occurring in the system are also considered. The presented model may support the design process and indicate the optimal strategy for selecting the number of services offered in the PSS (added value to the product and goods modification). It takes into account the focus on the customer's needs, but also the optimization of the system functioning. The model relates to the order preparation process (picking and commissioning with order customization elements of the product for the client's needs). Many possible operations performed at the loads were considered (also 'VAS' i.e. Value Added Services). The analyzed process is extremely important for the functioning of any PSS as it:

– generates significant costs (time-consuming and labor-intensive),
– affects the correctness and efficiency of the customer's order fulfillment,
– the manner of its organization determines the possibility of adapting the order to the customer's needs.

Apart from the mathematical model, a complex computer simulation was carried out in the environment of the FlexSim software. It has been developed in order to analyze the effectiveness of picking processes with given parameters. On the model, with the given constraints and parameters, a series of simulations were carried out to obtain a vision of the system operation in various variants. The model focuses on the logistics industry, which has a significant impact on most of the goods available on the market and most of the PSS. An attempt to build a universal model for too many system components or for every possible system type could be impossible (e.g., due to the degree of system diversification) or could lead to an overly generalized model. That is why authors decided to focus on the specific process i.e., order picking and commissioning.

2. Materials and methods

The aim of the article is to present information about PSS design. An analysis of the literature on PSS design was presented. The conceptual framework for PSS design was also presented, which is the result of in-depth literature research. The next part of the article presents a mathematical model aimed at presenting a selected PSS element.

In the further part of the paper, a practical example of designing PSS is discussed. Practical approach is based on mathematical and computer simulation model. Before the model's development the sub-

process from PSS system to analyze has been chosen. Two stages of PSS designing process has been specified for this reason.
First stage of the analysis was the construction of the mathematical model. The created model describes the dependencies that occur at selected stages of PSS design and allows the system designer to choose the right design solution. The model considers the profits resulting from the operation of the system, the degree of its advancement (the number of possible operations and the relationships between them) or the labor intensity. Mathematical model allowed for the formulation of an optimization function.
Then the mathematical model has been used as a base for a constructed computer model. FlexSim software has been used to create simulation computer model. Firstly, model has been developed in order to correctly map the dependencies occurring in the selected process. After determining the values of key parameters, it became possible to analyze the operation of the constructive model for various design variants. Each of the variants has been carefully analyzed. The results were presented, and conclusions were drawn on their basis.

3. Literature review

3.1. Servicization

Servicization is not only an area of academic research, but a market fact that has been going on for over a dozen years. Servicization was first mentioned in 1988. This concept aroused the interest of a few industries and companies operating in them (Vandermerwe and Rada, 1988; Baines et al., 2010). It is defined as the growing importance of the services sector in GDP and the economy and the accompanying increase in the number of jobs in services. Servitization is seen as a characteristic producer-customer relationship because of which customers are offered services along with the products (Kozłowska, 2020; Ahmad et al., 2019). Servitization is also the competences and capabilities of the enterprise, enabling the creation of additional value not only through the sale of tangible goods, but also through the sale or provision of PSS (Baines and Lightfoot, 2014). This is a signal for enterprises that, to stay on the market, should change their business models by adapting them not only to the production and sale of tangible products, but also to the sale and provision of services. It should be noted that product-service systems are a special case of servicisation (Baines et al., 2009; Vandermerwe and Rada, 1988).

3.2. Case study

The term PSS refers to the products, services and infrastructure that make up the system. It aims to meet customer needs while focusing on the environment and resource efficiency. PSS guarantees the customer access to a combination of products and services. This solution is to support the entire product life cycle. It is also related to the potential of sustainable development, as I consider all three elements of sustainable development: environmental, social and economic. This concept was developed in the late 1990s in Europe, namely in Scandinavia (Goedkoop et al., 1999; Van Halen et al., 2005; Idrissi et al., 2017; Sakao et al., 2009).
PSS are classified into three main types: product-oriented, use-oriented and result-oriented. Their classification is based on the transition from a pure material product to a pure non-material service (Figure 1). Product-oriented PSS is the traditional sale of a product with possible additional services. For a fee, the manufacturer provides services directly related to the product, such as installation, replacement of spare parts or transport, at the customer's request. With these systems, ownership of the product passes to the customer when the product is purchased. User-oriented PSS is the sale of usability or functionality provided by a product. For a fee, the manufacturer makes the product available to the customer who uses it, and then returns it. It is worth noting that several customers can use the product at the same time. In these systems, the ownership of the product remains with the manufacturer. Result-oriented PSS is the sale of the results that the product gives. The manufacturer supplies the customer with the specific product results that he expects (e.g., cubic meters of compressed air in the case of a compressor). In the case of these systems, the ownership of the product remains with the producer, the client pays only the obtained results (Tukker, 2004; Tukker and Tischner, 2006).

3.3. Product-Service Systems design

Product-Service System design is one of the leading areas of research on these systems (Chiu et al., 2015). It is also very important from the point of

view of the economy and the various industries operating in it. The most common ways of designing the systems in question are the servicisation of products and the 'productisation' of services (Figure 2) (Baines et al., 2009; Baines et al., 2010).
To learn more about this subject, an analysis of this subject was made. Information on PSS was searched for in leading scientific databases (including Scopus, Web of Science, Science Direct). By analyzing scientific papers that have appeared since the appearance of PSS (1988), as many as 60 methods of designing such systems have been found.
The interest in PSS design has changed over time. It was only in 2001 that the first methods of PSS design were developed. These include The Kathalys method, DES, The PSS Innovation Workbook and AEPSS (Luiten et al., 2001; James et al., 2001; Engelhardt et al., 2003). The conducted literature study illustrates the calendar related to the development of subsequent methods. Figure 3 illustrates the development of the analyzed methods over the years. In the analyzed period, the least analyzed methods were developed in 2007 and 2010 (one each year), and the most in 2015 (as many as eight methods). The analysis shows that the interest in the subject PSS design is growing, and in the coming years, new methods and their verification are to be expected.
Most of the analyzed methods are directed to specific industries. There are also methods that can be used in several industries (eg AEPSS) and methods (12 methods) in which the industry in which they can be applied was not indicated. Figure 4 presents the industries to which PSS are directed.
As many as 14 methods of PSS design are directed to the machine building sector. They were used, among others, in the design of this type of systems for CNC machine tools, cutting tools, production machines, compactors, road construction machines, agricultural machines and lifts (Salwin et al., 2020C). The methods available in the literature were also analyzed in terms of their structure. The authors propose a different approach to the PSS design. Among them, the multi-stage approach is the most popular. Figure 5 shows the most common construction patterns of the analyzed methods.

