Acta logistica - International Scientific Journal about Logistics
Volume: 9 2022 Issue: 4 Pages: 369-378 ISSN 1339-5629

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doi:10.22306/al.v9i4.327 Received: 13 July 2022; Revised: 25 Oct. 2022; Accepted: 15 Nov. 2022

OPERATIONAL CONCEPT OF AN INNOVATIVE PACKAGING MANAGEMENT SYSTEM

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Keywords: packaging management, simulation study, decision method, industry 4.0.
Abstract: Nowadays choosing the right packaging system is becoming increasingly challenging, mainly due to the pressure to meet dynamically changing customer needs. In order to remain competitive, the types of unit loads handled by companies are changing more and more frequently, which means that the choice of the ideal packaging system is also becoming increasingly important. The packaging of products influences the efficiency of logistics operations and the cost of running the system, whose role is becoming increasingly important. As a result of the detailed literature analysis presented here, it is concluded that no framework has been developed to date that provides an adequate answer to the choice of the optimal packaging system in different circumstances. The methods used in practice focus on a few narrow areas and ignore many relevant aspects. In this paper, we present the testing options for the packaging management system we have developed, the building blocks of the system and their role in the testing process. In addition, the basic process of one type of testing, namely the selection of the optimal packaging system for a new product type, is described.

1 Introduction

In industrial practice, the selection of appropriate packaging and the improvement of existing packaging systems are becoming increasingly challenging, mainly due to the significant expansion of product structures, the rise of e-commerce and the variety of seasonal packaging [1,2]. A detailed literature review was carried out using the systematic literature search method, the main aim of which was to determine the current state of the field and to identify the scientific gaps.

This literature analysis was carried out using the SLR (Systematic Literature Review) method. In practice, the usefulness of a research is mainly determined by its dissemination rather than its publication. The SLR includes documentation of all methods performed [3,4].

Traditionally, literature reviews present research findings in descriptive or narrative form. A good narrative presentation provides the reader with an overview of the different views of a discipline, including its key methodologies and theoretical traditions. Reports on systematic reviews should include a section on the methodology used and a precise description of the process of the study. This is mainly necessary, in their view, to ensure that all decisions are taken in a transparent manner [3,5].

The literature analysis (Figure 1) was carried out on 3 databases in order to capture the widest possible range of research. The first part of keyword search was performed for a broader domain. These were the following keywords:

- artificial intelligence,
- digital twin,
- digital twin technology.

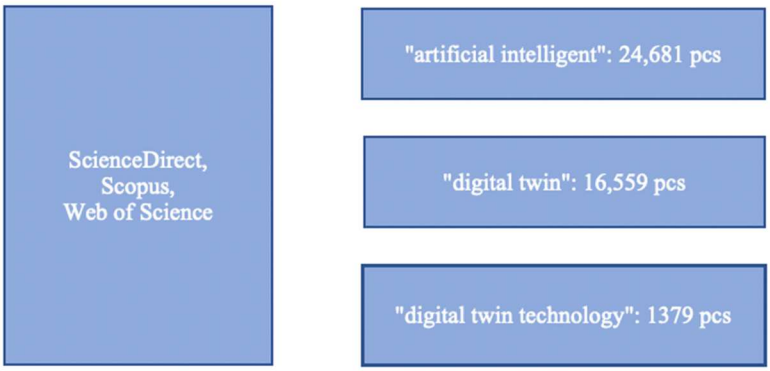

Figure 1 Previous literature reviews (own editing)

Specific keywords within these areas were then identified and also searched on Scopus, Web of Science and ScienceDirect. The research was also made in 3 databases Scopus, Web of Science and ScienceDirect. The used keywords were the same in all three databases.

Keywords:

- Packaging management AND logistics;
- Digital technology AND packaging system;
- Digital technology AND packaging planning AND logistics.

The timeline of publications is illustrated in Figure 2, which shows an increasing trend year by year in the ScienceDirect database. The search results for all keywords are summarised in Figure 2 for all fields.

