Test method for the optimal choice of packaging systems

Henriett Matyi
Institute of Logistics, University of Miskolc, Hungary
henriett.matyi@uni-miskolc.hu

Prof. Dr. habil. Péter Tamás
Institute of Logistics, University of Miskolc, Hungary

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Abstract
This publication discusses the importance of selecting the most suitable packaging system for companies' logistics processes. This is a valid social and corporate expectation, as it can reduce environmental impact and improve the efficiency of logistics processes, which are key factors in a company's competitiveness. The appropriate packaging system can be selected based on experience, but there is a lack of integrated methods that can help choose the right packaging system. The publication proposes an innovative packaging system based on corporate needs. This can also improve the efficiency of sustainable supply chain processes. Packaging systems have an impact on the total cost and operational efficiency of the process.

1. Introduction
Logistics is undergoing significant changes aimed at ensuring smooth business operations. As part of the supply chain, logistics encompasses the principles, system rules, and processes that enable the flow of material assets. Modern logistics has become an important industry for economic development, but traditional packaging design may struggle to meet new challenges. Packaging is the starting point of logistics, and its optimized selection and proper planning are crucial for process efficiency and sustainability. Significant changes are taking place in the way goods are produced and useful information shared, thanks to technologies such as artificial intelligence, Big Data, the Internet of Things, and blockchain. Integrating these technologies and adopting a collaborative approach can promote supply chain efficiency. Digital packaging design offers the possibility of efficient and effective product packaging design using advanced computer technology. More efficient packaging design is possible with software, which can lead to actual reductions in logistics costs. Proper packaging is important for environmental protection and waste management. Selecting the right packaging system is a key factor in achieving efficient logistics processes. This study aims to identify research gaps and provide opportunities for future research.

2. Literature Review
The literature analysis was conducted using SLR (Systematic Literature Review) method. This method is used to identify, categorize, select, and analyze relevant articles on a given research topic. The analysis should be conducted transparently to result in a comprehensive overview of the topic [1]. Literature analysis strives for a comprehensive scientific presentation on the topic, minimizing bias [2].
The first step of the literature analysis was to select the appropriate databases, considering easy accessibility and structured searching. It is important to note that the search was conducted on March 14, 2023, so newer publications may have been published since then. The Scopus and ScienceDirect databases were selected. The initial search was performed using the keywords 'packaging' AND 'logistics', and the results were as follows:

- Scopus: 16223 pcs
- ScienceDirect: 32507 pcs

The second search combination was 'packaging' AND 'logistics' AND 'digitalization', and the results were:

- Scopus: 470 pcs
- ScienceDirect: 8236 pcs

The search field was then reduced to only the title, abstract, and keywords. The result of this search:

- Scopus: 10 pcs
- ScienceDirect: 11 pcs.

Based on reading some of the abstracts, a summary was prepared on the current articles in the field. Publication [3] deals with the circular economy, focusing on maximizing resource utilization mainly in logistics. The study summarizes current knowledge on shared logistics and highlights areas that require further research. Article [4] examines the peculiarities of the operation of the agro-industrial complex in digitalization. Science [5] focuses on the opportunities offered by Industry 4.0 technologies in terms of digitalization. It outlines some possible ways of transforming traditional manufacturing and related service systems into cyber-physical environments in the era of Industry 4.0, in the manufacturing processes of the automotive industry, the collection and distribution systems of urban logistics hyper-connections, and the switch pool packaging logistics area. An overview is provided in the [6] study on the possible implementation of innovative solutions with collected digital elements, addressing the primary needs and issues of short food supply chains. The [7] paper presents the current status and future trends of innovative and environmentally sustainable technological solutions for the post-harvest food supply chain and the food industry, focusing eco-friendly packaging, active and/or intelligent packaging. The [8] research demonstrates the sensitivity of Life Cycle Assessment (LCA) results to transportation parameters, highlighting the importance of accepting digital twins in these complex logistics ecosystems to increase the accuracy of their environmental profiles. The [9] article presents a digital twin for supporting the dispatchers of trucks, enabling optimal dispatcher policies to be determined through simulation-based performance prediction. The [10] study reports on findings from an industrial survey in the general processing industry.
In the continuation of the paper, an innovative packaging management framework concept is presented, which can be optimized through simulation-based studies and is suitable for selecting optimal unit loading tools, considering corporate needs.