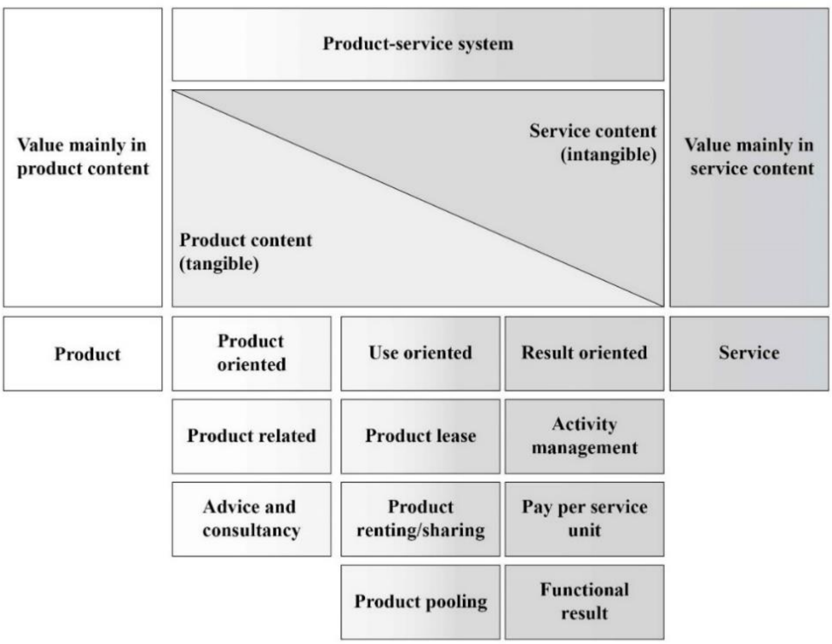

Fig. 1. Classification of Product-Service System

The analyzed methods of designing PSS use several supporting tools. The analysis of the literature shows that it was possible to identify 150 such tools. Figure 6 presents the ten most used tools to support the method of PSS design.

The authors of the analyzed methods most often used Blueprinting, House of Quality, brainstorming, questionnaires, a checklist and a system map as supporting tools. It is worth noting that usually one of the design methods may use several tools. TraPSS is a method of PSS design that uses the most supporting tools, ie 26 (Dimache and Roche, 2013). Only 6 design methods do not use any supporting tool.

Despite so many approaches to PSS design, the literature cannot find any use of systems engineering in this area. The application of systems engineering is not precisely described in the PSS design area. It is known that it can provide guidance and tools to improve the PSS design process (Maleki et al., 2017; Bertoni, 2019; Halstenberg et al., 2019; Wolfenstetter et al., 2018).

