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Operational Concept of an Innovative Management Framework for Choosing the Optimal Packaging System for Supply Chains

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Abstract: In relation to the logistics processes created and operated by companies, the choice of the optimal packaging system is a rightful social and industrial expectation. Choosing the right packaging system can reduce the environmental impact and make logistics processes more efficient. These aspects are key factors for the competitiveness of companies. It can be concluded that in practice, the selection of a right packaging system in a company is mostly based on experience. In the literature, the choice of such a system is based on the analysis of the processes of a single company, i.e., no method has been developed to integrate the processes of several companies to optimize the choice of a packaging system. Consequently, several losses can occur, both at the system boundaries and within the company processes, for example, losses from unnecessary material handling, operations, product damage, etc. The aim of this paper is to present the concept of an innovative packaging management framework that can be used to select the optimal unit load handling equipment based on the company's needs defined by simulation-based optimization. The application of the concept is also presented through a case study. It is demonstrated that the application of the developed concept can be a significant step towards the realization of sustainable supply chains through more efficient process design.

Keywords: decision support method; supply chain; packaging system; simulation

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Citation: Matyi, H.; Tamás, P. Operational Concept of an Innovative Management Framework for Choosing the Optimal Packaging System for Supply Chains. *Sustainability* **2023**, *15*, 3432. https://doi.org/10.3390/su15043432

Academic Editor: Ting Chi

Received: 23 November 2022
Revised: 8 February 2023
Accepted: 9 February 2023
Published: 13 February 2023

1. Introduction

Logistics is going through major changes nowadays. The task of logistics is to ensure the availability of the product necessary for the proper functioning of business processes at the right place and time in the right quantity, quality and selection. The supply chain is part of the logistics support network and includes the concepts, rules and processes making the flow of material assets from the point of the initial economic resource to the user, and vice versa [1]. Modern logistics has become an important industrial branch for economic development. Traditional packaging design has struggled to keep up with current business developments. Packaging is the starting point of logistics, and an important precondition for this is the optimum selection of the right packaging materials, the design of the packaging structure and the preparation of the right packaging technology [2]. Progress towards sustainable production and overall process efficiency depends largely on the development of research and its efficient and effective implementation. Access to supporting technologies and effective, trust-based communication between managers, researchers and policy makers are key to overall process efficiency [2]. The digitalization of the economy is affecting many countries and organizations which are opening to new business models. Technologies such as artificial intelligence, big data, internet of things or blockchain are transforming the way people do business and collaborate, as well as the way goods are produced, and useful information is shared along supply chains with other stakeholders. The integration of these technologies can enhance the overall impact through a collaborative approach between the participants [3,4].

Nowadays, digital packaging design is the rational, efficient and effective design of product packaging using advanced computer technology. These digital solutions are still at an early stage [2]. The efficiency of digital packaging design can be improved by using software and the actual logistics costs can also be reduced through this way [5].

Packaging has six main functions: product storage, protection, distribution, unitization, comfort, and communication [2]. These are shown in Figure 1.

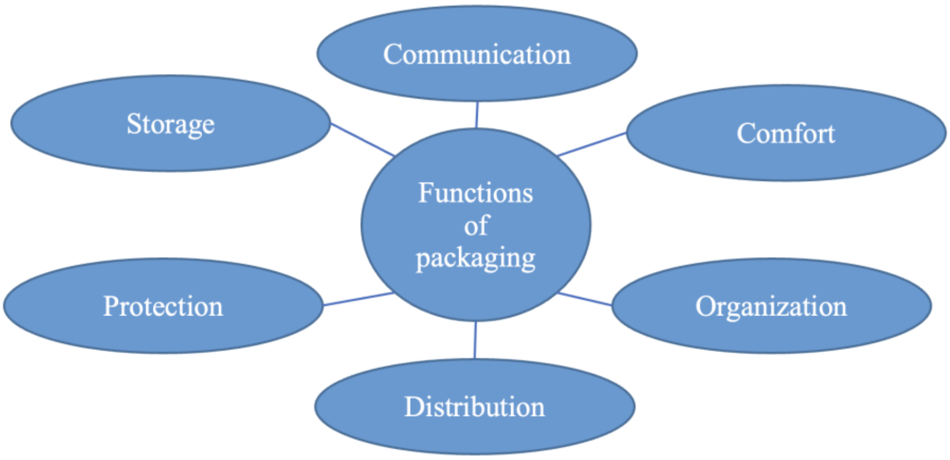


Figure 1. The main functions of packaging (Source: own edit).

There are three levels in packaging: primary, secondary and tertiary, which are important, for example, for protection (Figure 2). Primary packaging is the packaging of the product itself, followed by secondary packaging, which consists of boxes or containers containing certain amount of primary packaging. Tertiary packaging consists of pallets and large shipping containers for storage and warehousing. In addition to the main functions, packaging affects the supply chain in many ways, as it is linked to logistics, marketing and information systems, as well as manufacturing, waste management and transportation [2]. The publication [6] discusses the importance of the availability of information in the correct time in order to avoid food waste and the spread of harmful products and to achieve sustainable development goals in terms of economic, social and environmental, i.e., transport and CO_2, impacts. The necessity for the manufacturer is to load, store and handle packages, while the carrier aims to achieve efficient loading and unloading as well as volume and weight efficient packaging. Thereafter, the role of the warehouse and the store is to efficiently unpack, stack, store and load packaging, and to open, use, unload and dispose of packages easily and conveniently. In addition to its many functions and roles, packaging aims to maximize performance, minimize environmental impact, and meet ergonomic and legal requirements [7].

Figure 2. Packaging levels (Source: [8]).

Packaging has a huge role to play in extending the product life, according to research [9], which claims that innovative packaging increases the life of fresh products and the sustainability of food without compromising quality. The necessary information is provided to consumers through labelling. Articles [10–12] demonstrate the importance of good packaging, which gives consumers the information they need to make purchasing decisions through labelling. Research [13] discusses the role of packaging in environmental protection, waste and its management and reuse, which is one of the most important challenges of our time.

Packaging is the starting point of logistics [2], which can make logistics processes more efficient, so the choice of the right packaging system is a key factor. Current packaging systems are not yet digitally evaluated.

One of the goals of our study is to identify research gaps and provide opportunities for future research.

The paper is structured as follows. First, the methodology and the results of literature analysis are presented to define the research gaps. Then, the operation of the developed packaging management framework is described and its significance is verified by presenting a case study. At the end of the paper, the experiences, results and options for further development are summarized.

2. Materials and Methods

The literature analysis was done using SLR (systematic literature review) method. Systematic literature review methodology consists of operations to detect, categorize, select, and analyze relevant articles on a specific topic [14]. The analysis needs to be performed in a transparent manner that results in an overview of the research topic under study [15]. The present research work was carried out by following specific steps to achieve the objectives, which ensures the quality of the thesis and prevents the loss of scientific information [14]. The aim of the literature review is to provide a transparent scientific presentation of the subject area and minimize the risk of bias, mainly through an extensive search of published studies in English and Hungarian. SLR is scientific research itself, although it does not require a laboratory experiment, but it involves preliminary design and application of the method [16].

Steps for systematic literature analysis [14,17] (Figure 3):

Step 1. Motivation: The research was motivated by the importance of packaging in logistics, as described in the introduction, as it has a huge role in extending the life of a product, reducing environmental impact and making logistics processes more efficient.

Step 2. Identification of research questions (what research has been done within this topic area, where are the scientific gaps)

Step 3 Define keywords: keywords were defined, first focusing on a specific area. Academic papers were selected using an "AND" combination.

- Keywords: "logistics", "packaging", "digitalization"
- Combinations: First search was done without the keyword "digitalization", to find publications in the field of logistics packaging. Then the search was extended with the keyword "digitalization". The results are summarized in Figure 4.
- "logistics" AND "packaging"
- "logistics" AND "packaging" AND "digitalization"

Step 4. Literature analysis: Explore related literature in databases that support academic research. Database selection was based on easy accessibility, structured search, and the experience in literature analysis. Considering these criteria, Scopus, ScienceDirect and Google Scholar were selected. The search was limited to the years 2000–2022. The beginning of the search year was close to the end of the third industrial revolution, near the beginning of the fourth industrial revolution, until the end of last year [18]. Keywords were the same in all three databases. The search was performed by limiting the field to title, abstract and keywords only.