3. Description of packaging management system

The chapter presents the operational concept and application method of the packaging management system. The developed concept was created using inductive and deductive methods, considering the simulation testing needs in the industry and the operating mechanisms of electronic marketplaces.
Structure of the framework operation.
The aim of packaging management is to select the optimal packaging system for designated product types at decision points in the chosen supply chain. The developed system concept is based on the structure of the framework and the definition of task to be carried out. At decision points, there is an opportunity to choose packaging systems, although there are operations where the type of packaging system to be applied is predetermined. The framework can be divided into three main parts: study participants, important tools to be applied, and necessary databases. The management defines the development guidelines and is responsible for making strategic and tactical decisions, while experts manage the entire examination process. The client utilizes the services of the examination system and, with the assistance of the experts, selects the optimal packaging system. The R&D group develops the operation of the framework according to the approved development guidelines of the management and maintains the necessary infrastructure for operation. Information providers are those who provide additional information which is necessary for the examinations carried out.

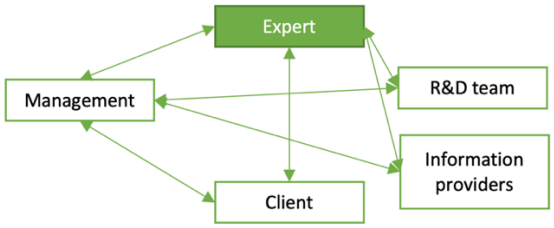

Figure 1: The study participants of the framework and the relationships between them (own edit)

The main tools to optimize the supply chain are described below. The simulation framework allows to model the supply chain under study and to analyze the impact of different packaging system combination with the optimal objective function value. The web-based data input interface enables data recording and uploading to the databases required for the examination. The tracking system provides the necessary quantitative and qualitative data for running the simulation model and allows for data uploading, from manual data recording to automated digitization solutions, which may affect the quality of the examination.
Three databases are necessary for the system to operate:

- the packaging system database,
- the logistics system database,
- the database related to optimization.

The first database contains packaging system data that are uploaded through a web interface by information providers and experts. The seconds database contains the data necessary for modeling

the examination process, which are recorded based on the examined company and/or on-site surveys. The optimization database contains the data needed to select the right packaging system, such as decision variables, conditions and objective functions, which are captured partly by the experts and party by running the simulation study.

3.1. Description of test cases

To select optimal packaging systems, several logistics tasks must be defined and modeled. Supply chains can vary, which can influence the number of decision points and investigations. The basic types and their combinations determine changes in packaging systems throughout logistics processes. In practice, six basic types and their combinations occur, which can vary depending on the extent of the supply chains. The basic types are as follows [11]:

1. The packaging system remains unchanged during the process, such as when the same packaging used during product quality control as when the product was removed.
2. The packaging system changes in a process without splitting, such as when a different packaging system is required after laser cutting.
3. The packaging system remains unchanged when multiple processes converge, such as during painting.
4. The packaging system changes when multiple processes converge, such as during picking.
5. The packaging system remains unchanged in splitting, such as delivering a particular type of product to multiple customers.
6. The type of unit load device changes in splitting, such as after disassembly or sorting.

4. How does the packaging management system work?

The optimal packaging system is determined as a result of the operation of the packaging management system within a defined supply chain or material flow system. Based on pre-registered data in background databases, a limited simulation model is automatically created. The applicable packaging system is selected based on the configured objective functions and conditions.

Steps for using the system [11]:

1. The initial step in optimization projects is to determine the objective of the study. In this step, the client and experts define the system to be studied, including processes, products, and decision points that they wish to optimize or improve. The objective of the study and the magnitude of the study area must be clarified during this phase. Precisely defining the objective of the study helps in designing the project efficiently and structuring it appropriately.
2. In the second step, management the client, with the help of the expert, enter into a service agreement that specifies the tasks to be performed, expectations, and the mode of remuneration for the service. This step ensures the availability of resources and budget necessary for the project and officially records the expectations during service delivery. Contracting helps to ensure the effective implementation of the project and to solve problems that may arise during implementation.
3. During the process of familiarizing with the system under study, the expert, with the client's involvement, reviews and understands the logistics processes under study. The aim is for the expert to understand the system's operation, structure, material flow paths, as well as possible constraints and problems. Thorough understanding is essential for the development of later analyses and recommendations.
4. In the fourth step material flow diagram is creating. Within the defined system, fixed installations for material flow must be determined, as well as the connections between them, for each type of product.
5. Material flow processes are captured in this step. The material flow processes for each product type are recorded by the experts on a web-based interface, based on the material flow diagrams.
6. The delimitation of the examined packaging system is carried out in this step. Based on the data received from the client and/or information providers, experts enter the data of the examined packaging systems into the web-based data input interface, such as measured data, self-weight, load capacity, specific amortization cost projected on the transportation relation.
7. When determining the data of the packaging systems that can be applied at the material flow nodes, two types are distinguished. In one type, the packaging system remains constant for the passing product types, while in the other type, there is room for decision making. Experts work with the client to determine the testing options, and then they specify the types of packaging systems that can be applied to the product types passing through the respective nodes, as well as their loading quantity, loading time, specific logistics cost, and quality attribute data through the web-based interface.