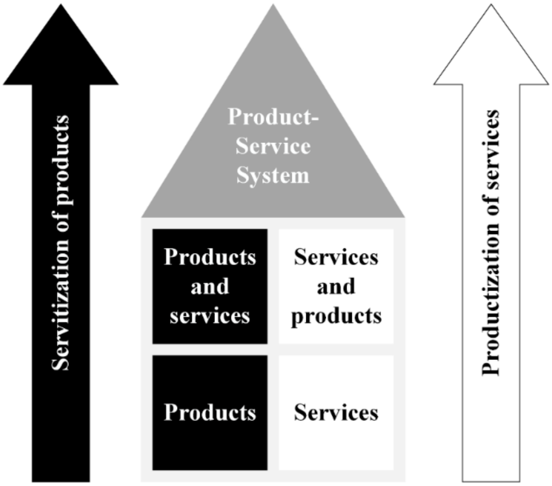

Fig. 2. Two paths of development of Product-Service System

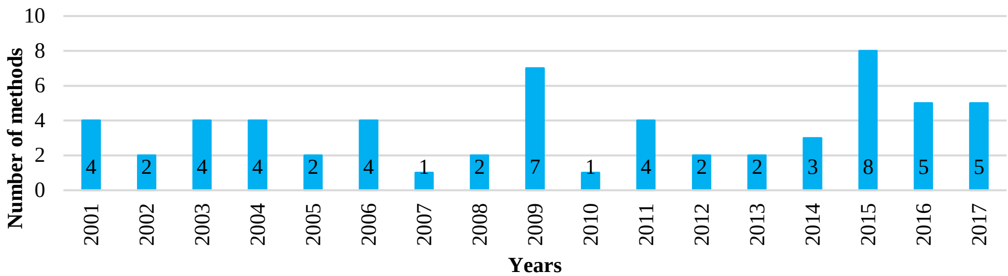

Fig. 3. Methods of Product-Service System design - historical outline

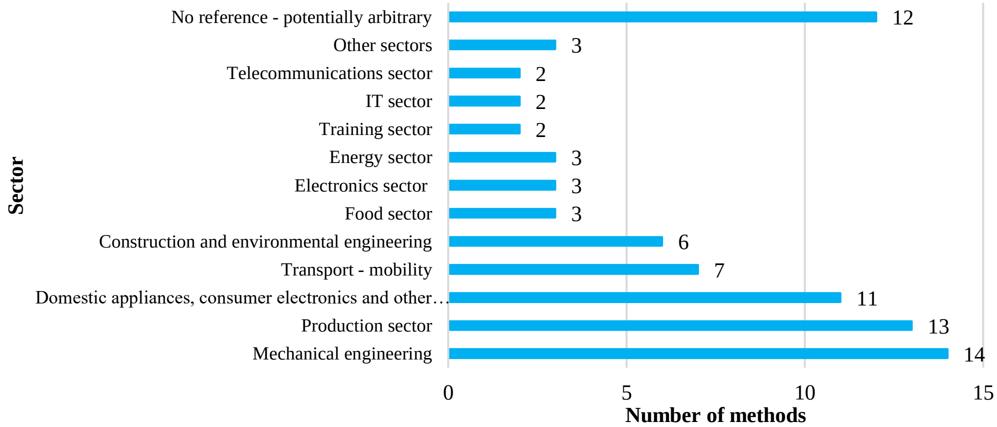

Fig. 4. Methods of PSS design - sectors to which they are addressed

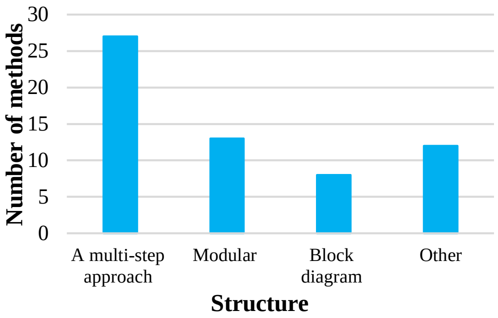

Figure 5. Methods of PSS design - structure methods

3.4. Product-Service System in logistics

PSS show a strong connection with the logistics industry. After all, it has an impact on the goods offered on the market: their availability, type, possible variations and modifications. It also determines the scope of possible benefits and services related to the product. To properly condition the above-mentioned elements, it is necessary to have knowledge about the logistic systems designing or supply chains, in particular their designing, management, dimensioning and shaping. The basic methodology of designing logistics systems has been presented in extensive holistic studies (Jacyna and Lewczuk, 2016) and in papers related to various areas of logistics. The importance of the issue of system design and optimization of their operation has been discussed since the 1980s. As a result, a series of ISO 9000 standards was created, which present a universal set of recommendations that should be used when designing systems (Nehring, 2021). Most of the recommendations are still accepted as important to this day and are the basis for optimizing performance. Designing large scale logistics systems may refer to e.g., national logistics system. An ideal example is the study (Dang and Yeo, 2018) presenting the analysis of the mentioned logistics system on the example of Vietnam and debating the possibilities of its improvement, including key indicators for its evaluation. Other studies on this topic can also be found (Jacyna, 2013). This elaboration relates more generally to material flows on a larger national scale, and to the issue of comodality in transport.
Apart from the system design, the assessment of systems has become one of the most important issues - as evidenced by numerous publications and many developed methods for assessing them. Due to the dynamically occurring changes in the logistic industry, they must be continually improved. The approach to the customer preferences and product improvements must be modified to meet the product and service standards. Often older ‘classic’ systems are focused only on distribution, and they do not consider customers’ needs. Nowadays attention should also be paid to many more aspects than just material flow. The attempt to achieve the so called ‘Perfect Order Rate’ (POR), which is an important indicator presenting, in a holistic approach, how efficiently and flawlessly a given logistics system works and was implemented. This indicator has been also investigated by (Jacyna-Gołda et al., 2019). The study considered numerous factors affecting the flow of materials or the quality and scope of customer orders. Numerous available indicators for the evaluation of systems allow for a better analysis of their work and facilitate design.
The above-mentioned study refers to the analysis at the level of the supply chain. However, there are also numerous scientific publications researching other elements: from logistic industry (Brudlak and Zakrzewski, 2013), to very detailed issues such as reverse logistics (Liao, 2018). The first of these studies presents numerous indicators that can be used to assess PSS. The indicators can be also helpful while system designing process. The second mentioned publication focuses only on the issue of waste logistics trend (i.e., efficient management of its flow, reduction of environmental impact and maximization of the possibility of secondary use). Many factors such as customer satisfaction and environmental aspects have been considered.
The processes related to the shaping of modern logistics industry aimed not only at the delivery of goods, but also at the provision of services and building added value to the product have been widely described in publications. The scope and level of service provision have become extremely important. Trade of goods is not a key factor anymore. This topic has been analyzed for a long time (Hwang, 2002).
In connection with the selection of an element of the logistics system, which was analyzed in this study, it is also worth paying attention to publications related to the picking and commissioning process. Due to the importance of this process, many authors have taken up this topic. At the same time, it is worth paying attention to the wide range of publications and

a diverse approach to the issue: from review studies (Gils et al., 2018) up to specified case-studies (Yudiansyah et al., 2020; Habazin, Glasnović, Bajor, 2016). More and more of them refer to automated picking systems (e.g., Jaghbeer, Hanson, Johansson, 2020). This is a natural result of the development of technology. The simulation model presented further in the study can also be regarded as an automated order-picking system. Some publications, however, focus on more classical picking methods, the way they are organized and effective. This issue was dealt with in the publication Dmytrów (2018). In addition to the way the process is organized, numerous other aspects can also be considered, such as the distribution of the assortment (Wang, Zhang, Fan, 2020) or errors appearing in the process of commissioning (Cierniak-Emerych, Golej, Różycka, 2021). The commissioning process has a significant impact on the possibility of obtaining the perfect order rate, which is one of the most comprehensive indicators when assessing the effectiveness of the logistics system (Jacyna-Gołda et al., 2019). Because the picking process occurs in virtually every supply chain, picking systems will be organized differently and will have different requirements.

4. Conceptual framework of the Product-Service System design method

The overall design process consists of five main modules. The entire process begins with the planning module. The end is, however, the development of a PSS and its verification. The method defines inputs, outputs, activities that meet control and mechanisms, i.e., in this case the human resources responsible for project activities. The conceptual framework of the method for PSS design is presented in Figure 7.

The first module is planning. Organizational and research activities take place here. The market is analyzed, the cases of PSS operating on it, and market opportunities. Here, a project team is also appointed, and tasks are assigned to each of its members. The result of this module is the determination of the key assumptions and goals of the designed PSS. The second module is concept development. This module analyzes the company's potential and considers customer needs. Additionally, a stakeholder analysis takes place. The result of this module is the determination of the form and function of the PSS and its specific features. The third module is system-level design. Here, elements of systems engineering are used. This module specifies the requirements to be met by the PSS, service recognition and system architecture construction. The result of this module is a geometric model of the PSS and its functional specification. The fourth module is detailed design. It includes the full specification of the PSS that is being designed. In this module, marketing and distribution strategies are developed. It is being determined how the PSS will be made available. The result of this module is a PSS ready for implementation. The fifth module is design verification. It includes the implementation into the enterprise and verification of the PSS.

5. Practical use of the conceptual framework of the Product-Service System design method

5.1. Methodology in the design and analysis of PSS system element

In the further part of the paper, practical example of designing PSS element is discussed. Attention is paid to the selected process, i.e., order picking and commissioning in the system. This process aim is to compile the final order in accordance with the customer's requirements. The choice is justification and the and the specification of this process is described in chapter 5.2. It was decided to focus on one selected process from a specific industry to avoid overgeneralization, which would lead to a reduction in the applicability of the model (by its excessive generalization or expansion).

Further study focused on two selected stages of designing PSS, i.e., design at the system-level and detailed design (Figure 7), the considerations led to the creation of the mathematical model presented in chapter 5.3. Next chapter (5.4.) describes and presents the adaptation of the mathematical model in a computer simulation environment. A properly designed computer model significantly increases the possibilities of analysis and simulation while reducing time and costs. FlexSim software was used to build a computer model.

At this point, it is worth noting that the presented simulation model is not a case study relating to the selected existing logistics system. The intention of the authors is not to find an optimal solution for the system, e.g., a selected company, but to present a general template that can be easily modified and adapted to the needs of the future. The simulation model has a simple and clear structure to minimize

the impact of the structure of the constructed system itself on the results and the possibility of focusing on the system parameters and analyzed variants. The selected ranges of parameters were also not taken from the actual system. In the model, the key factors for the process and their impact on its implementation were analyzed in an exemplary manner.
It should be taken into account that in reality picking systems in the warehouse facilities can be much more complex and use specific technologies (e.g. pick by light) with different work patterns (product to person or person to product and others). The presented system is a kind of representation of the picking process and its detailing and adding details will result from the application to a given case, e.g. in the case of conducting a case study for an analogous process.