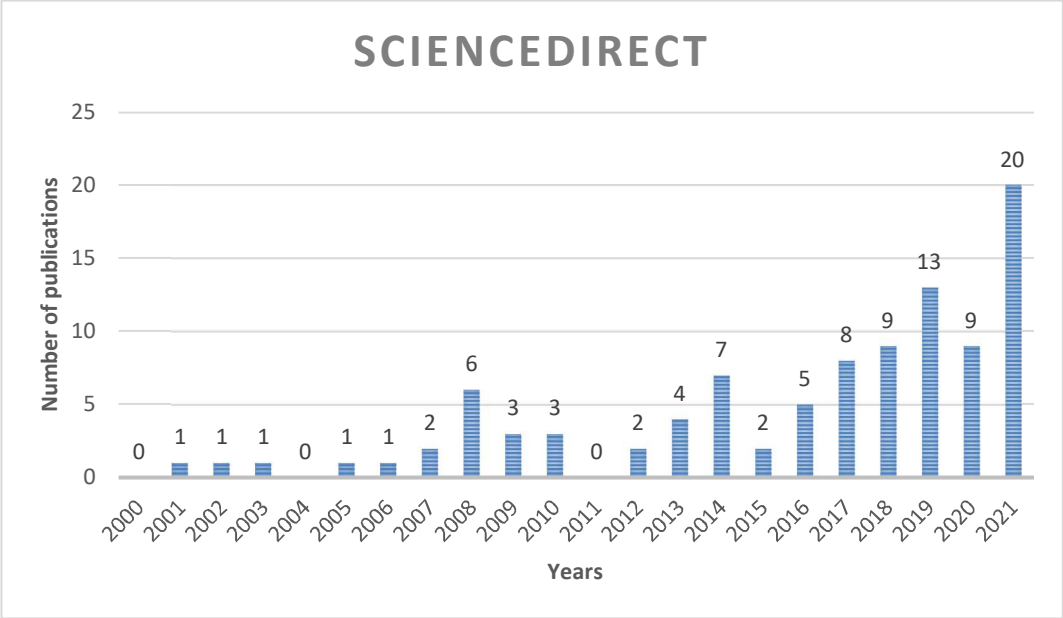

Figure 2 ScienceDirect database's publications result (own editing)

Publications in the Scopus database are illustrated in Figure 3, which also shows the summarised keyword search results for all fields.