8. When modeling material flow processes, it is important to specify the possible transport relations between the individual nodes. During this, professionals enter the data in the web application, which helps to make the material flow models more accurate. Data related to relations include, for example, transportation duration and quantity.
9. Parameters required for the operation of given technological equipment are specified. This includes the capacity and efficiency of the equipment etc. If modeling the equipment is extremely specific, further coordination may be required for the description or modeling of its operation. This data is important in the scheduling process as it helps to determine which equipment should be used and when.
10. The input data on material handling activities is carried out in this step, where we record the time factors and distances of material handling between individual workstations. This helps accurately determine the duration required for material handling and the route to execute material handling tasks. The accurate and proper recording of data on material handling activities contributes to making the production process more efficient and effective.
11. The scheduling task is the planning of the production process in terms of time, determining when and in what quantities of each product type will be launched at different nodes. The scheduling task considers available resources, such as machines, human labor, and raw materials, and aims to optimize duration and capacity. Proper execution of the scheduling task plays an important role in increasing production efficiency, reducing waiting time, and meeting deadlines.
12. In this step, the decision criteria influencing the selection of the packaging system are analyzed. Lead time measurement refers to the duration between objects within the system. The determination of the total cost of ownership is important in the selection of the packaging system, and the average usability and the quality of the packaging system are also important. The evaluation of packaging quality considers various aspects, such as packaging clarity, readability of shipping marks, proper packaging closure, and drop testing.
13. During the examination, not only the best packaging system combination needs to be determined based on the optimal objective function but also the conditions that the selected combination must meet. These can be, for example, lead time, cost, utility, or quality. These conditions are jointly determined by the client and the expert, and the expert then records the data. The goal is to select only those alternatives that meet these criteria.
14. The point of this step is to consult with the client on the criteria they would like to use to optimize the packaging system. Then the objective function is generated, the weighted amount of which is calculated for each packaging system combination. The objective function aims to minimize lead time and cost, moreover, to maximize usability and requirements.
15. The simulation model is automatically generated based on the data recorded by the experts. The simulation model runs based on the data uploaded to the web application. When creating the simulation model, it is important that the data is reliable and accurate. Automatic generation helps to save time during the simulation model building process and reduces the possibility of human error. The web application allows to upload data easily and quickly and run the simulation model easily, so you can get results quickly. Creating and running the model helps decision makers understand how the system works and makes predictions about possible outcomes.
16. Testing and validation of the simulation model are important steps in the development process. During testing, data, programming errors, and other conceptual errors are checked and eliminated by experts. The validation process involves comparing the model with reality for existing systems and verifying data and processes for future systems. Testing and validation of the simulation model ensure that the model accurately reflects the real world and provides reliable and valuable results for real-life situations.
17. A tested and validated simulation model can be used to predict which packaging system will be the most suitable for a given product. The model calculates the value of the objective function for each possible packaging combination, allowing the best option to be selected. Depending on the number of products, packaging systems and decision points under consideration, the number of variations being examined can significantly vary. It allows to increase the efficiency of the packaging process and reduce the costs of packaging.