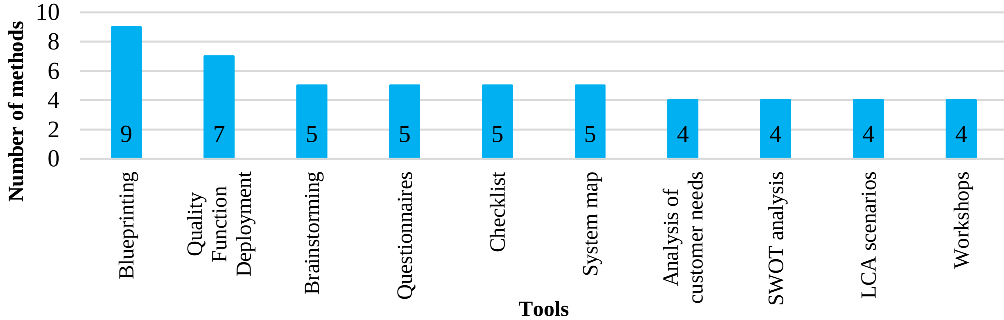

Figure 6. Methods of PSS design - supporting tools

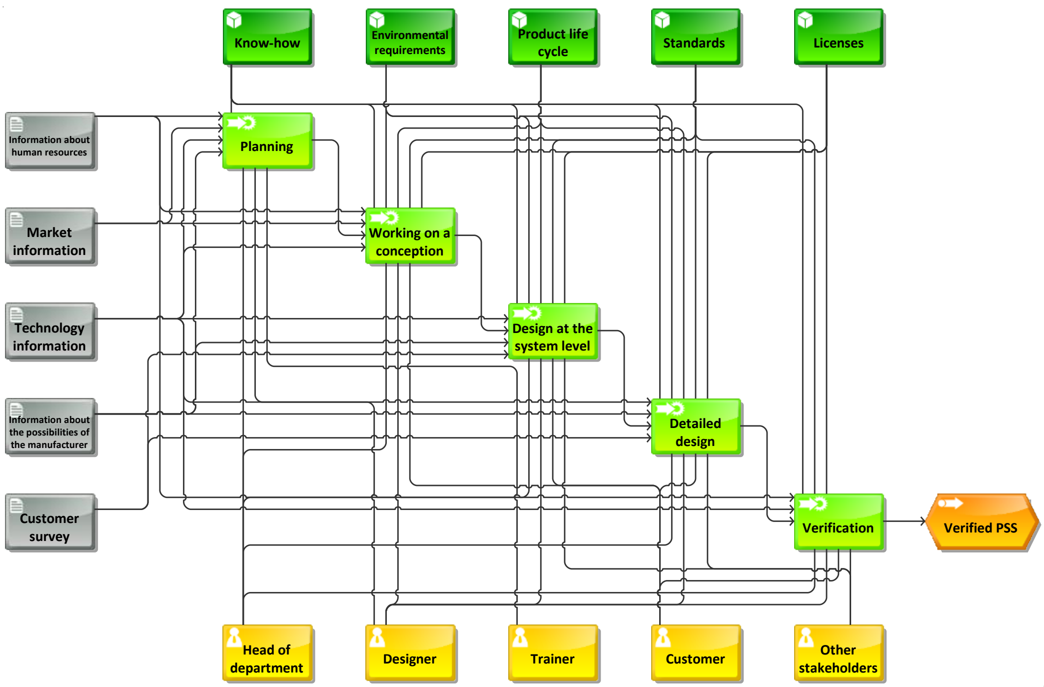

Fig. 7. Conceptual framework of the Product-Service System design method

As it is described above, the research and analysis were based on two main methods: mathematical modelling and computer modelling. Both models are to help in finding the optimal value of the system operation parameters under the adopted conditions and constraints. The mathematical model is more theoretical. However, having the appropriate data set for the selected system, using the solver, it is possible to find an answer to the question what variant of the system operation will be optimal (or at least more favorable than other considered for the parameter ranges).

The key parameters for the system are the scope of services provided. It implies both costs and profits. Depending on the number of services provided, the duration of the task will vary and generate labor consumption. The number of required means of work or the number of orders completed within a given shift time depends on the labor intensity.

When analyzing the simulation model, it can be seen that it was based on the same assumptions. The same parameters remain key. The difference is, however, that the scope of services is not specified. This element has been reduced to the time of carrying out additional tasks in subsequent variants (gradual increase of time) and no further types of activities have been assigned. In real conditions, it would be necessary to use a matrix from a mathematical model that determines which processes can be combined with each other for a given product. In the case of the FlexSim model, a total of 15 different datasets for the commissioning process has been used. For each dataset simulation has been carried out and results has been analyzed. In the case of consideration based on the described assumptions, it is also worth noting that the course of the process will be conditioned by variables and not by the changing structure of the system. Details of the decision variables, parameters, and the limitations and factors involved are presented in chapter 5.4.

5.2. Design and analysis of PSS system chosen element

Designing and implementing PSS is a complex task. Especially the theoretical development can be very complicated due to the data uncertainty, the demand for a lot of data etc. It also requires the participation of many parties (decision makers, customers, designers, experts) and the appropriate knowledge (knowhow, knowledge of the industry, standards, market analysis). There are five main steps in system design: planning, concept development, system level design, detailed planning, and verification. The attention in the next section is focused on phase three (design at the system-level) and phase four (detailed planning). To present the issue and difficulties related to system design, the example of planning the picking and commissioning process can be used. The picking process was selected for the purposes of the study as one of the most important among the supply chains that cocreate and combine various elements of PSS. The picking process consists of many subprocesses aimed at the final preparation of the customer's order with POR. This process includes inter alia creating a picking list, picking assortment items from warehouse inventory, securing, and packing, order customization, value added services.

At this stage, numerous VAS services (e.g., enabling the tracking of the package, shipping method, packaging method through appropriate labelling, determining the time of order fulfilment, after care) or customization of the order in accordance with the customer's requirements (non-standard item configurations, selection of materials, selection of colors and other features) are being realized.

Based on the knowledge of the above-described process, a model of the completion process was developed. Analyzed process plays an important role in supply chains. In PSS most often picking and commissioning is carried out in warehouses. Examples of the operations carried out on the customer's order, and their placement in the process is presented in the Figure 9. A simplified diagram of the supply chain with the marked place of the completion process execution is presented in Figure 9. The figure also presents the directions of flows and their types (materials and information)..

At the design of the system stage, reference should be made to the structure of the designed product and service system. Its components, their features, functions and requirements set by the collected design data should be distinguished. These elements may differ significantly from each other depending on the designed system and the industry. Mathematical model presented in chapter 5.3. is intended to be a universal aid that considers elements and factors such as the number of services offered, possible modifications of the product;, connections between individual services and modifications (possibility of combining), order fulfilment time depending on added services and modifications, the costs and prices of operations and products.

5.3. Mathematical model

The model aim is to enable finding the optimal solution for maximizing the profit of an enterprise providing services and offering goods on the market, while maintaining appropriate restrictions. The limitations will result from both the physical characteristics of the products (the possibility of modification, etc.) and the specificity of service provision (time and cost). The result of optimization should be an answer on how many and what services to offer to guarantee the customer the maximum range of services and to meet all the limitations while maximizing profits. It is worth considering that the service product systems are focusing on the customer satisfaction largely.

A function that can be interpreted as a base of the mathematical model leads to profit maximization in order fulfilment with available additional services implemented at the stage of storage and transport:

$$F(\boldsymbol{X}) = \sum_{i\in \boldsymbol{I}}\sum_{j\in \boldsymbol{J}} ((z_{ij} - c_{ij}) + (Z_0 - C_0))x_{ij} \rightarrow max \quad (1)$$

where:

$\boldsymbol{I} = \{1, \dots, i, \dots, I\}$ – a set of services available in the system,

$\boldsymbol{J} = \{1, \dots, j, \dots, J\}$ – a collection of assortment items in the warehouse,

$\boldsymbol{C} = [c_{ij}]$ – costs of adding the i-th service to the j-th assortment position,

$\boldsymbol{Z} = [z_{ij}]$ – profit resulting from adding the i-th service to the j-th assortment position,

$\boldsymbol{T} = [t_{ij}]$ – time of adding the i-th service to the j-th assortment position,

T_0 – base time of order fulfilment,

C_0 – base cost of the contract,

Z_0 – order performance base profit,

T_{max} – maximum time foreseen for the execution of the order,

$\boldsymbol{Z} = [z_{j1\,j2}]$ – matrix of mutually exclusive added services, where:

$$z_{ij} = \begin{cases} 1, \text{if service } j1 \text{ can be combined with } j2 \\ 0, \text{if service } j1 \text{ cannot be combined with } j2 \end{cases} \quad (2)$$

$\boldsymbol{X} = [x_{ij}]$ – possibility to add the i-th service to the j- th assortment position, where:

$$x_{ij} = \begin{cases} 1, \text{if the service can be added} \\ 0, \text{if the service cannot be added} \end{cases} \quad (3)$$

The considered function must meet the presented limitations related to the specification of the analyzed process:

a) the various services provided may be used for a given product if they are not mutually exclusive in terms of their feasibility i.e., for a given case of combining services $z_{j1\,j2} \neq 0$.