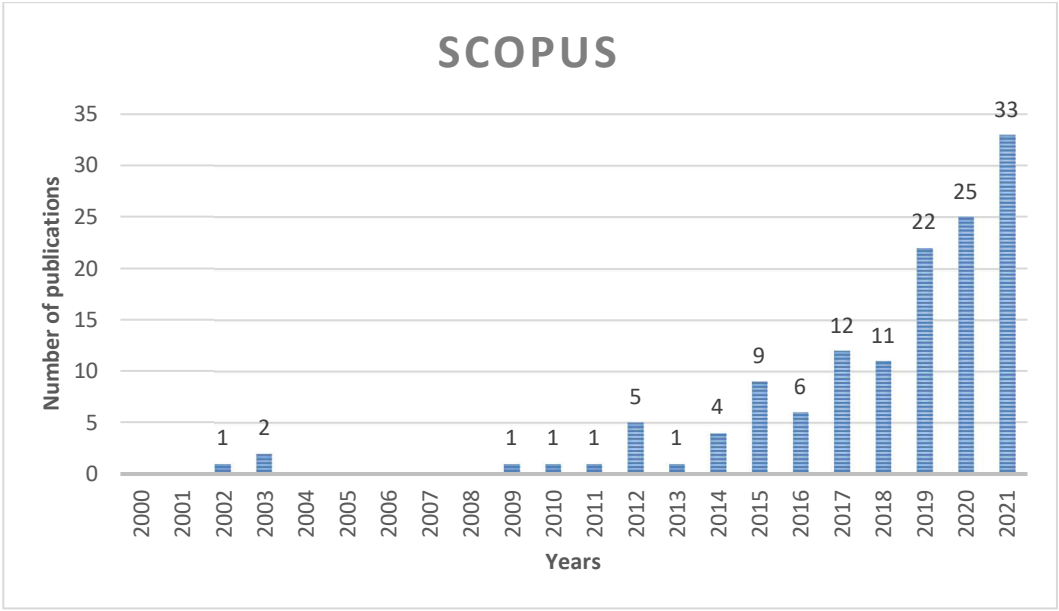

Figure 3 Scopus database's publications result (own editing)

It is clear from both figures that the number of publications on the subject has increased over the years. In the Web of Science database, the used keywords resulted only two publications, published in 2015 and 2020.

The number of publications shows an increasing trend, and after reviewing the abstracts of some publications, the articles can be grouped into 2 major categories. The first group is sustainability and the second group is digital technology and industry 4.0. It can be seen that there are significantly more publications related to sustainability in the databases. The publication [6] describes the principles of green packaging and the investments in its development. Study [7] aims to identify the main environmental sustainability initiatives of some logistics service providers and to identify future projects. The article mentions that the interviewed companies have implemented several initiatives such as energy efficiency, CO2 emission reduction. The publication [8,9] deals with the generation of packaging waste and the growth of e-commerce. This study considers several types of packaging materials, including disposable primary packaging, disposable protective packaging and returnable packaging. Sustainability and the circular economy are also addressed in [10,11]. A critical issue for circular economy industries is the development of reverse logistics for packaging and transport of semi-finished products. The journal [12] deals with the use of packaging in the automotive industry, where comparisons of different sustainable packaging systems are presented, but does not deal with digital technologies and the benefits of their application. The article [13], published in 2021, after the coronavirus pandemic, deals with soaps, hand sanitizers and their packaging. It has become essential to manage and recycle soap packaging waste to reduce its environmental impact. The study [14] also deals with the circular economy and presents a structured literature review. The strict environmental regulations related to the transport of environmentally hazardous materials offer a high cost saving potential for an optimized transport and packaging concept. This publication [15] is a case-oriented journal dealing with product-specific transportation of engine components, but digital technologies are not mentioned in the paper. The second category includes publications related to digital technologies and industry 4.0. Publication [16] deals with e-commerce logistics business models, Big Data analysis. It develops a hybrid content analysis model for in-depth analysis of the fundamental knowledge of e-commerce logistics. Publication [17] addresses the operations management problems of returnable shipping items. Publication [18] has already addressed the new opportunities of the digital age, but has not investigated packaging. This paper presents views that may be representative for the context of future bus services and the design of bus services. Research in [19] deals with artificial intelligence and the development of information technology. It proposes an approach to design business models for supply chain applications of artificial intelligence. Journal [20] deals with the application of the digital twin concept for proactive diagnosis of technology packaging systems. An important issue in the manufacturing of process equipment, especially packaging equipment, is the modernization of manufacturing automation systems. It deals with the elimination of failures in packaging equipment, applying Big Data analysis methods, artificial intelligence principles and digital technologies to solve these problems. The article Packaging 4.0 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 different sectors, including logistics [21]. The paper [22] provides a solution to the shortcomings of material handling systems in cloud-based manufacturing, presenting a new material handling paradigm. The identification and analysis of recyclable packaging in the automotive industry is addressed in [23]. Currently, if a product meets the requirements, it is labelled and then placed on steel pallets. Products are also secured with adapters to prevent movement within the pallet.

Based on the literature analysis, it can be concluded that no packaging management system has been developed so far, which ensures the optimal choice of packaging materials for the products under investigation by applying mathematical methods and Industry 4.0 technologies. In the rest of the paper, the operational concept of this system is presented.

2 Operational concept of the packaging management system

The presented packaging management system is basically concerned with the optimal choice of collection and transport packaging systems, that is does not cover the choice of consumer packaging. The operational concept of the packaging management system is presented, including the structure of the system, the tasks to be performed, the cases to be examined and the operational process.