Step 5. Selection of relevant literature: In this step, the focus was on reducing the results, selecting relevant publications, and reading them to determine the main research direction.

Step 6. Systematic review: The literature search analysis was reduced. Those papers were selected that met the following fields: research article, review article, chapter of book and minireview. The rest were not selected, and duplication was eliminated.

Step 7. Define research gap: Major scientific breakthroughs and achievements were identified in this step. The scientific section or bottleneck was defined.

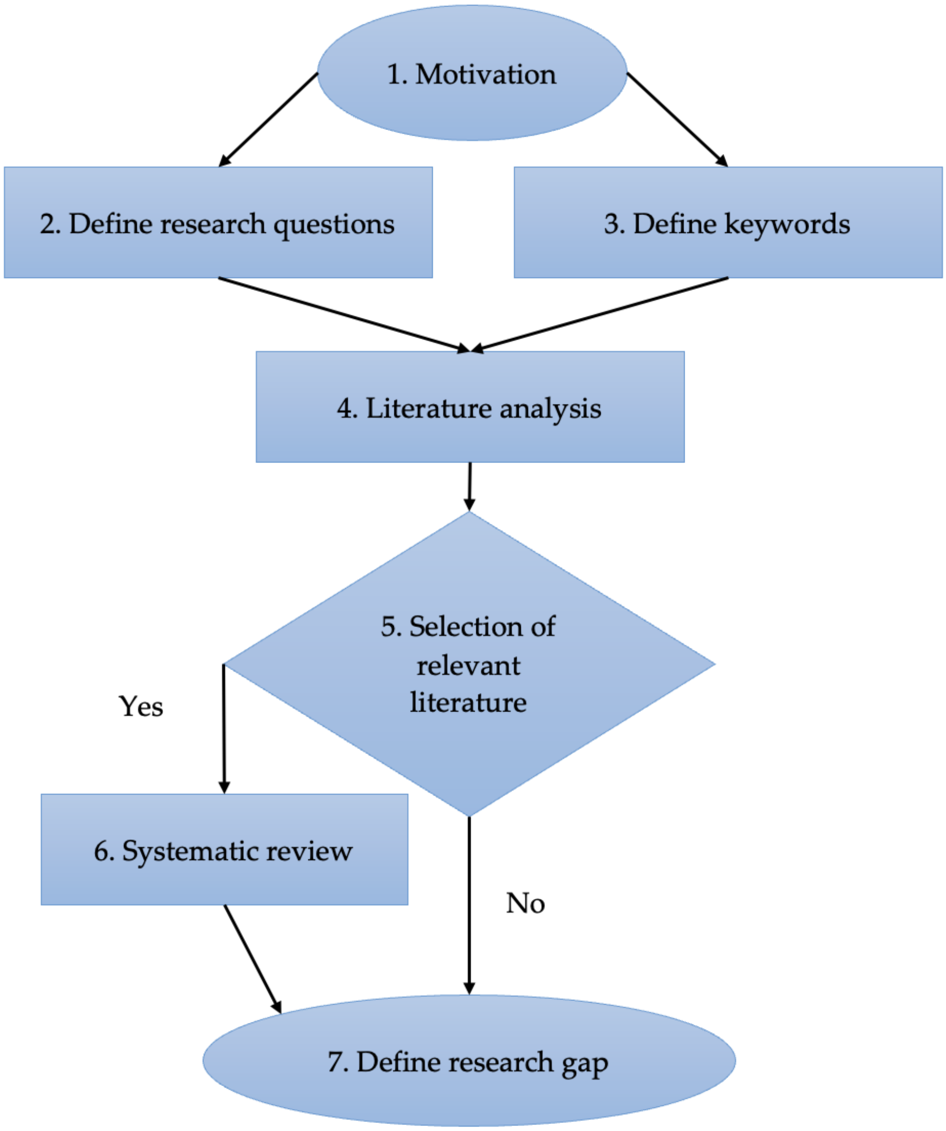


Figure 3. Graphical illustration of the steps of a systematic literature analysis. (Source: own edit).

Going through the steps, the searches were carried out. The detailed search in the google scholar database is limited, although a total 8 publications were found in Scopus and ScienceDirect database.

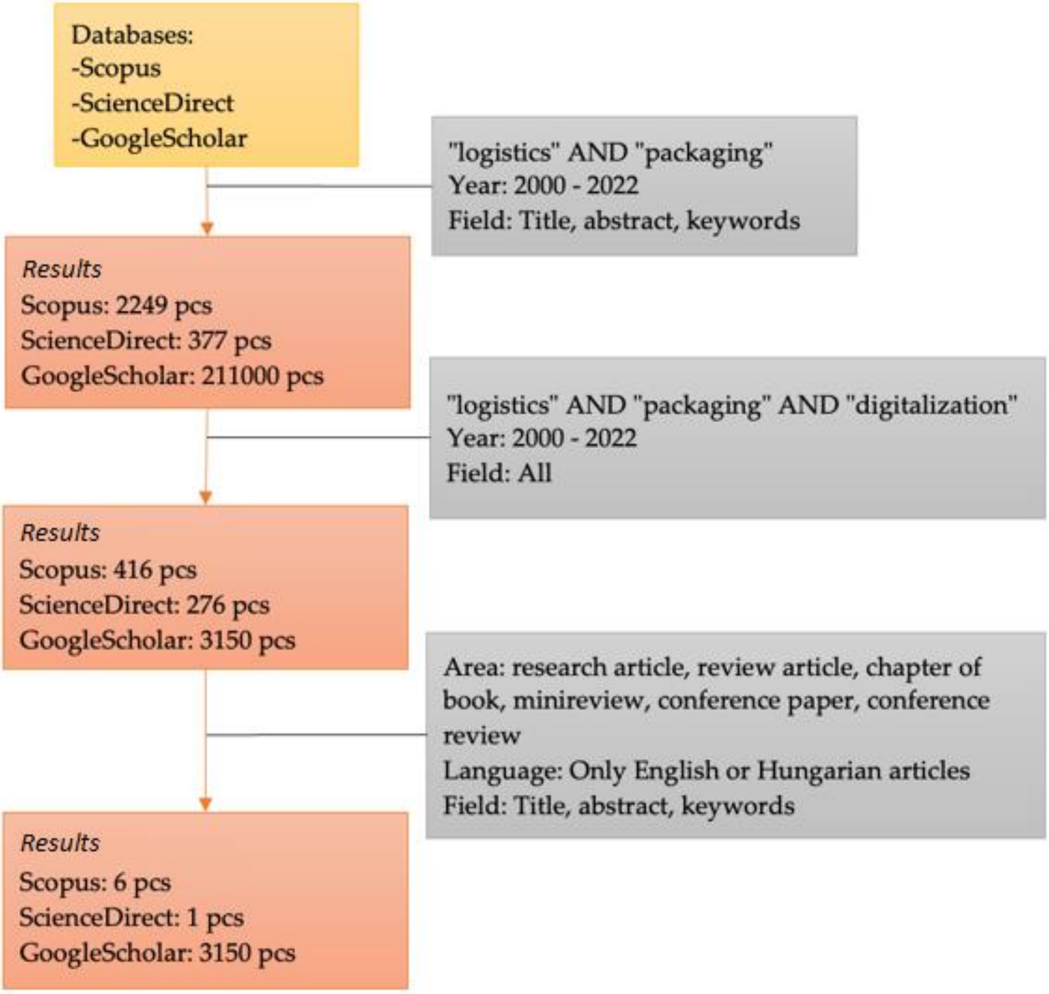


Figure 4. Systematic literature search results (Source: own edit).

3. Summary of the Literature Review

In the publication [19], a mapping method was developed to provide a systematic overview of the performance of the packaging system at different parts of the supply chain. This is called the packaging scorecard, which includes a few environmental criteria. The journal [20] focused on providing contactless smart packaging solutions. This paper suggests a data-driven decision-support system that uses smart packaging as a smart product service system to manage a sustainable food business supply chain during epidemics to prevent food waste. The model presented dynamically updates the price of packaged perishable products according to the level of freshness, while reducing food consumption waste and the number of rejected customers and maximizes profits by increasing the inventory turnover rate of grocery stores. Publications [21] describe the role of packaging systems in logistics as a requirement for making packaging and logistics decisions based on the supply chain approach. The paper describes what a packaging system should fulfill in the retail supply chain. The journal [22] presents a literature review of studies carried out over nearly 20 years, with the aim of developing a better understanding of sustainable packaging in supply chain management work. The research in [23] aims to explore how integrated approaches are being applied in packaging development processes along supply chains for ecological efficiency. This research is based on an investigative case study of food and manufacturing industries.