b) the function $F(\boldsymbol{X})$ value shall be greater than zero:

$$\forall i \in \boldsymbol{I} \;\; \forall j \in \boldsymbol{J} \quad F(\boldsymbol{X}) > 0 \quad (5)$$

c) the maximum order processing time cannot be exceeded:

$$\forall i \in \boldsymbol{I} \;\; \forall j \in \boldsymbol{J} \quad \sum_{i\in \boldsymbol{I}}\sum_{j\in \boldsymbol{J}} (T_0 + t_{ij})x_{ij} \leq T_{max} \quad (6)$$

d) variable x_{ij} must be a binary value:

$$\forall i \in \boldsymbol{I} \;\; \forall j \in \boldsymbol{J} \quad x_{ij} = \{0,1\} \quad (7)$$

e) elements of the matrix $\boldsymbol{Z} = [z_{j1\,j2}]$ must be a binary value:

$$\forall j \in \boldsymbol{J} \quad z_{j1\,j2} = \{0,1\} \quad (8)$$

As already mentioned, the model was developed with an emphasis on its versatility. It can be used in many industries and depending on the case, the variables and the ranges of data values under consideration may differ significantly.

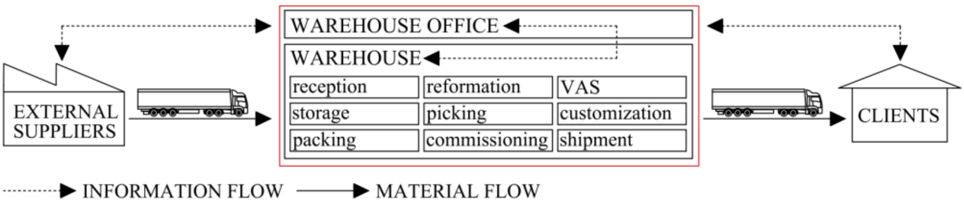

Fig. 8. Supply chain and types of services performed on goods

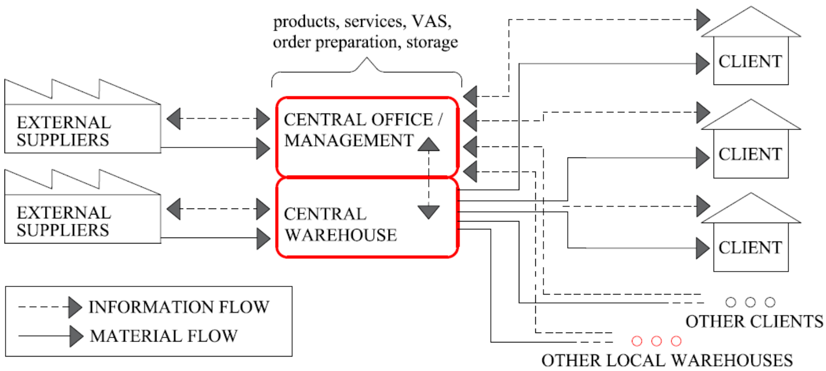

Fig. 9. Diagram of the supply chain and place of the picking process execution

5.4. Virtual simulation in the FlexSim

The simulation model made in the virtual environment of FlexSim is presented below. It is directly related to the mathematical model presented in chapter 5.3. Its translation into the simulation environment of the FlexSim software has been made to develop possibilities of the analysis of the process.

FlexSim has been chosen as one of the most popular and versatile simulation software. Wide range of the built-in objects allows to carry out simulations of almost every industry process. In case of logistic industry components corresponds to real processing stations (e.g., packaging, preparation for shipment, labelling) or physical areas of the logistics facilities (storage, order picking, input and output buffers). FlexSim software offers numerous possibilities for the simulation, including possibility of selection of the order execution time based on mathematical distributions etc. It also includes programming module and process flow function which allows to manage the processes even without creating physical connections between objects in the model. Many studies concerning similar problems, such as (Nehring et al., 2021) or (Szczepański et al., 2021), used FlexSim models to analyze possible scenarios of the analyzed system component. The research focuses on problems related to the operation of a logistics facility such as an intermodal terminal (loading of an intermodal train or facility layout). In fact, however, the methodology of considering the problem presented in them is similar to the model presenting the picking and commissioning process below.

Aim of the presented below model is to study how does the designed element of the system influences its functionality and to verify what are the consequences of incorrectly planned system. A design error may be the selection of the wrong number of means of work for the implementation of tasks (e.g., creating too few workstations), the selection of inappropriate devices for the tasks or incorrect design of information and material flows (disrupting their flow). It also has much more built-in logical functions The dependences described in mathematical model are presented on the example of the picking and commissioning process. An arrangement of elements simulating chosen process is presented in Figure 10. The description of elements is included in Table 1. Figure 11 presents the same arrangement of elements during system functioning. On Figure 11 system working and items flow between the stations is visible.

As it can be seen, presented system is designed in order to simulate picking and customization process on the items from the warehouse. To explain the whole process better references to Figure 10 and Table 1 are made in the following description.

Before the picking process start items are stored in the warehouse (1). The warehouse is based on storage places (simulated by queues with maximum capacity of 100 items). Cubes representing different products are stored in each place. Different colors are used to distinguish item type (there are 10 types of items). Materials of one type are stored in only one place (item and queue number are the same). The size of the loads has been selected so that they can easily create a pallet load unit with a given structure (box size: 0,25x0,25x0,25m). Products are placed on a standard EUR1 pallet (1,2x0,8m).

The picking process itself takes place at a stand equipped with a combiner (2). Structure of the picking orders consist of 10 different products. On average, 7 items of each type of each item type are collected. This means that the average structure of a picking order is 10 lines x 7 assortment item (10x7). This is an example of an average pick order considered in the system. Average picking time for the system is 10 minutes. After completing the picking of loads, the unit is transferred to the queue (3) and to the key element of the system i.e., processing stations (4). The handling time of units vary depending on the model variant. In each considered variant, processing time has been extended to imitate a greater number of operations and items customization processes at the customer's request. Four processors are intentionally placed in the system in order to study workload. The processors work according to the dependency 'send to first available'. It means that second processor will be used only if the first one will be occupied. Third will be used only if the previous two are processing and so on. Such a system and FlexSim analysis tools (e.g., dashboards) allow to verify the workload of the system elements and the required number means of work for operation. Therefore, this element of the system (4) can be considered as crucial for process implementation. Queue (3) placed before the processors allows to verify how many units are waiting for the processing if all the processors will be occupied. Storage and picking process is also presented on Figure 11.

Then the loads are transferred to the control stations, also simulated by processors (6). Control time is set for 5 minutes. For similar reasons as before, not one but two workstations and a queue (5) in front of them are set up at this stage. The entire system ends with stand number consisting of a single queue (7). Loads ready for shipment that have passed all the previous stages are placed on it. It shows the number of tasks performed by the system within a given working time (standard working shift time was initially adopted i.e., 8h). Next to the described elements, there are roller conveyors placed in the system to reflect the time of cargo transport between stations. 0.6 m/s was assumed as the conveyor transporting speed. Safety distances between the loads transported on the conveyors are also considered (min. safety distance 0,3m). The system also takes into account the fact that the first 10 minutes of a work shift are spent on system startup, not the task itself. Queues (3) (5) (7) do not have limited capacity.