2.1 Structure of the packaging management system

Figure 4 shows the initial conceptual design of the packaging management framework. To build the system, it is necessary to clearly define the actors, the main tools, the databases and the relationships between them. As shown in Figure 4, the framework can be divided into three parts: the study participants, the main tools used in its operation and the databases to be used.

Study participants: In order to define and continuously improve the development of the system and to ensure the quality of the inspections, the following participants need to be involved:

- ***Management:*** Management defines the development guidelines. They takes strategic and tactical decisions,

negotiates with new companies on the basis of expert advice and concludes contracts.

- ***Experts:*** The experts are completelty knows the packaging management system and doing the necessary tests. They have a complete knowledge of three main areas: selecting the right packaging for a new product (collective and/or transport packaging), selecting the right packaging for an existing product, and testing packaging because of quality reasons. They will also be responsible for data collection, data processing and evaluation tasks according to the type of test selected. The use of software and simulation programs supporting the packaging management system is also part of the scope of the duties.
- ***R & D team***: The research and development team develops the methods and procedures approved by management and required for testing
- ***Information providers*:** The information providers are those who provide the additional information needed to carry out the investigation. In particular, they provide data and parameters of possible packaging systems for a product, according to the needs of the experts.

Used major tools during process: In many cases, the tasks to be carried out by the packaging management system require environmental data and digital inspection facilities, the tools for which are:

- ***Simulation software:*** Solving manufacturing logistics problems in each area requires the use of computer simulation tools, mathematical statistics, modelling, and algorithms. The aim of logistics solutions is to properly influence and manage material flows. The application of mathematical modelling is almost impossible, as it requires the combined planning of material, information, and financial flows. Therefore, computer simulation is a perfect tool to solve these problems [24]. A discrete event driven simulation framework is used to examine the events associated with the proposed packaging system. This allows the virtual model of the plant to be coupled with the real plant control for the actual simulation [25]. Thus, the entire operation can be tested and optimized. With the discrete event driven simulation system, it is possible to improve and simulate logistic processes, optimize material handling, machine utilization and labor demand with statistical analysis capability. By using tools with object-oriented and 3D modeling capabilities, manufacturing accuracy, efficiency, throughput, and system performance can be increased [26]. Simulation processing starts with a preliminary analysis to identify problems, and then simulation plans, checks and validations are created to generate them. After collecting and examining the packaging data, the software processes it to identify the problem and generate simulation plans [27]. The simulation solution has several advantages over the real system, as it is cheaper, faster and allows to test many more possible cases, as well as to analyse designed systems that do not yet exist [28].
- ***Sensors, cameras****:* Other major tools include sensors and cameras. In some cases, it is necessary to collect and manage the data of the real system, and on the basis of these data we can propose a better, more efficient system, as well as to detect and manage quality defects during the inspection of packaging.

Required databases for system operation:

- ***Packaging system database:*** Database of packaging schemes that can be used in the optimization
- ***Logistics system database:*** A database containing the logistical data of the process under study, which are determined based on the data provided by the study company and/or a simulation study.
- ***Database for decision and optimization algorithm:*** Database of decision/optimization methods (conditions, objective functions) for selecting the right packaging.