The aim of publication [24] is to present an integrated management model for packaging design. A model has been developed that provides a useful quantitative tool for companies to find a compromise between the reduction of logistics costs and the ability to differentiate packaging. The paper [25] uses two case studies to illustrate how a well-managed supply chain promotes reusable packaging, as well as how logistical and packaging factors influence the cost of a reusable packaging system. The journal [26] presents an application of the digital twin concept for proactive diagnosis of technological packaging systems. An important issue in the production of technological equipment, especially packaging equipment, is the modernization of production automation systems. It deals with the elimination of failures in packaging equipment, applying big data analysis methods, artificial intelligence methods and digital technologies. The article [27] was published in 2022, examines the applicability of Industry 4.0 in packaging science, including the lack of research in this area. It discusses the potential benefits of Industry 4.0 packaging in various sectors, including logistics. The paper [28] provides a solution to the shortcomings of material handling systems in cloud-based manufacturing, presenting a new material handling paradigm. The paper [29] deals with the identification and analysis of recyclable packaging in the automotive industry. Publication [30] deals with the use of sustainable materials and design for packaging goods. It analyses green packaging research from a business and consumer perspective. The aim of the paper [31] is to investigate and provide an overview of the application of green and reverse logistics in the context of sustainable development is Slovakia. Research [32] conducted a data analysis, with results describing the state of the art of sustainable management practices and digitization in wine cooperatives. Article [33] discusses digitization and its importance. It identifies the innovative digitalization technology barriers that prevent the digital rise of supply chain logistics in the pandemic. The single result in the ScienceDirect database [34] provides an overview of the area of digitalization and intelligent robotics in the circular economy. The article deals with waste management and recycling using digitalization and intelligent robotics in the circular economy. The abstract of 6 relevant publications in the Scopus database were identified. Paper [35] applies digital solutions to improve the operation of short food supply chains. By conducting this research, they suggest possible innovations and some of the identified solutions have significant digital elements. Publication [36] also deals with the food supply chain, describing the current state of the art and future trends of innovative and environmentally friendly technological solutions for post-harvest in the food chain and food industry, in terms of organic packaging, active or smart packaging. Research [37] deals with freight transport in seaports. It describes how many innovations fit together in a real logistics system, addressing digitalization, standardization, flexibility and environmental sustainability. Article [38] also deals with the food industry, including food safety. The paper provides an overview of work, challenges, findings and a summary of the project. Paper [39] deals with the automatic identification of meat products at item level, proposes and evaluates the use of different RFID technologies. It also examines ultra-high frequency (UHF) technology and near field communication (NFC) technology. Publication [40] deals with the study of non-stationary queuing systems, based on the assumption of the presence of an infinite number of servers. It deals with a special mathematical technique based on graph theory and probabilistic computation in the study on continuous service systems. Research [41] presents a PC-based packaging logistics game developed for Schenker AG in Leipzig. It is important to highlight the recent study on sustainability [42], which analyses digital transformations and their impact on the supply chain to create traceability and transparency. The publication also mentions that there is little empirical evidence on the benefits of digital transformation of the supply chain. Paper [43] discusses the role of good packaging in reducing food waste and providing consumers with necessary information about the product.

Solutions for the assessment of packaging systems are presented in the following. These are life cycle assessment (LCA), zero-based analysis and value-added ratio (VAR). Life cycle analysis is a commonly used method for identifying and assessing the total environmental burden associated with a product, process, or activity by identifying and quantifying the energy and materials used and the waste released into the environment [44].

The main advantage of life-cycle analysis is that it supports decision-making with scientific data and expertise and thus helps to distinguish between scientific facts and value systems. LCA method should be used in collaboration with other techniques such as environmental impact assessment and environmental risk assessment. Thus, the approaches complement each other [45]. Publication [46] compares two cases using life cycle analysis, the first case where logistics functions are performed in the company and the second case where the functions are outsourced. The study [47] uses life cycle analysis to examine the environmental benefits and burdens of a logistics system, taking waste into consideration.

The zero-based analysis method can be applied in the case of packaging material management when the type of packaging system or the type of packaging is used as the unit of analysis. The basis of the method is that the resource-consuming activities of the system are broken down into two main parts. The first part represents the work required in the perfect system and the second part represents the losses and the costs of the system [48]. There are three types of application in which a zero-based analysis can be used to understand a system more effectively. These applications are determining the rationalization potential of a system, comparing systems with the same preconditions in terms of the work required, and comparing systems with different preconditions. If the type of packaging system or the type of packaging is used as the unit of analysis, all three applications can be adapted [49].

The value-added ratio is a performance measure defined as the ratio of total value-added time to total process cycle time. This method can be used for all types of process evaluation. Paper [50] applied the method to packaging logistics and proposed its suitability as an evaluation method to improve supply chain efficiency. Article [51] describes the value-added ratio method, which can be used to measure improvements in all processes of a company and requires systematic, intensive effort and input from many sources.

As a result of the literature analysis, it can be concluded that the most common way to select the right packaging system in corporate practice is through experience. The methods used only consider the processes within the scope of a single company and do not address the integrated management of sub-processes managed by several companies regarding the optimal choice of the packaging system. Consequently, significant losses can occur, mainly at system boundaries, but also within processes. Such losses may include unnecessary transshipment activities, longer material handling times and more waste, etc. In the further part of the paper, the concept of an innovative packaging management framework is presented, which is suitable for the selection of optimal unit load devices based on the company's needs by means of simulation-based optimization. The effectiveness of the developed method is demonstrated by a case study. Table 1 summarizes the literature analysis.

Table 1. Summary table of the reviewed literature (Source: own edit).

Publication Topic	Solution	Literature Reference Identifier in the Thesis
Sustainable production and overall process efficieny	Research and development, efficient and effective implementation	[3]
Food waste, spread of harmful products	Timely acces to information, sustainability	[6]
Extending product life with packaging	New packaging	[9]
Providing the necessary information to consumers	Labelling, the importance of correct packaging	[10–13]
Packaging system performance	Packaging scorecard	[19]
Contactless packaging solution	Decision support system	[20]
Tasks to be performed by a packaging system in a retail supply chain	Increasing awareness	[21]

Table 1. *Cont.*

Publication Topic	Solution	Literature Reference Identifier in the Thesis
Sustainable packaging in the supply chain	A literature review of 20 years of studies	[22]
Food and processing industry packaging development, packaging designs	Using integrated approach	[23,24]
Reusable packaging and system costs	Description of the case study	[25]
Applying the digital twin concept to proactively diagnose the system	Modernisation of production systems	[26]
Industry 4.0 applicability in packaging and its gaps	Applying the benefits of Industry 4.0	[27]
Gaps in material handling systems for cloud manufacturing	Introducing a new material handling paradigm	[28]
Managing recyclable packaging in the automotive industry	Reusable packaging in preparation for the delivery of the finished product	[29]
Using sustainable materials and designs for packaging goods	Green packaging	[30,31]
Sustainable management practices	Data content analysis	[32–34]
Operation of short food supply chains	Innovations with digital elements	[35]
Food supply chain	Innovative and environmentally friendly technological solutions	[36]
Cargo transport in seaports, sustainability	Digitalization, improvements	[37,40,42]
Food safety	Overview of project work	[38]
Automatic identification of meat products at labelling level	RFID, UHF, NFC technologies	[39]
PC-based serious game evaluation study	Packaging logistics game to train employees	[41]
Reducing food waste	The role of correct packaging	[43]

4. Description of the Operational Concept of the Packaging Management System

The chapter describes the types of supply chains that can be examined, the operational concept of a packaging management system, and the method of its application to selected product types in a defined system. The application of the test method is presented through a case study. The concept was developed using an inductive method, i.e., the experience gained from satisfying a variety of simulation test needs, mainly in the automotive industry, inducted the research direction, the undeveloped status of which was confirmed by the literature analysis. In essence, the methodology developed is based on the practical context of the field and the mechanisms of operation of e-marketplaces.