Figure 12 focuses on the most important element of the process which will define the differences between the model variants i.e., processing station where the additional services are carried out and unit customization is don (4). Most parameters and logic of working are the same for every considered variant. However, for each variant other processing time on workstation (4) is considered. 10 variants were created for the research (V1, V2, V3…, V10). Each variant has an increased processing time. First variant processing time is 5 minutes. Every next variant adds extra 5 minutes to the process. It means that the longest processing time (variant V10) is 50minutes. The other parameters, such as control or picking time, remain unchanged.

First part of the results, analyzing processors work is presented in the Table 2. Results concerning control process and final system efficiency are included in the Table 3. Results presented in the Tables 2 and 3 were taken from the graphs analyzing the work of the FlexSim system elements (Figure 13). The results contained in the tables are averaged variants of 10 measurements made for each variant. As it can be seen in Figure 13 following parameters has been analysed:

- number of tasks performed by selected stations (number of prepared loads);
- workload of each processor (processing and control station) along with an analysis of the time occupied by a given type of task (two processor states were observed: idle and processing);
- queue final content (number of units prepared during 8h work shift);
- number of items remaining at the queues before processors (occurs in the event of system insufficiency. Loads are waiting for a service).

Figure 13 shows the example results for variant V6 after an 8-hour shift. In the upper left part of the figure, data on the completed orders are presented. These data are distinguished for each picking station and control stations. The content of the final queue determines how many orders have been completed during the shift. In the lower part of the figure, the average queue content is analyzed. This parameter allows identification of queues in the system. The right side of the drawing shows the extent to which the processing capacities of the processors and control stations are used. Basing the analysis on this data allows to determine the system performance (the number of completed and processed orders) and the load (queues and the use of device performance). An analogous analysis was performed for all other variants.

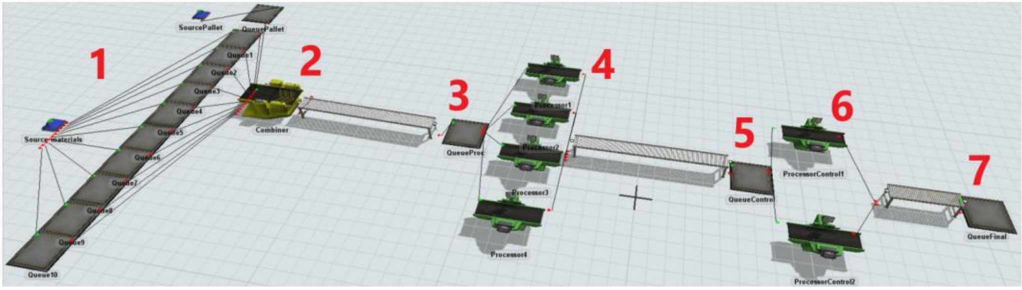

Fig. 10. Simulation model of the commissioning process in FlexSim software

Table 1. Description of the elements of the model presented in Figure 10

No	Elements	Function
1	Source of materials (item types: 1-10) Source of pallets Queues for materials (item types: 1-10)	An element that generates defined 10 types of items at the entrance to the system in accordance with a given distribution. Items are queued and waiting to be picked up for the next stage of the process. Separate source and queue is predicted for pallets.
2	Combiner	Picking items on a pallet in accordance with the picking list.
3	Queue (before unit processing)	Storage of load unit before the implementation of additional processing after picking (commissioning and order customization).
4	Processing	Implementation of additional service processes (creating added value, customization services). Time and workload depend on the studied variant.
5	Queue (before unit control)	Storage of load unit before the control (unit after picking and customization).
6	Control of units	Control process before the shipment prosses
7	Queue (with units before shipment)	Unit prepared for the shipment and waiting for the shipment process. Allows for easy verification how many units has been prepared during the processes.

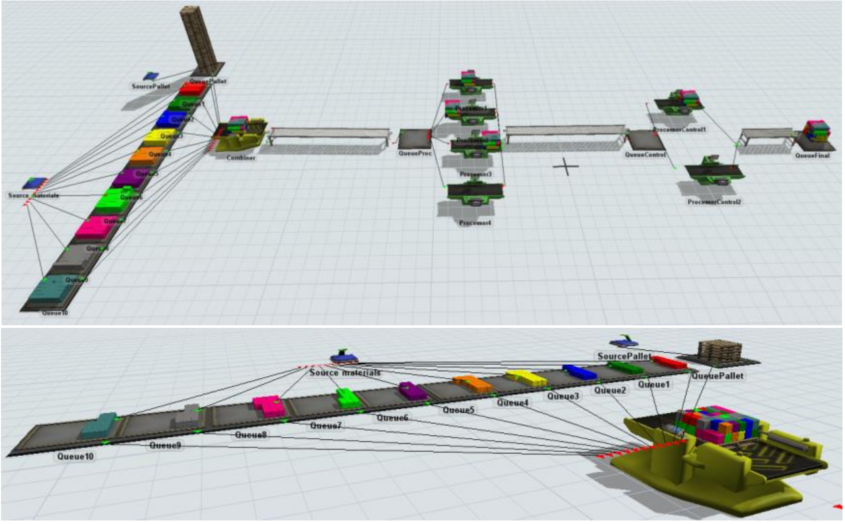

Fig. 11. Working of the process simulation model in FlexSim- the entire picking and commissioning system

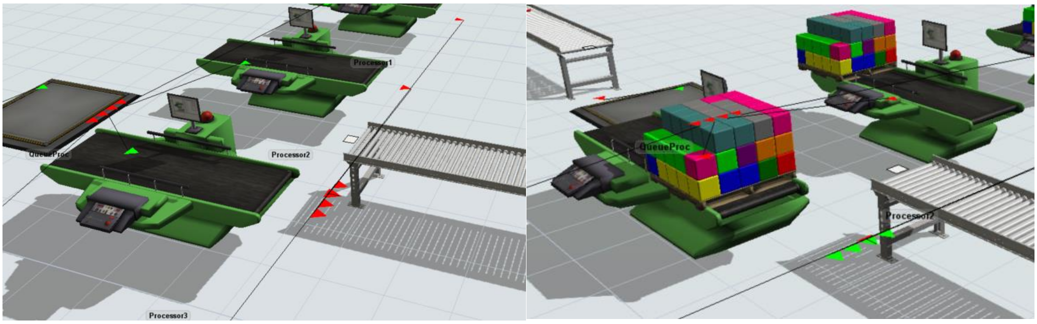

Fig. 12. Items processing stations - implementation of additional processes

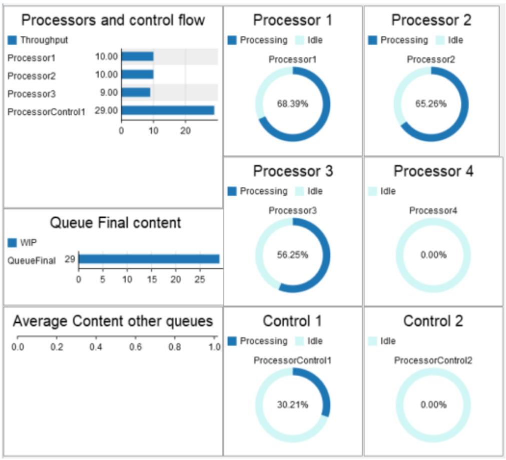

Fig. 13. An example of a set of graphs for the operation of the system (e.g., variant no. 6) (after 8h work shift).