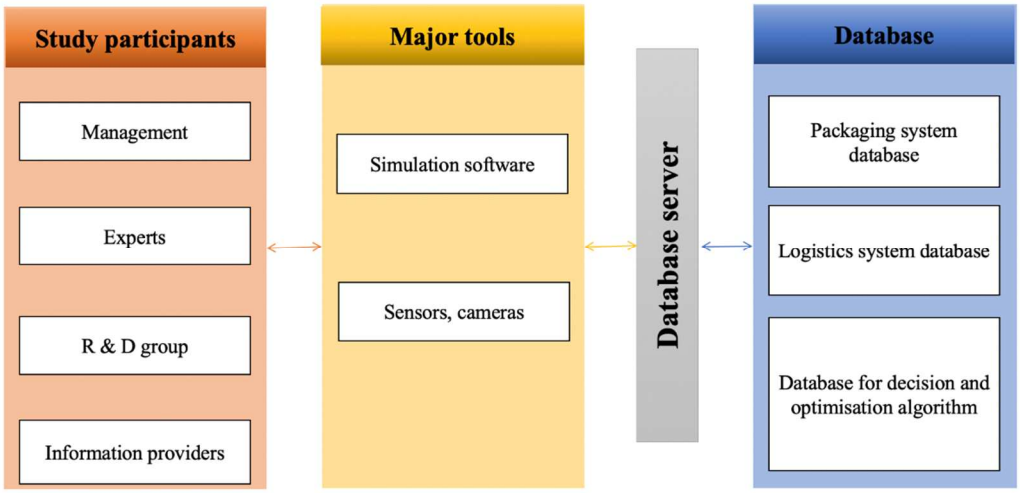

Figure 4. Packaging management system concept (own editing)

2.2 *Tasks to be performed by the packaging management system*

In this paper, the conceptual design of a packaging management system is presented, which, in terms of its function, helps to select and improve the appropriate packaging system and to ensure the quality of the packaging system used in relation to the designated logistics process. The developed packaging management system performs 3 main tasks, which are presented in Figure 5.

These are the followings:

- ***Selection of the appropriate packaging for the new product: model „A”***, which requires the use of a digital model.
- ***Improvement of the appropriate packaging for the existing product: model „B”***, which requires the use of a digital shadow.
- ***Testing the packaging to eliminate quality defects: model „C”***, which requires the use of digital twins.

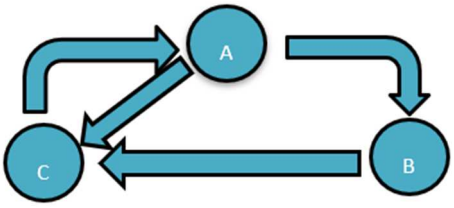

Figure 5 Packaging management system operational process (own editing)

In practice, these tasks are becoming frequent as a result of the drive to meet specific customer needs and increasingly effective product innovation, and all three types of tasks can occur within a short timeframe for a single product.

2.3 *Define the examine cases*

The designated logistics process can be extensive from supplier to customer. Once the system has been defined, the cases and their complex cases from supplier to buyer can be formed. We distinguish 6 elementary types and the complex cases that can be formed from them.

In order to understand the system to be analysed and defined, the 6 types are first presented. The packaging system for these types may change (full circle) or remain the same (empty circle).

The types defined for the purpose of the study are:

Type 1 (Figure 6): The type of packaging does not change during the test process. For example, if it is removed from the same packaging during production and then returned to the same packaging after processing.

Figure 6 Type 1 (own editing)

Type 2 (Figure 7): Unit load device changes in a process without branching. In this case, machining takes place after delivery to the production area, so the packaging system will change, as shown by the full circle.

Figure 7 Type 2 (own editing)

Type 3 (Figure 8): The unit load device will not change when several processes come together. For example, picking or assembly.

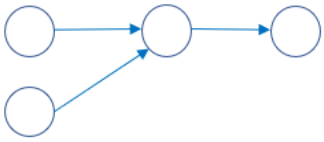

Figure 8 Type 3 (own editing)

Type 4 (Figure 9): The unit load device will change when several processes meet, e.g. picking or assembly.

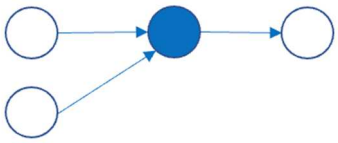

Figure 9 Type 4 (own editing)

Type 5 (Figure 10): The unit load device will not change for multiple forks of a process. In this type, product arrives at the production area from one supplier.