4.1. Description of Test Cases

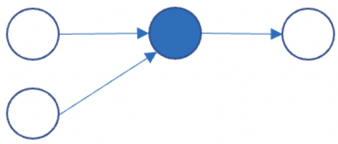
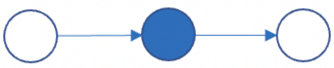
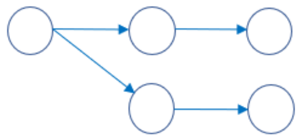
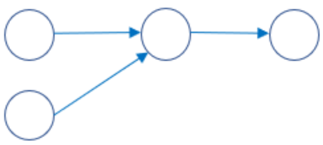
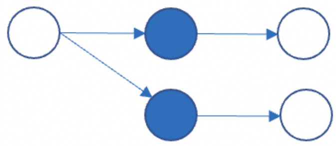
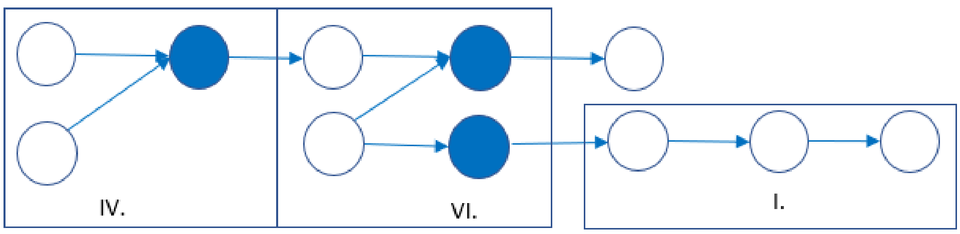
In order to optimally choose the packaging systems associated with the designated supply system, it is necessary to define the transformation possibilities for the most diverse logistics tasks. Based on this, six basic types and the combinations that can be formed from their occurrence in practice. As a result of globalization, the extent of supply chains can change significantly, so the decision points defined in the examined system, as well as the number of cases that can be examined, also differ. The 6 basic types are defined in the Hungarian book Simulation Modelling in Logistics [52].

The types defined in Table 2 are:

1. The packaging system does not change in the process under consideration, for example, if the product is removed from the same packaging for a given operation and then returned to the same packaging for quality control.

2. The packaging system changes in the process without branching for example, when a different packaging system is required after machining in the case of laser cutting.
3. The packaging system is not changed when several processes meet, for example, painting products.
4. The packaging system changes when several processes meet, for example, commissioning or assembly.
5. The packaging system does not change in the case of branching, for example, delivery of a given product type to several customers.
6. The type of unit load device changes in case of branching, for example, after disassembly or sorting.
7. Combination of sub-types, for example, a supply chain in which types 4-6-1 are followed by each other.

Table 2. Types of packaging systems (I–VI), combinations (VII) (Source: own edit).

Numbers	Type	Numbers	Type
I.		IV.	
II.		V.	
III.		VI.	
VII.			

4.2. Structure of the Packaging System

The task of the presented packaging management system is to choose the optimal packaging system for the selected product types at the decision points in relation to a designated supply chain. Those operations where it is possible to choose a packaging system can be considered as decision points. There may also be operations where the type of packaging system to be used is predefined. The concept of the developed system is presented through the architecture of the framework and the definition of the tasks to be performed.

As shown in Figure 5, the framework can be divided into three parts: the participants of the study, the main tools used in its operation and the databases.

The solutions suggested for capturing the framework data is most similar to the solutions used in electronic marketplaces, i.e., it should be mostly implemented through a web interface [53].

The participants in the operation of the framework are:

- Management: management sets the development direction. The management sets the strategy. The management is responsible for taking strategic and tactical decisions, negotiating with new companies based on expert advice, and concluding contracts. The development guidelines include defining development ideas for marketing, technology and the services provided.
- Client: The company using the services of the test system, which concludes a service contract with the management, while the test for the choice of the optimal packaging system is carried out with the assistance of the expert. Publication [54] discusses the procurement of business services becoming increasingly important for companies as they seek competitive advantage. Service contracts are an essential part of the procurement of business services and the complexity of contracts increases with the complexity of services [54].
- Experts: The experts are fully familiar with the functions of the packaging management system, who manage the conduct of the entire inspection. The main tasks include:
    - defining the task to be performed based on the client's needs,
    - defining the range of data required for the system to operate, and managing their production,
    - uploading data via a web application,
    - conducting a study and negotiating the results with the client.
- R&D team: The team develops the framework along the development guidelines approved by management and maintains the infrastructure necessary for its operation.
- Information providers: Information providers are the actors that provide additional information needed to carry out the study (e.g., important parameters of available packaging systems, distance of actors in supply chains, etc.).

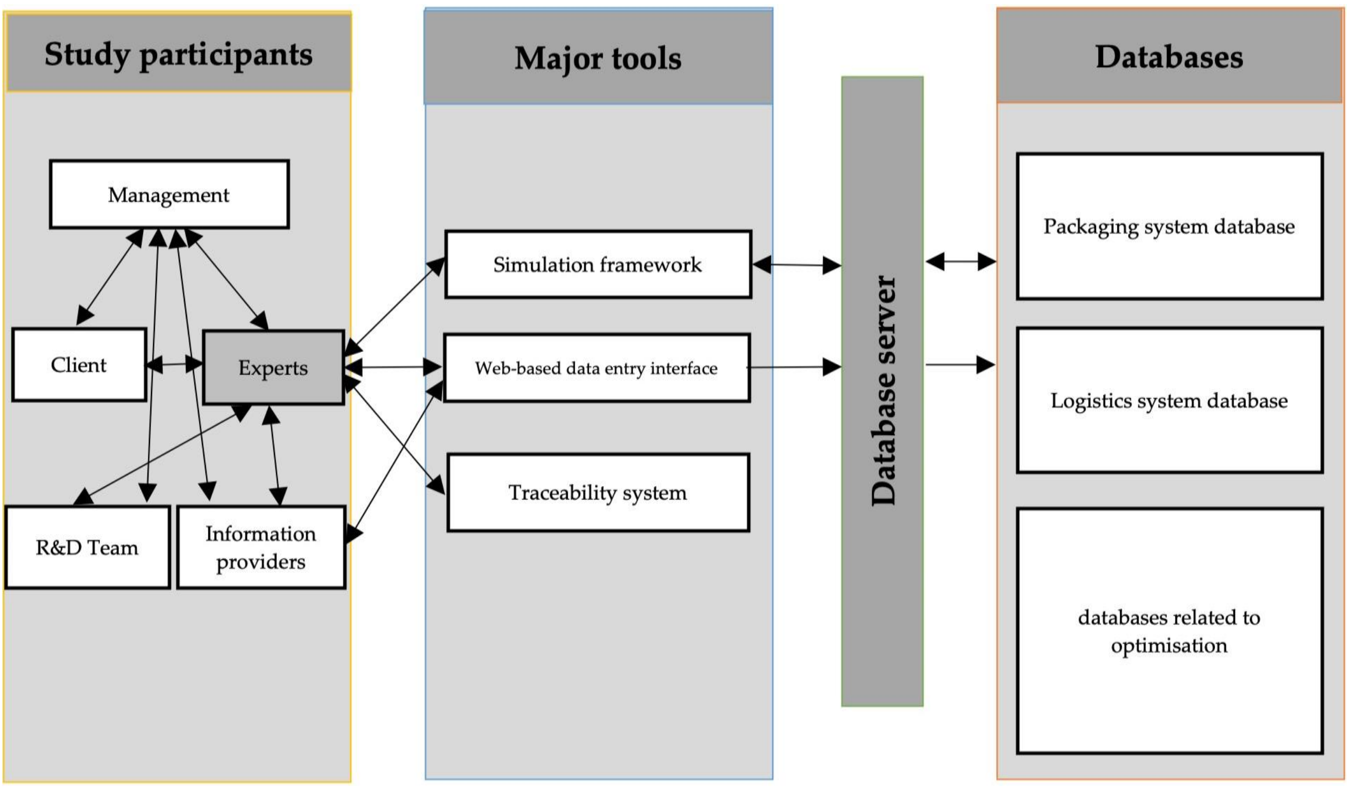


Figure 5. Basic concept of the framework system (Source: own edit).