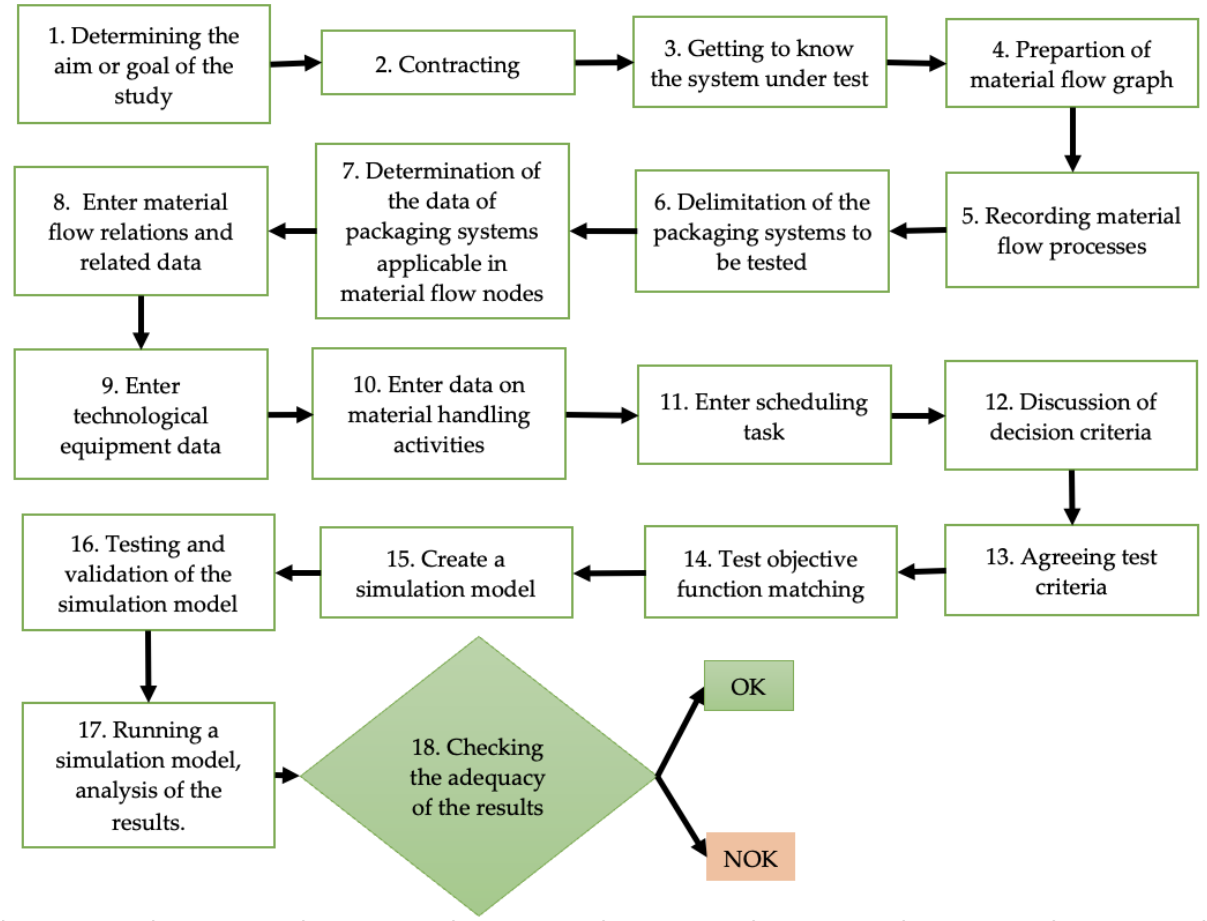

Figure 2: Steps for using the system (own edit)

18. During the examination of a given process or project, it is important to verify the accuracy of the results. If the results of the examination are feasible for the company, then the examination is successfully completed, and based on the results, further steps are taken towards implementation. If the results are inadequate or unfeasible, then it may be necessary to modify the examination model and conduct further examinations. The goal of the verification process is to ensure that the implementation process encounters as few errors and problems and that the projects produce the best possible results.

The method described allows the choice of packaging system to be made considering the interests of the company and the decision criteria. During the optimization process, it is also possible to integrate the processes they manage and to study the impact of different packaging options. However, the literature shows that such a complex system has not been developed in the field yet.

5. Summary

Based on the literature analysis, it was concluded that there is currently no framework that effectively defines the optimal packaging scheme for a given system as a service. However, given the increasing number of packaging systems and the growing complexity of logistics systems, the development of a science-based assessment framework could provide a significant competitive advantage for companies.

The paper presented the basic concept of a self-developed framework, which includes the actors, the applied tools, and the databases. In addition, as 18-step process defined to manage the selection of the appropriate packaging system.

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