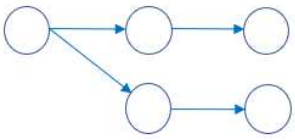

Figure 10 Type 5 (own editing)

Type 6 (Figure 11). The unit load device will change when several processes meet. In this type, product arrives at the production area from one supplier. For this type, a disassembly process takes place, where the packaging system will also change.

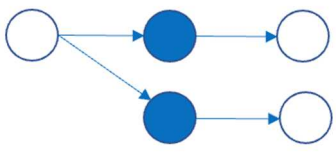

Figure 11 Type 6 (own editing)

These types can be combined to form chains.

2.4 Operational process of a packaging management system when choosing a packaging system for a new product type

Due to the complexity of the operational concept, only the operational process for model „A" of the three task types is presented in this publication.

Steps in the process under examination (Figure 12):

1. **Delimitation of the examined system:** The selection of the logistic subsystem to be developed should be done in this step [29].

2. **Define the purpose of the study:** This initial step in the process involves defining exactly what we want to achieve as a result of the study, including the decision criteria for the choice of packaging, their weight and the requirements for the packaging systems. The main decision criteria identified in the literature are as follows [29]:

- Transit time*:* The average time elapsed between two points in the delimited system. The duration of logistical operations can vary considerably depending on the type of packaging system and can be shortened by choosing the right packaging system. Shorter lead times, faster response to customer needs and lower losses increase the competitiveness of the company [30]
- Total operating cost: The choice of packaging system is a major determinant of the design of material flow systems and their operating costs, as well as the cost of purchasing and maintaining the packaging system. It is in the company's clear interest to choose a packaging system that minimizes the overall operating costs.
- Quality of the packaging system: the quality of the packaging system can be an important criterion for the choice of the packaging system. Only packaging systems that meet the essential requirements should be included in the test. This factor is a component defined by the company, with a value ranging from 1 to 10 (1 being the worst to 10 being the best). Examples of factors considered in relation to this factor are the availability of the packaging system, its recyclability, its modernity, its integration into the current system [31].
- Usability within the process under test: this indicator is used to measure the expected number of times the packaging system under test can be reused in the designated logistics process. The packaging system can be divided into two main parts. One is plastic and the other is wood based. Plastic devices have a lifetime of about 100 cycles in the supply chain, while wood devices have a maximum of 15-20 cycles [32].
- Environmental impact of the logistics process: environmental protection is becoming increasingly important today. Sustainability, particularly about regulatory and public concerns about single-use packaging waste, is driving a major change in consumer packaging. Regulators are moving forward, and companies and retailers are proactively committing to improve the sustainability of their packaging and fundamentally rethinking their packaging systems. For packaging processors with the right focus and innovation capabilities, the new environment could offer significant growth and new partnership opportunities in packaging review [33]. The environmental impact of the logistics process is determined subjectively by the experts conducting the study, on a scale of 1 to 10, where 1 is the worst and 10 is the best rating.

Weighting method: there are several methods in the literature for determining the weighting of decision criteria according to the interests of the company. The weighting process can be either a serial scale or an interval scale. When solving multicriteria decision tasks, one of the essential elements is to determine as precisely as possible the order of importance of the evaluation criteria, 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, and it is therefore important to perform weighting steps. The interval scale also provides information on the degree of preference. In this respect, the Guilford method is recommended as it is the most widely used and accepted in terms of reliability, accuracy and applicability. The method requires the use of an analytical team with a minimum number of staff. In the design of the present system, this procedure is carried out by the expert group, with a minimum of 5 persons being suggested. The procedure requires a comparison work in pairs of factors to be compared, weights are already automatically added [34]. The Guilford weighting pairwise comparison method is used to determine the order of the evaluation factors, transforming them to an interval scale. From a set of evaluation factors, any 2 can be selected to determine which is more preferred over the other, i.e., which characteristic or attribute is more important than the other. Each decision maker in each pair assigns a score of 0 or 1 to express which evaluation factor is preferred [35].