The main tools to be used in the operation are:

- Simulation framework: A simulation framework is used to model the operation of the supply chain in the case of different packaging system combinations defined at the decision-making points. The simulation test model basically determines the packaging scheme combination containing the most favorable objective function value. Based on the data of the databases uploaded via the web application, the system to be developed will automatically create the system under investigation during the examination initiated by the expert, and then perform the optimization task.
- Web-based data entry interface: An interface accessible via the internet where experts and information providers can enter the data required to perform the study using a predefined data entry structure.
- Tracking system: The availability of a tracking system to capture relevant environmental information to provide the quantitative and qualitative data needed to run the simulation test model. In most cases, these data can be queried by company management systems, but at the same time, if needed, an on-site survey becomes necessary. Monitoring solutions in companies can range from paper-based manual data capture to advanced automated digitalization solutions, which of course have an impact on the quality of the study. The data provided by the traceability system are uploaded via a web-based interface to the databases required to perform the test.
- Databases needed for the system to work are:
- Packaging system database: a database of packaging system that can be used during optimization, which is uploaded by information providers and experts via a web interface.
- Logistics system database: a database containing the data needed to model the process under study, which will be entered by the experts via the web interface, based on the company under study and/or on-site survey.
- Databases related to optimization: a database containing the data (decision variables, conditions, objective functions) needed to select the appropriate packaging system, which is partly captured by the experts and partly by running the simulation study.

4.3. Operational Concept of the Packaging Management System

As a result of the operation of the packaging management system, the optimal packaging system is determined in relation to a limited supply chain or material flow system. Basically, a simulation model of a delimited system is automatically generated based on the previously recorded data in the background databases, and then the applicable packaging system combination is selected based on the set conditions and objective functions (which packaging system is applicable at each decision point for the product type(s) under consideration).

The steps to use the system can be summarized as follows and shown in Figure 6.

1. Definition of the purpose of the study: the client, with the involvement of the expert, defines the task to be performed, namely the subsystem to be studied, the scope of its processes, products and decision points.
2. Contracting: the management and the client, with the support of the expert, fix the task to be performed, the expectations and the method of payment for the service contract.
3. Getting to know the system under test: the expert with the assistance of the client, gets to know the logistical processes of the system under test.
4. Preparation of the material flow graph: For the system defined, the fixed objects of the material flow and the links between them shall be identified for each type of product. The objects in the material flow graphs under consideration are given a unique identifier (e.g., a sequence number) and are marked if they are decision points (see Figure 7, color blue). Decision points are defined as objects on which the choice of the optimal packaging system can be tested.

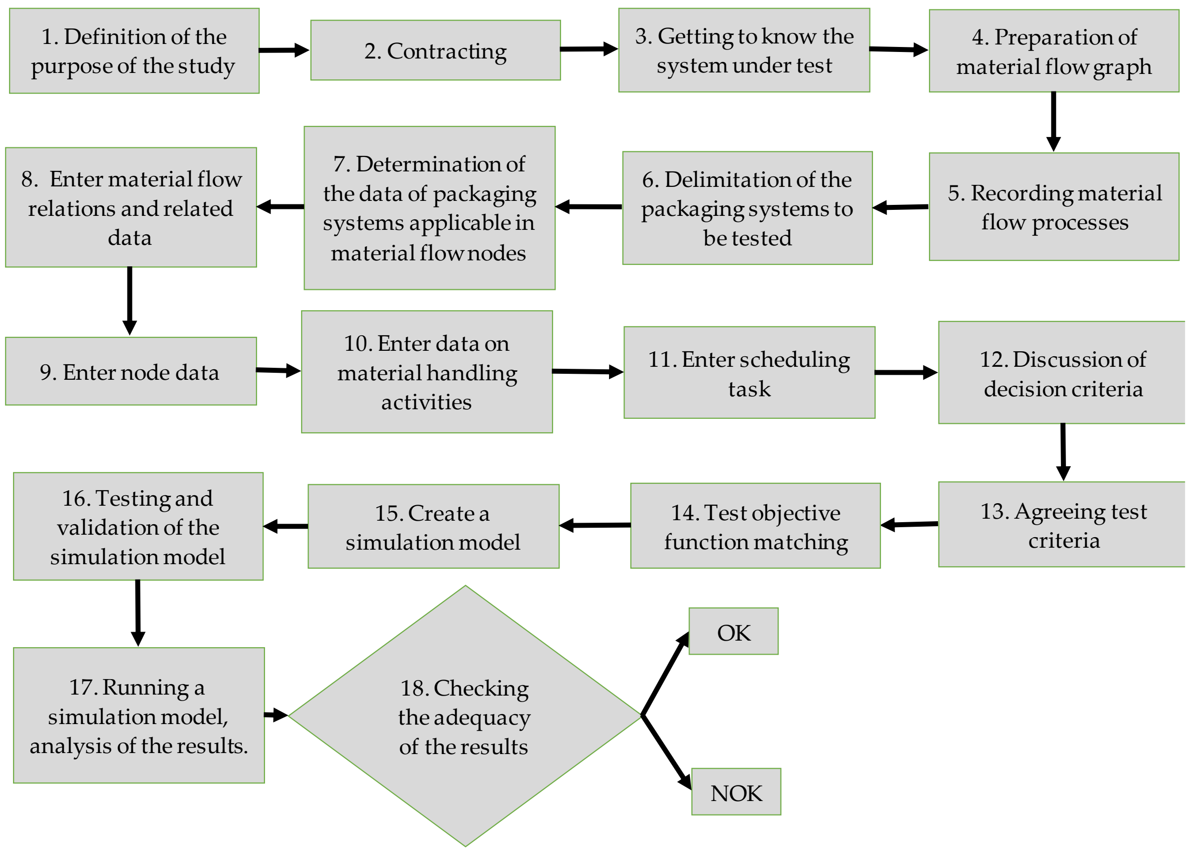


Figure 6. Steps to use the system (Source: own editing).

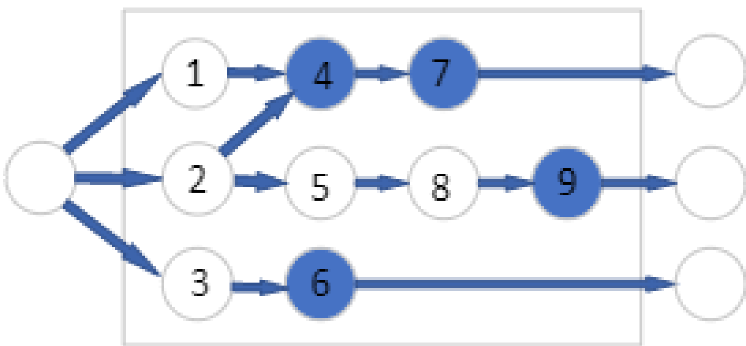


Figure 7. Example for the material flow graph (Source: own edit).

5. Recording material flow processes: based on the material flow graphs for the product types, experts record the material flow process of the products via a web-based data entry interface.
6. Delimitation of the packaging systems to be tested: based on the data received from the customer and/or information providers, the experts record the data of the packaging systems to be tested (size data, tare weight, load capacity, specific amortization cost per transport relation) via the web data entry interface.
7. Determination of the data of packaging systems applicable in material flow nodes: Two types of material flow nodes can be distinguished, those where the packaging scheme does not change for the product types that pass through, and decision points where it is possible to do so. The experts, in consultation with the client, will identify the test options and then, via the web interface, will specify the types of packaging

system that can be used for the product types passing through the nodes, as well as their filling volumes, loading times, unit logistics and quality characteristics.
8. Enter material flow relations and related data: experts enter, via the web application, the data of possible transport relations for the defined nodes.
9. Provide information on technological equipment: In this step, information describing the operation of the technological equipment is provided. If the modelling of the equipment is very specific, the description and modelling of the operation will require future discussion.
10. Enter data on material handling activities: in this step, distance and time data for the material handling tasks associated with the nodes representing the material handling activity are entered for the packaging systems for the given product types (transport capacity, average transport time).
11. Enter scheduling task: in this step, it is specified when and what quantities of each product type will be launched from each node.
12. Discussion of decision criteria: In this step, the logistic indicators that influence the decision are presented, the range of which is defined based on the literature analysis [17]. The value of some indicators can vary depending on the combination of γ packaging system.
    - Transit time: The transit time is the time between the objects bounding the delimited system. The transit time may be interpreted by product type associated with the output points of the system under study using Equation (1), and for the whole system using Equation (2).