Table 4 contains an example of a calculation for labor costs and the resulting profits for each design variant. It was assumed that one employee per shift (8h) is needed to service each workstation. The cost of an hour of work of one person is PLN 25. After increasing it by the company costs (50%), this value is PLN 37,50. It was assumed that the profit from processing one standard order is PLN 50. For each subsequent variant, due to the added value generated by services, the profit increases by 15%. This is an example of a calculation adopted for the purposes of the study. It aims to increase the scope of the analysis of the problem under consideration and to take into account financial aspects next to the number of labor resources involved and their efficiency. Table 5 shows the number of handled load units at given workstations (4) (6) and the content of the final queue (7) reflecting the total number of loads prepared for shipment. In variants V1 - V10, no units had to wait before processing or control so the information on queues (3) (5) was not included in the tables. Figure 14 presents the dependencies between the labor costs, income and financial balance.
Variants V1 - V10 allowed for the involvement of three workstations (processors (4)). To analyze the operation of the system in the case of higher workloads and to determine the performance limit, it was decided to analyze an additional five variants with processing times of 60, 70, 80, 90 and 100 minutes. They were given variant numbers respectively V11, V12, V13, V14 and V15. Tables 6-9 show the same results for variants V11-V15 as before for the variants with processing times from 5 to 50 minutes.
Figure 15 presents the dependencies between the labor costs, income and financial balance for variants V11-V15. Figure 16 presents the same cost/ income dependency, but collectively for variants V1 to V15, i.e., processing times varying from 5 to 100 minutes. This time information about queues (3) (5) is included. The simulation shows the relationship between the labor consumption of the process, resulting from the type of tasks performed in the system and the number of required means of work. We can see how this dependency shapes the involvement of individual elements of the system and its efficiency. Further discussion of the results is included in the next chapter.

Table 3. Results obtained after 8h simulation for each variant: control stations and queue before control stations, units prepared for the shipment (V1-V10)

Variant no.	Workload [%]		Units ready for shipment (final queue)
	Control station 1	Control station 2	
1	23,96	-	23
2	23,96	-	23
3	23,45	-	22
4	22,92	-	22
5	22,92	-	22
6	22,92	-	22
7	22,41	-	21
8	21,88	-	21
9	21,88	-	21
10	21,78	-	21

Table 4. Labor costs and income resulting from the execution of orders for variants (8h workshift) (V1-V10)

Var. no.	Number of working processors			Total cost of work (PLN)	Number of completed orders	Profit from one order (PLN)	Income (PLN)	Financial balance (PLN)
	Picking	Processing	Control					
1	1	1	1	900,00	23	50,00	1150,00	250,00
2	1	1	1	900,00	23	57,50	1322,50	422,50
3	1	1	1	900,00	22	66,13	1454,75	554,75
4	1	2	1	1200,00	22	76,04	1672,96	472,96
5	1	2	1	1200,00	22	87,45	1923,91	723,91
6	1	2	1	1200,00	22	100,57	2212,49	1012,49
7	1	2	1	1200,00	21	115,65	2428,71	1228,71
8	1	3	1	1500,00	21	133,00	2793,02	1293,02
9	1	3	1	1500,00	21	152,95	3211,97	1711,97
10	1	3	1	1500,00	21	175,89	3693,77	2193,77

Table 5. Number of proceeded tasks during the workshift (8h) on chosen workstations (V1-V10)

Var. no.	Number of completed orders					
	Processor 1	Processor 2	Processor 3	Processor 4	Control station 1	Control station 2
1	23	-	-	-	23	-
2	23	-	-	-	23	-
3	23	-	-	-	22	-
4	12	10	-	-	22	-
5	11	11	-	-	22	-
6	11	11	-	-	22	-
7	11	11	-	-	21	-
8	8	7	6	-	21	-
9	7	7	7	-	21	-
10	7	7	7	-	21	-

Table 6. Results obtained after 8h simulation for variants: processors and queue before processors (V11-V15)

Var. no.	Processing time [minutes]	Workload [%]				Queue before processors
		Processor 1	Processor 2	Processor 3	Processor 4	
1	60	74,53	70,36	66,19	62,50	-
2	70	84,94	80,78	76,61	72,92	-
3	80	95,36	91,19	87,03	82,86	-
4	90	95,36	91,19	87,03	82,86	2
5	100	95,36	91,19	87,03	82,86	4

Table 7. Results obtained after 8h simulation for variants: control stations and queue before control stations, units prepared for the shipment (V11-V15)

Var. no.	Workload [%]		Queue before control station	Units ready for shipment (final queue)
	Control station 1	Control station 2		
11	20,83	-	-	20
12	20,83	-	-	20
13	19,79	-	-	19
14	17,71	-	-	17
15	15,63	-	-	15

Table 8. Labor costs and income from the execution of orders for variants (8h work shift) (V11-V15)

Var. no.	Number of working processors			Total cost of work (PLN)	Number of completed orders	Profit from one order (PLN)	Income (PLN)	Financial balance (PLN)
	Picking	Processing	Control					
11	1	4	1	1800,00	20	228,66	4573,24	2773,24
12	1	4	1	1800,00	20	297,26	5945,21	4145,21
13	1	4	1	1800,00	19	386,44	7342,34	5542,34
14	1	4	1	1800,00	17	502,37	8540,30	6740,30
15	1	4	1	1800,00	15	653,08	9796,22	7996,22

Table 9. Number of proceeded tasks (prepared units) during the work shift (V11-V15)

Variant no.	Number of completed orders					
	Processor 1	Processor 2	Processor 3	Processor 4	Control station 1	Control station 2
11	5	5	5	5	20	-
12	5	5	5	5	20	-
13	5	5	5	4	19	-
14	5	4	4	4	17	-
15	4	4	4	3	15	-

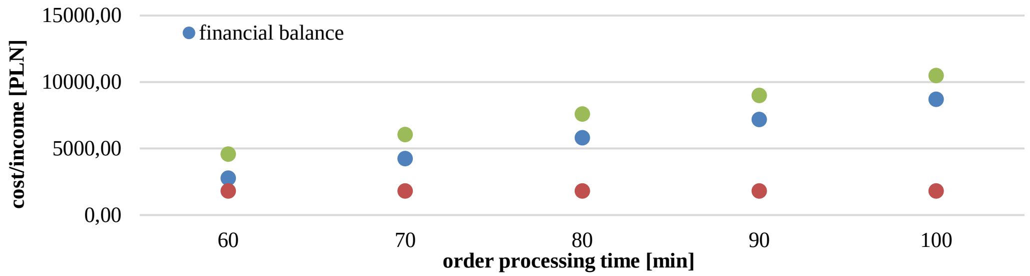

Fig. 15. Relationship between labor costs, income and financial balance (V11-V15)

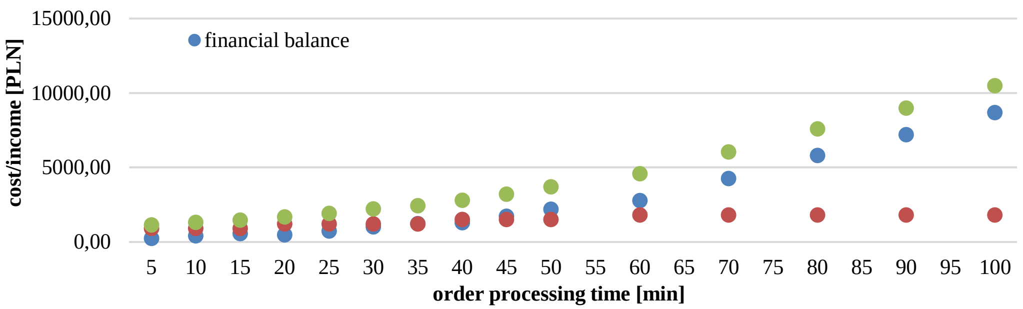

Fig. 16. Relationship between labor costs, income and financial balance (V1-V15)