Setting requirements for the packaging system: criteria can be set for specific aspects of the possible packaging systems for the product types under consideration, which will influence the outcome of the selection process (e.g. the operating cost of the system under consideration must not exceed a certain value).

3. **Define the objects relevant for the choice of packaging system(s):** the operations and objects relevant for the choice of packaging system(s) shall be identified for the logistics system defined. For example, the formation, dismantling, quality control of the packaging system(s), i.e. the points where the formation and/or dismantling of the packaging system(s) can take place. Based on these objects and the material flow relationships between them, a material

flow graph can be constructed from combinations of the cases from Figure 6 to Figure 11.

4. **Material flow graph:** Based on the relevant objects and the material flow relationships between them, a material flow graph can be constructed using the cases from Figure 6 to Figure 11 to illustrate the optimization task.

5. **Uploading packaging scheme database with datas:** The packaging scheme database contains several data tables, which are:
- Ranks of packaging systems under study: a data table containing the main information of the packaging systems, with data on size, load capacity, capacity, purchase cost, maintenance cost, quality, usability, book load data for the packaging systems. It is the responsibility of the information providers to fill in the data table.
- Conformity data for packaging systems tested: This data table shows which packaging systems can be used for which material flow object according to the requirements defined by the company. The experts are responsible for completing the data table.

6. **Uploading the logistics system database with datas:** the database containing the main data of the logistics system under study contains the following data tables:
- Time factors for the packaging systems tested: this data table shows the unit load formation and/or dismantling and/or handling times of the packaging systems tested for the material flow objects. The data in this table are filled in by the experts.
- Material handling equipment data: a data table containing data on speed, size, operating cost, maintenance cost, capacity of the material handling equipment in the process under investigation. The experts are responsible for completing the table.
- Technological operations data: a data table containing the time factors and capacity data of the technological operations in the material flow system under study, to be completed by the experts.

7. **Making possible test variants:** in this step, the variants of the packaging systems that can be assigned to the objects defined in step 3 are trained, so that all possible packaging system chains to be tested by the simulation test model are obtained. A packaging scheme chain shows which packaging scheme is applied to which object with respect to the defined scheme.

8. **Determining the test conditions, the objective function:** the test criteria defined in step 2 are converted into normalised objective function components and weighted using the Guilford weighting method. By determining the weighted sum of the normalised objective function components, an objective function can be formed for which the highest value packaging system chain variant gives the optimal value. If necessary, it is possible to select conditions for the attributes (e.g. lead time, operating cost, etc.). In case an attribute of a packaging chain does not satisfy the condition(s), it cannot be selected.

9. **Designing a simulation test model:** the basic principle of simulation is based on a simplified representation of a real system [36]. To build a real simulation model, it is necessary to know the simulation technique and other areas of the company, such as the logistics of production and service processes [28]. Simulation tests have been designed by building a custom application or by using predefined simulation frameworks (e.g. Plant Simulation, Arena, Simul8, etc.). Development time can be significantly reduced by using these frameworks, as predefined objects can be used and parameterized, while at the same time the specific behaviour of the model can be managed by methods if necessary. The design of the simulation model should be done taking into account the defined system and the test objectives. The material flow model and the information flow model shall be developed and the method of operation shall be defined in order to produce the objective function defined in the previous section.

10. **Simulation model implementation:** the simulation test model designed in step 9 is integrated into the simulation framework in this step.

11. **Upload simulation test model data:** in order to run the simulation model, the simulation model data tables must be populated with the data defined in the previous steps.

12. **Testing and validation of the simulation model:** after the simulation model has been created, the model is tested to eliminate possible data errors, program errors and conceptual errors. For an existing system, the validation of the simulation model is done by comparing the model with reality, while for a future system, it is done by checking the data and processes.

13. **Running the simulation model, evaluating the results:** running the tested and validated simulation model results in the value of the objective function for each packaging system chain variant, so that the most favourable variant can be selected. The number of variants tested depends to a large extent on the number of packaging system variants that can be tested for the objects, as well as on the number of objects.