Regarding product type p,

$$\overline{T_p^{\gamma}} = \frac{\sum_{i\in\theta_p^{\gamma}} \left(t_{p,i}^{O} - \min_{j\in\theta_{p,i}^{\gamma}} \left\{ t_j^{I} \right\} \right)}{\left|\theta_p^{\gamma}\right|} \tag{1}$$

where:

- i: unique identifier of the unit load of product type p,
- $t_{p,i}^{O}$: exit date of the unit load i of product type p from the tested system,
- $\theta_{p,i}^{\gamma}$: for unit range i of product type p, the set of components to be incorporated,
- t_j^{I}: data of entry of snap-in j into the system

Note: In the model, the process of assembling unit loads of product type p for the system output point i can be diverse and thus very complex, involving continuous changes in the material handling paths of the products contained and/or the physical properties of the products and/or the type of packaging systems used. From this point of view, as long as the material flow path, the physical characteristics and the packaging system of a product do not change, we are talking about a specific component, but if they change, we are looking at a different component with a different identifier.

For the system under consideration, this can be determined from Relation (2).

$$\overline{T}^{\gamma} = \frac{\sum_{p=1}^{n} \overline{T_p^{\gamma}} \cdot \left|\theta_p^{\gamma}\right|}{n} \tag{2}$$

- Total cost of operation: the cost of operation of the material flow systems depends to a large extent on the choice of the packaging system combination, and the method of determining this for the system under consideration by the following Equation (3).

For the delimited system:

$$K^{\gamma} = \sum_{k,o\in\theta^{\gamma}} \sum_{p\epsilon\theta_{k,o}^{\gamma}} \sum_{i\in\theta_{p,k,o}^{\gamma}} \left(L^{k,o} \cdot k_{p,i}^{k,o,l} \right) + \left(k_{p,i}^{k,ul} + k_{p,i}^{o,ul} \right) + \left(S_{p,i}^{k} \cdot k_{p,i}^{k,s} + S_{p,i}^{o} \cdot k_{p,i}^{o,s} \right) + \left(k_{p,i}^{k,o,a} \right) \tag{3}$$

can be determined from the relation where:

- θ^{γ}: the set of pairs of the transport relation of the system under consideration,
- $\theta^{\gamma}_{k,o}$: set of product types moved in a transport relation k, o,
- $\theta^{\gamma}_{p,k,o}$: set of unique identifiers of unit loads of product type p in relation k, o,
- $L^{k,o}$: length of the transport relation k, o [km],
- $k^{k,o,l}_{p,i}$: unit transport cost for unit load i of product type p in transport relation k, o [EUR/UL·km],
- $k^{k,ul}_{p,i}$: specific loading cost for unit load i of product type p at material flow object k [EUR/UL]
- $k^{o,ul}_{p,i}$: specific loading cost for unit load i of product type p at material flow object k [EUR/UL]
- $S^{k}_{p,i}$: number of storage days for unit load i of product type p at object k [day·UL]
- $S^{o}_{i,f}$: number of storage days for unit load i of product type p at object o [day·UL]
- $k^{k,s}_{p,i}$: specific storage cost for unit load i of product type p at object s [EUR/day·UL]
- $k^{o,s}_{p,i}$: unit storage cost for unit load i of product type p at object o [EUR/day·UL]
- $k^{k,o,a}_{i,f}$: amortisation cost of the packaging system for unit load i of product type p for transport relation k, o [EUR/UL].

- Average usability within the process under consideration: This factor takes into consideration how many times the packaging system γ under examination is expected to be used in the relation k, o for a given product type p. The values are defined by the information providers, the data structure of which is shown in Equation (4).

$$\mathrm{F}^{\gamma} = \left[f_{p}^{\gamma,k,o} \right] \tag{4}$$

- Quality of the packaging system: The choice of the packaging system should be based on its ability to meet expectations. Only packaging systems that meet the essential requirements should be included in the test. This factor will be determined with the help of the company under investigation and external information providers [18]. The following criteria are considered in the evaluation:
    - delivery marks are clear and easy to read on the outer packaging,
    - sufficient choice and number of items,
    - package printing, material, content, size and color are all appropriate,
    - package fully sealed by appropriate methods,
    - carton box drop test,
    - barcodes and labelling are clear, accurate and legible,
    - environmental impact,
    - pallet packaging meets specification.

In essence, an indicator is defined as the average of the subjective ratings given by the selected actors between 1 and 10 (1-bad, 10-best). Equation (5) shows the acceptability of the packaging scheme under consideration γ for a given product type p in relation k, o.

$$\mathrm{M}^{\gamma} = \left[m_{p}^{\gamma,k,o} \right] \tag{5}$$

13. Agreeing test criteria: the previous step showed how to define test criteria for a packaging system combination (one predefined packaging system per decision point). These criteria may have a different value for each γ packaging system combination, so it may be necessary to formulate criteria to exclude packaging system combinations that are not acceptable to the client. The formulation of the criteria is carried out jointly by the expert and the sponsor, while the data recording is carried out by the expert. From Equations (6)–(10) define the requirements for the optimal packaging

system alternative in terms of lead times, costs, availability and quality. In fact, only the alternative which meets these criteria can be selected.

Conditions:

$$\overline{T_p}^{\gamma} \le \overline{T_p}^{Max} \tag{6}$$

$$\overline{T}^{\gamma} \le \overline{T}^{Max} \tag{7}$$

$$K^{\gamma} \le K^{Max} \tag{8}$$

$$f_p^{\gamma,k,o} \ge f^{Min} \tag{9}$$

$$m_p^{\gamma,k,o} \ge m^{Min} \tag{10}$$

14. Test objective function matching: In this step, the method of determining the objective function is presented to the client, and the weights of the objective function components are produced and uploaded to the background database. To produce the objective function of the optimization, the weighted sum of the normalized objective function components must be formed in relation to each γ packaging system combination, and then the combination with the most favorable value is chosen. In the analysis, the goal is to select a packaging system combination that minimizes transit time and cost, as well as maximizing usability and quality. The normalization steps are described in Equations (11)–(18).

Normalization of objective function components:

- Normalization of transit time:

$$\overline{T}^{(min)} = \min_{\gamma}\left\{\overline{T}^{\gamma}\right\} \tag{11}$$

$$\alpha_{\gamma}^{1} = \overline{T}^{\gamma} / \overline{T}^{(min)} \tag{12}$$

- Normalizing operating cost:

$$K^{(min)} = \min_{\gamma}\{K^{\gamma}\} \tag{13}$$

$$\alpha_{\gamma}^{2} = K^{\gamma} / K^{(min)} \tag{14}$$

- Usability within the tested system:

$$f^{(max)} = \max_{\gamma} \sum_{k,o \in \theta^{\gamma}} \sum_{p \epsilon \theta_{k,o}^{\gamma}} f_p^{\gamma,k,o} \tag{15}$$

$$\alpha_{\gamma}^{3} = 1 - \frac{\sum_{k,o \in \theta^{\gamma}} \sum_{p \epsilon \theta_{k,o}^{\gamma}} f_p^{\gamma,k,o}}{f^{(max)}} \tag{16}$$

- Quality within the system tested:

$$m^{(max)} = \max_{\gamma} \sum_{k,o \in \theta^{\gamma}} \sum_{p \epsilon \theta_{k,o}^{\gamma}} m_p^{\gamma,k,o} \text{ [EUR]} \tag{17}$$

$$\alpha_{\gamma}^{4} = 1 - \frac{\sum_{k,o \in \theta^{\gamma}} \sum_{p \epsilon \theta_{k,o}^{\gamma}} m_p^{\gamma,k,o}}{m^{(max)}} \tag{18}$$

Determining the weights of objective function components:

There are several methods in the literature for determining the weighting of decision criteria according to corporate interests. The weighting process can be either on a serial scale or on an interval scale. When solving multi-criteria decision tasks, one of the essential elements is the most accurate determination of the order of importance of the evaluation aspects, or in other words, the weighting of the order of importance. In addition to the best decision alternative, a ranking of possible choices can also be developed, so it is important to perform weighting steps. The interval scale also provides information on the degree of preference. Since the Guilford method is the most widely used and accepted method in terms of reliability, accuracy and applicability, it is the method proposed to determine the weights of the objective function components. The method requires the use of an analytical team with a minimum number of people. In the design of the present system, this procedure is carried out by the expert group, with a minimum of 5 persons. The Guilford method is based on a specific objective, the weighting and quantification of the attributes used in the assessment and their corresponding categories on an interval scale ranging from 0 to 100. The weightings and the range of the points to be set should be such that the total number of points awarded to all tenders is between 0 and 100. In practice, the weights are set so that they add up to 100, so the minimum and maximum scores for the gap criteria should be 0 and 1. If the sum of the weights is 1, then the maximum number of points that can be assigned to the gap criteria should be between 0 and 100, so that the initial condition is satisfied. The most important feature of the method is that the quantifications are based on the results of expert judges [55]. The procedure requires a comparison to be made between pairs of factors to be compared, to which the weights are already automatically added. By selecting any 2 of the evaluation factors, it is possible to determine which one is more preferred over the other. Each decision maker in each pair assigns a score of 0 or 1 to express which evaluation factor is preferred [56,57]. It is important that the weighting factors should have a value between 0 and 1 according to Equation (19) and that their sum should be 100, according to Equation (20).