5.5. Model discussion

The simulation model presented in the chapter 5.4. is an example of a picking and commissioning process built on given flow principles and sample data as close to the real ones as possible. Of course, as in every model, minor simplifications have been introduced. The key to building a simulation model is the correct representation of the given case under analysis. For each considered system factors such as stages of the process, selected devices (means of transport: forklifts, conveyors…), workers, workstations (separators, combiners, processors), storage elements (racks, floor storages) should be considered. Also reflecting the real dimensions of the system is important. The system parameters related to costs, equipment efficiency, etc. should also be carefully examined and selected. Huge advantage of the virtual simulation is costless and easy modification of system parameters. Number of the sources, types of goods, and other elements can be easily modified. It is one of the biggest benefits of simulation conducting- no real resources are involved to verify system functionality. Practically every process and system can be mapped by selecting the appropriate simulation environment.

However, referring to the developed system and its functioning. It is stated that the designed system performs its functions and has been developed correctly. As expected, along with the change in the parameters of the operations, changes in the intensity of the workload, the workload of individual elements and the involvement of an appropriate number of processors were observed.

For the first variant V1, only one processing station was involved in the work with the commitment of 23.96%. The second processor was engaged after changing processing time to 20 minutes (variant V4) and the third processor after setting processing time to 40 minutes. For all base variants (V1-V10) system turned out to be efficient and the workload did not exceed the performance standards of the processors. The key factor is to notice how much impact on the profits, the number of orders processed, and the overall operation of the entire system have its parameters, which must be correctly selected and taken into account for each considered system.

It is worth noting that if there was only one processing station in the system, its efficiency would not be sufficient already with the processing time of 20 minutes (V4). Further research showed that with the involvement of only one processor, system performance and operating profit would start to decline. This data is presented in Table 10. Table 10 shows that the number of orders processed is starting to decline. It has been checked and with a processing time of 100 minutes, the system with one processor will be able to handle only 4 orders a day.

The profit function is not linear and profit no longer grows as with the involvement of more pro-cessors. Theoretically, with the current assumptions, the profit continues to grow slowly despite the decline in the number of completed orders. However, it should be remembered that with each subsequent variant, the number of loads waiting in the queue for processing increases. They will have to be handled the next day or after the predicted work shift time. Thus, significant work delays are created in the system, which can lead to financial losses. At the same time, it can be seen how the capacity utilization of Control Station 1 is decreasing.

Table 10. Simulation for one workstation for the processing time in the range of 20-50 minutes

Var. no.	Processing time [min.]	Workload [%]		Number of completed orders [units]				Income (PLN)	Financial balance (PLN)
		Processor 1	Control station 1	Processor 1	Control station 1	Queue before processors	Units ready for shipment (final queue)		
4	20	95,36	22,92	22	22	0	22	1672,96	772,96
5	25	95,36	18,75	18	18	4	18	1574,11	674,11
6	30	95,36	15,63	15	15	7	15	1508,52	608,52
7	35	95,36	13,03	13	12	9	12	1387,84	487,84
8	40	95,36	11,46	11	11	11	11	1463,01	563,01
9	45	95,36	10,42	10	10	12	10	1529,51	629,51
10	50	95,36	9,37	9	9	13	9	1583,04	683,04

In order to deepen the model from chapter 5.4. analysis and find the tipping point (where the system would be overloaded), an additional five variants were created covering processing times from 60 to 100 minutes. It can be observed that with the processing time of 90 minutes, even four involved processors ceased to be sufficient and queues of loads waiting for the process in front of the stations began to form. The highest observed processor load that has been observed is 95.36%. This is a value that indicates that the processor is overloaded. After considering the factors influencing the available in real-life time of the work shift, it can be assumed that the system would lose its functionality with such a workload.
Importantly, despite the increase in labor intensity and a decrease in the efficiency of the system, the profits resulting from its operation grew. This is due to the increase in the value of one order. However, it is possible that after a certain point income would start to decline sharply due to the reduction in the number of orders processed. It is also worth noting that the longer the processing time became, the more and more loads remained in the system as unfinished orders. The greater the processing time, the greater the probability that the load will be stopped at the end of a shift while executing a subprocess in the system. The first load that did not reach the final queue at the end of the working day already appeared in the V3 variant. In the V7 variant, a situation was observed where there were already two loads left in the system during the execution of subprocesses. This means that their processing would not be completed until the next work shift. An important observation is also that under the assumptions of the system's operation, the profits did not grow linearly. It was caused, among others, by engaging additional workstations and the resulting increase in labor costs. Only after reaching the maximum labor costs did the profit begin to grow in an approximate linear manner. Interestingly, regardless of the number of orders processed, the control process was carried out only by one control station. Its workload even decreased with the involvement of additional processing stations at the preceding commissioning subprocess (from 23.96% for the V1 variant to 15.63% for the V15). This is due to the longer duration of tasks at the previous stages of the process. No queues were formed in front of the control stations. This subsystem has proved to be reliable for each variant. The problem with its efficiency would probably arise only after extending the time of the control process itself. A strong dependence and mutual influence of the various stages of the process has been proven during simulation.

6. Conclusions

Literature analysis shows great interest in PSS design. The design methods developed so far are characterized by a low level of detail, which means that the needs of scientists and business practitioners are not fully satisfied in this area. The methods contain a number of imperfections and gaps, which include the lack of financial assessment, assigning tasks to specific employees of the company, market analysis, precise assessment of the client's needs, assessment of the company's condition and the scope of changes that need to be introduced in it when PSS design.
The concept of the method developed in the paper aims to fill in the imperfections and gaps of the already analyzed methods. It has been enhanced with stages that have not been included so far. The aim of further work is to improve the presented method of PSS design with issues important both from the academic and industrial point of view. Additionally, its practical verification in an industrial environment is planned.
The second part of the paper focused on the practical aspect of designing PSS, especially designing at the system level. Reference was made mainly to the logistics industry and the constructed models presented the order picking and commissioning process. It is one of the most time-consuming and cost-intensive processes carried out at any level of PSS based on supply chains. Thanks to this process, it is possible to adapt products and services to customer requirements. Presented mathematical model is aimed at optimizing the number of offered services and modifications to the goods ordered by customers, while considering factors such as the possibility of combining services or the product selected modifications and VAS (value added services). Thanks to the correct analysis, it is possible to achieve the perfect order rate. Such a model, with the input data for the selected case, can be extremely helpful.
The simulation model based on the mathematical model, made in the environment of the FlexSim software, further increases the possibility of analysing the process implementation while visualizing it. Numerous built-in analytical tools and functions

(charts, distribution time distributions, the possibility of modifying picking lists and others) mean that the model can be easily adapted to the analysed case and modified in order to improve the implementation of the process. The model allowed to analyze an example of a picking system. Based on variants with different values of selected parameters, its operation was carefully analyzed. A set of results was obtained, showing the number of resources required for the work, received profits or the number of orders completed. All forming queues, load on individual elements or arising errors are visible. The possibility of modelling and simulation can be used in various PSS system while its designing and optimization.

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