14. **Checking the appropriateness of the results:** in this phase, the validity of the results obtained is checked,

and if it is feasible for the company, the test is completed and the company moves on to implementation, otherwise further tests are carried out by modifying the test model.

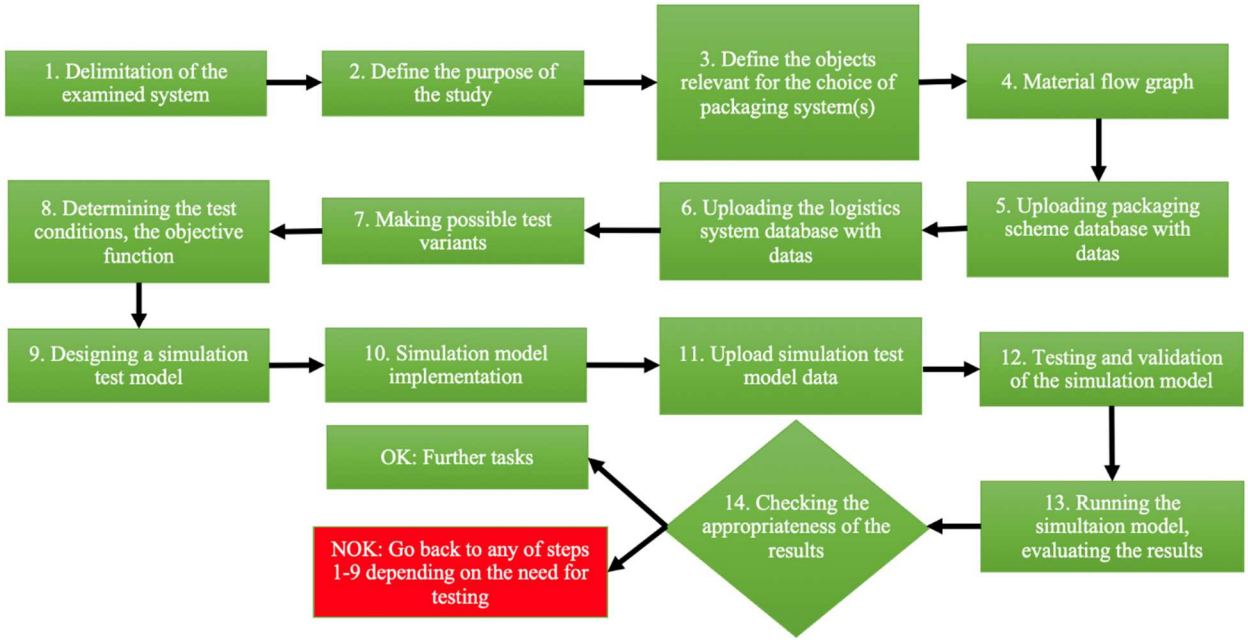

Figure 12 Steps in the process under examintaion (own editing)

3 Conclusion

The publication focused on the area of packaging system choice which area are continuously growing. Following a detailed literature review, a major gap in the competitiveness of companies in this area was identified. Companies are increasingly confronted with the issue of choosing the right packaging system due to the variability of customer needs, but the available methods only address a subset of these issues and overlook a number of important aspects. The paper presented the basic operational concept of an innovative packaging management system in which advanced digitalisation technologies (e.g. digital twin, digital shadow, etc.) played an important role. It is considered that by creating a packaging management system based on scientific modelling and optimisation methods, the packaging system selection process can be made more efficient than before (considering multiple variants and aspects), reducing several losses (e.g.: transport loss, loading loss, maintenance loss, etc.). The concept presented the testing options, the building blocks of the framework and their role in the testing process. The main steps in the application of the framework were described through the choice of packaging system for new products. In the following, we plan the detailed development, implementation, testing and application of the presented framework in a corporate environment.

Acknowledgement

The described article was carried out as part of the NTP-SZKOLL-22-0023 National Talent Program of the Ministry of Human Capacities.

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