$$0 \leq \partial_h \leq 1, \tag{19}$$

$$\sum_{h=1}^{4} \partial_h = 100 \tag{20}$$

Definition of objective function:

$$\omega = \min_{\gamma} \sum_{h=1}^{4} \partial_h \cdot \alpha_{\gamma}^{h} \tag{21}$$

15. Create a simulation model: based on the data recorded by the experts, the simulation model is automatically created, which runs based on the data uploaded on the web application.
16. Testing and validation of the simulation model: After the simulation model has been created, the model is tested by the experts to eliminate any data errors, program errors and conceptual errors. For an existing system, the validation of the simulation model is carried out by comparing the model with reality, while for a future system, it is carried out by checking the data and processes.
17. Running a simulation model, analysis of the results: As a result of running the tested and validated simulation model, the value of the objective function is generated for each packaging system combination, so that the most favorable variant can be selected. The number of variants tested depends to a large extent on the number of product types, packaging systems and decision points tested.
18. Checking the adequacy of the results: In this phase, the correctness of the results obtained is checked, and if it is feasible for the company, the test is completed and the next step is to proceed towards implementation. Otherwise, further tests are carried out by modifying the test model.

4.4. Case Study on the Choice of the Optimal Packaging System

The chapter describes the elements of the packaging management system using a fictional model based on practical experience. The steps of the test are illustrated through the previously described process. The aim was to present the concept of the developed method, therefore for practical reasons the following simplifications have been made:

- Data was entered directly into the data tables without using a web-based data entry interface.
- The model was created manually, using recorded data. The test model was implemented in the Plant Simulation Framework, version 2021. The simulation framework operates in a discrete, event-driven paradigm, which contributes significantly to user-friendly model creation and shorter runtimes.

Steps of an examination:

1. To define the purpose of the examination: to select the optimal type of unit load forming devices at three locations in an automatically operating forging plant with a defined material flow based on a predefined objective function and a set of conditions.
2. Contracting: in a real system, the management and the customer, with the support of the expert, would define the task to be performed, the expectations and the method of payment for the service in a service contract.
3. Getting to know the system under test: This step would involve getting to know the operational processes of the system under test. In summary, the process starts with an automatic forging machine that produces different types of parts according to a defined production plan and schedule. The coinage parts are placed in an automated way in a unit load device. The unit load is then transferred via conveyor lines to a heat treatment oven to carry out the necessary structural modifications. After the heat treatment, the products are transported via conveyor lines to one of the two granulator units. After the granulation process, the products are also automatically transported to a selected unit loader, from where they are delivered to an external warehouse. In understanding the system, it is important to define the range of material flow and process characteristics to be considered.
4. Material flow graphs: In this step, the process operations and material handling equipment of the system under study are selected and uniquely identified as material flow nodes and the connection between them is made using directed edges. For the easier understanding of the model, the circular objects marked in blue are the place where it is possible to choose the way of unit load training, and for the circular objects some material handling/technological operation is performed. For Figure 8, the marking of nodes and edges is incomplete, i.e., not all of them are marked, but the example is a good illustration of the method developed.

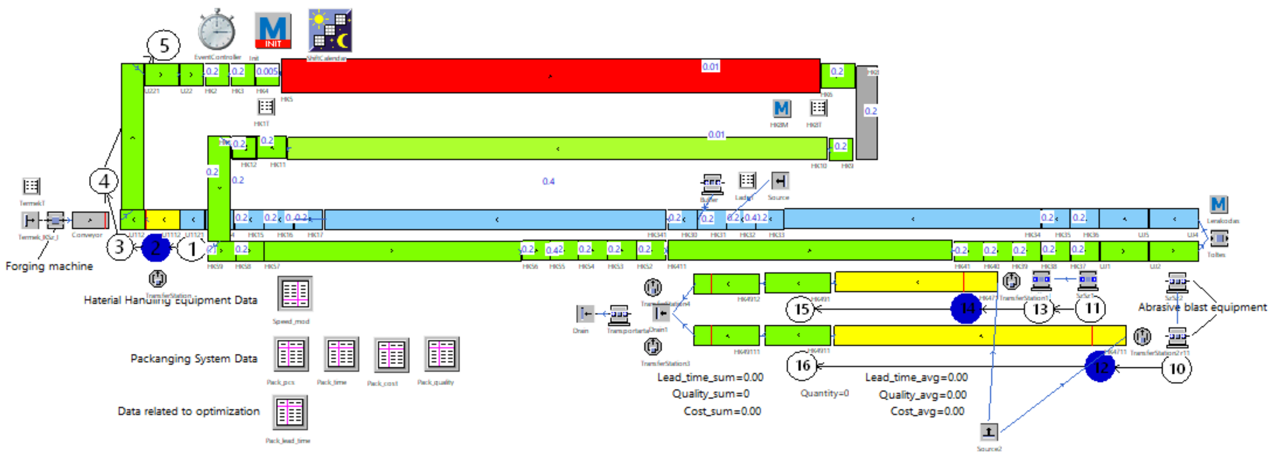


Figure 8. Marking of material flow graphs (Source: own edit).

5. Recording material flow process (see Table 3): In this step, the experts record the material flow processes, i.e., the order in which each product goes through which material handling and processing equipment, via a web application, according to the concept developed. For the simplicity of the present case study, this method of data recording is not used, i.e., the connections are created manually.

Table 3. Recording material flow processes (Source: own edit).

Name of Product	**Material Flow Object**					
	1	**2**	**3**	**4**	**5**	...
Product_1	1	2	3	4	5	...

6. Delimitation of the packaging systems to be tested: The concept is that experts will record the data of the packaging systems to be tested on the web-based data entry interface, based on the data received from the sponsor and/or information providers. In the present case study, 3 types of unit loaders for loading products coming out of the coinage machine and 2 types of unit loaders for loading products coming out of the granulator. The aim is to select 1 type of unit loader after the coinage and 1 type of unit loader after the granulation process.
7. Determination of the data of packaging systems applicable in material flow nodes: The concept is that the experts, in consultation with the client, will jointly define the testing options and then, via the web interface, specify the types of packaging system that can be used for the product types passing through the decision nodes, as well as their main data. In this case study, four types of characteristics have been selected, whose data can be as follows (see Figure 9):
    - Loading volume (see Figure 9a): shows how much of a given product can be loaded into a given unit loader [pieces per unit loader].
    - Loading time (see Figure 9b): shows how long it takes to load one product of a given product type into a given unit loader [s/pcs].
    - Specific logistics cost (see Figure 9c): shows the logistics cost of placing one unit load of a given product type in a given unit loader [EUR/pcs].
    - Quality feature (see Figure 9d): shows the degree to which the placement of a given product type in a given unit load device meets the company's quality expectations (1—worst, 10—best).

(a) Loading volume data

	string 0	integer 1	integer 2	integer 3	integer 4	integer 5
string	Product name	Pallet1	Pallet2	Pallet3	FPallet1	FPallet2
1	Product_I	100	120	150	100	200
2	Product_II	50	80	90	150	250
3	Product_III	20	40	70	50	100

(b) Loading time data

	string 0	real 1	real 2	real 3	real 4	real 5
string	Product name	Pallet1	Pallet2	Pallet3	FPallet1	FPallet2
1	Product_I	1.00	1.30	0.50	2.00	3.00
2	Product_II	2.00	2.50	0.70	4.00	5.00
3	Product_III	2.50	2.80	0.90	5.00	7.00

(c) Specific logistics cost

	string 0	real 1	real 2	real 3	real 4	real 5
string	Product name	Pallet1	Pallet2	Pallet3	FPallet1	FPallet2
1	Product_I	0.40	0.20	0.80	0.40	0.70
2	Product_II	0.40	0.20	0.80	0.40	0.70
3	Product_III	0.40	0.20	0.80	0.40	0.70

(d) Quality feature data

	string 0	real 1	real 2	real 3	real 4	real 5
string	Product name	Pallet1	Pallet2	Pallet3	FPallet1	FPallet2
1	Product_I	5.00	8.00	9.00	6.00	10.00
2	Product_II	5.00	8.00	9.00	6.00	10.00
3	Product_III	5.00	8.00	9.00	6.00	10.00

Figure 9. Data of packaging systems applicable in material flow nodes (Source: own edit).

8. Enter material flow relations and related data: The concept is to have experts define possible transport relations via the web application. The value of the Table 4 is 1 if there is a material flow relation between the material flow objects they have selected, otherwise it is not filled in.

Table 4. Data for material flow relations (Source: own edit).

Material Flow Object	Material Flow Object					
	1	**2**	**3**	**4**	**5**	...
1		1				
2			1			
3				1		
4					1	
...						

9. Enter technological equipment data: In this step, information describing the operation of the technological equipment is provided. In this case study, this means entering the data for two pieces of technological equipment, namely the coinage machine and the grain milling machines (Table 5).

Table 5. Technological equipment data table (Source: own edit).

Node ID	Name of Technolog-ical Equipment	Product Type	Operation Time [sec/pcs]	Setup Time [sec/type]	Capacity [pcs]	Width [mm]	Length [mm]	Specific Property
10	Abrasive blast equipment	Product_I	300	-	1500	2000	2000	handling products together
...								

10. Enter the data of the material handling activity: In this step, the data of the nodes representing the material handling tasks are entered. The data for this case study are given in Table 6.

Table 6. Data table for material handling activities (Source: own edit).

Name	Speed [m/s]	Remark
HK2	0.2	Roller conveyor
HK3	0.2	Roller conveyor
HK4	0.005	Roller conveyor
HK5	0.01	Heat treatment unit

11. Specify scheduling task: The tasks to be performed by the forging machine and their sequency are listed in Table 7. The table shows which product types, and in which sequence they will be started by the coinage machine.

Table 7. Production task scheduling (Source: own edit).

MU	Number	Name
.UserObjects.Product_I	4000	Product_I
.UserObjects.Product_II	3000	Product_II
.UserObjects.Product_III	7000	Product_III

12. Decision criteria matching: For the case study, there are 3 types of pallets to choose from after the forging machine and 2 types of pallets after the granulator. This means

a total of 6 packaging system variants for the selection of unit load devices (1 after forging machines and 1 after granulators). To select the appropriate packaging system variant, it is necessary to define the decision criteria (Table 8). Three types of decision criteria were selected, namely:

- Lead time: total lead time per product [sec] for a given packaging system variant.
- Logistics cost: average cost per product [EUR/pcs], determined from the sum of the specific logistics costs assigned for a given packaging system.
- Quality: average quality per product, determined from the sum of the quality attributes assigned to the loading operations for a given packaging system.

Table 8. Decision criteria (Source: own edit).

Version	Pallet1	Pallet2	Pallet3	FPallet1	FPallet2	Lead Time	Quality	Cost
1	1			1				
2	1				1			
3		1		1				
4		1			1			
5			1	1				
6			1		1			

13. Agreement on the test criteria: no restrictive criteria were formulated for the case study in relation to the decision criteria.
14. Test objective function matching: The weight factors are lead time: 0.5 TTT, 0.2 TTT, logistics cost: 0.3. The objective function is defined as the weighted sum of the normalized objective function components, where the packaging system variant with the lowest value indicates the type of unit load devices to be used.
15. Simulation model creation: Based on the data recorded in the previous steps, the simulation model was created manually (Figure 8). In the context of the model, different colors were used to indicate the empty pallets (blue color), the unit loads (green color), and the conveyor systems used to move the unit loads during the heat treatment (red color). The technological equipment is indicated by a separate label.
16. Testing and validation of the simulation model: after the simulation model was created, the model was tested, during which data errors and program errors were corrected and the planned concept was verified.
17. Running a simulation model, analysis of the results: as a result of the run, the decision criteria (Table 9), the normalized objective function components (Table 10) and the objective function values (Table 11) were determined for each packaging system variant.

Decision factor values by packaging scheme variant:

Table 9. Decision criteria evaluation (Source: own edit).

Version	Pallet1	Pallet2	Pallet3	FPallet1	FPallet2	Lead Time	Quality	Cost
1	1			1		9785	11	0.8
2	1				1	11,587	15	1.1
3		1		1		10,520	14	0.6
4		1			1	12,268	18	0.9
5			1	1		11,060	15	1.2
6			1		1	12,811	19	1.5

Normalized objective function component values per packaging scheme variant:

Table 10. Normalized objective components (Source: own edit).

Version	Pallet1	Pallet2	Pallet3	FPallet1	FPallet2	Lead Time	Quality	Cost
1	1			1		0.76	0.52	0.53
2	1				1	0.90	0.21	0.73
3		1		1		0.82	0.26	0.40
4		1			1	0.96	0.05	0.60
5			1	1		0.86	0.21	0.80
6			1		1	1.00	0.00	1.00

Determination of objective function values per packaging scheme variant:

Table 11. Definition of objective function (Source: own edit).

Version	Pallet1	Pallet2	Pallet3	FPallet1	FPallet2	Lead Time	Weight (LT)	Quality	Weight (Q)	Cost	Weight (C)	Result
1	1			1		0.76	0.50	0.42	0.20	0.53	0.30	0.63
2	1				1	0.90	0.50	0.21	0.20	0.73	0.30	0.71
3		1		1		0.82	0.50	0.26	0.20	0.40	0.30	0.58
4		1			1	0.96	0.50	0.05	0.20	0.60	0.30	0.67
5			1	1		0.86	0.50	0.21	0.20	0.80	0.30	0.71
6			1		1	1.00	0.50	0.00	0.20	1.00	0.30	0.80

18. Checking the adequacy of the results: based on the objective function values, it can be concluded that for the presented case study, the optimal packaging system alternative is packaging system 3 (See Table 11), i.e., the unit load device Pallet2 after the forging machine and FPallet1 after the granulating machine.

As a result of the study, the second-best packaging system variant (packaging variant with ID 3) was selected, considering the interests of the company in terms of lead time and quality, and the best packaging system variant in terms of cost. Without the application of the methodology, the wrong choice of packaging system variant could have led to significant increases in lead time and costs as well as quality problems.

The method presented allows the selection of a packaging system variant to consider the decision criteria selected based on the company's interests and their weighting. In addition, the optimization process can be used to integrate the processes managed by several companies and to take into account the impact of the different packaging system variants on the logistics system under consideration. Based on the literature analysis, it was found that such a complex analysis system has not been developed in the field so far.

5. Conclusions

Following a detailed literature analysis, this publication has found that companies essentially develop and apply their own methodologies for selecting the appropriate packaging system, i.e., no framework has been developed to date that could determine the optimal packaging system for a specific solution under consideration as a service. This area is also becoming increasingly important in the future, as the range of packaging systems that can be tested is constantly expanding and the complexity of the logistics systems being developed is increasing, so the development and application of scientifically based test systems can provide a significant competitive advantage for the companies using them.

The type of used packaging systems has a significant effect on the environmental impact and on the development of logistics-related operating costs.

In this paper, the basic concept of a developed framework is presented. It describes the actors of the framework, the tools used, the range of databases required to perform the analyses and the links between them. An 18-step process for the assessment was defined to manage the process of selecting the appropriate packaging system. The validity of the concept was demonstrated in a case study. The main difference between the methods used so far and the developed concept is that the latter can be applied to all types of companies and to a wide range of different system variants, and that simulation modelling can be used to minimize the risks of forecasting and to optimize more efficiently.

In the present case, the developed test concept can be applied only for the selection of the optimal packaging systems for delimited logistics system with homogeneous unit loads using the method of total counting. It can be said that the application of the test concept at this stage requires the manual creation of a simulation model.

The research is planned to be continued in several phases. Firstly, the plan is to extend the concept to inhomogeneous unit loads and to implement the automatic generation of the model based on the data structures of the simulation model. This will of course include testing in an enterprise environment. In the subsequent phase, the plan is to implement the web connection and to further develop the optimization algorithm to handle larger scale tasks.

Author Contributions: Conceptualization, H.M. and P.T., investigation, H.M. and P.T., methodology, H.M. and P.T., supervision, P.T., writing—original draft, H.M., writing-review and editing, H.M. and P.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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