SIMMAG3D AS A TOOL FOR DESIGNING OF STORAGE FACILITIES IN 3D

Marianna Jacyna[1], Mariusz Wasiak[2,] Andrzej Bobiński[3]

[1,2,] Warsaw University of Technology, Faculty of Transport, Warsaw, Poland

[3] Logifact-System Sp. z o.o., Warsaw, Poland

[1]e-mail: maja@wt.pw.edu.pl
[2]e-mail: mwa@wt.etu.pl

Abstract: *Designing of storage facilities is an interdisciplinary process that requires consideration of technical, economic, social or environmental issues. Storage facilities, as a part of supply chain are designed to provide customers availability of goods at a certain time, quantity and place. This involves the functions resulting therefrom, such as storage, sorting, picking, packing, etc. The efficiency of processes in the supply chains is strongly influenced by the location and shape of the storage facilities that are critical components. These issues are multi-threaded, and they are subject of an iterative approach in which information tools are playing a special role. One of such tool is the SIMMAG3D system. It is a system for modelling and visualization in 3D of warehouse facilities, which was built based on developed mathematical models, computational algorithms and functional dependencies necessary for the designing of storage facilities. It also takes into account the different types of warehouses and design methodologies as well as the location of warehouses in the logistic network. The article presents the elements of the SIMMAG3D system and characterizes its functional capabilities. It has been pointed out that one of the key elements of the system is the module for 3D visualization of storage facilities. It has been described in detail. In addition, an example of the visualizer operation on real data concerning one of the FMCG storage facility is provided.*

Key words: *SIMMAG3D, storage facilities designing, 3D visualization, IT system.*

1. Introduction

The problem of storage facilities designing is an interdisciplinary process requiring consideration of technical, economic, social and environmental issues that involve the use of various IT tools, including simulators (Ashayeri & Gelders, 1985; Rushton et al., 2006). The project of facility should be considered due to space, technology, organization and economic considerations. However, the way to take into account of these factors is conditioned by the functions, which the object has to perform in the scope of execution of the logistic task. Designing of storage facility in the aspect of the object's surroundings is shown in fig. 1.

As previously pointed out, project of a storage facility is difficult in itself because the size and functional structure of the facilities depends on many factors. Storage facilities, as a part of the supply chain, are designed to provide customers the availability of goods at a certain time, quantity and place. This involves the functions resulting therefrom, such as storage, sorting, picking, packaging, etc. Therefore, depending on the

environment and configuration of the logistics network, the designing process of the warehouse must take into account not only the functions that will be performed according to the demand but also its location in the supply chain.

The subject of analysis conducted in this paper is to present a tool supporting modeling, simulation and visualization of the storage process developed under the project "System for modeling and 3D visualization of storage facilities" (SIMMAG3D), funded by the National Center for Research and Development. The authors' idea was that the developed tool would enable to map the behavior of the warehouse system with the accuracy of the logistics units movement. This approach allows for conducting research on the interrelationships between tasks, equipment and organization of systems operation with accuracy, which is comparable to real systems. In addition, it is a condition for obtaining simulation results comparable to WMS data, and integration of the tool with this system is the basic assumption of the SIMMAG3D project.
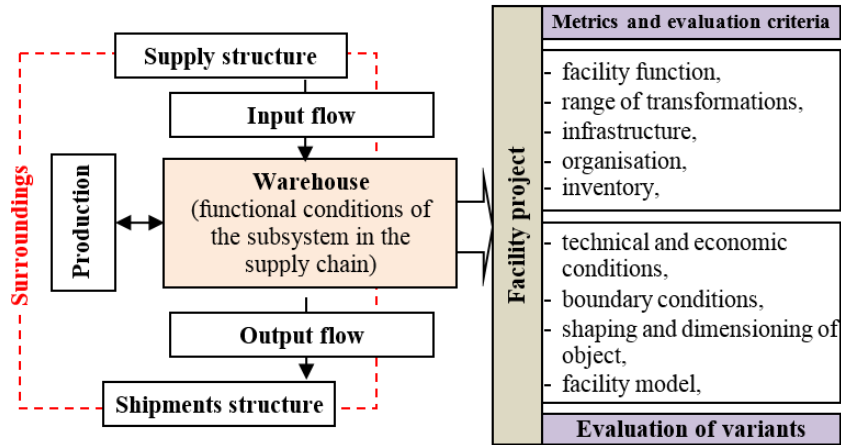
Fig. 1. Project of the warehouse taking into account its surroundings

2. Processes implemented in storage facilities

In a typical warehouse system model, there are three basic groups of processes, including (fig. 2.):
- processes related to the freight flow that appear on the entry,
- processes related to the handling of freight flow inside the object,
- processes related to the freight flow that appear on the exit.

The above processes affect the project of warehouse. However, for the designing apart from the processes taking place in the object, processes occurring in the vicinity of the object are extremely important. The procedure for comprehensive designing of storage facilities is shown in fig. 3.

Designing of storage facility in terms of variant involves defining a number of factors that can be classified into four groups:
- space and movement in space,
- selection and configuration of technology,
- materials management,
- process and resource allocation.

Apart from the factors related to the interior of the storage space, should also be taken into account external factors - the surroundings of the object. To these factors should be included conditions connected with supplier and receiver associated with the supply chain profile, location, and infrastructure. Defining of these factors allows for running a simulation process, which will allow for generating of multiple variants. Then these variants are evaluated and the best one are visualized. If after the visualization, the user thinks that something needs to be corrected, then corrections are made and, if necessary, the simulation process is starting again.

3. IT tools supporting the designing of storage facilities

The designing process can be aided by a variety of IT tools, beginning from application for development of technical project through advanced tools for process simulation in storage facilities. Due to the functionality of the SIMMAG3D application (see next chapter), the article focuses on simulation tools.

Simulation provides answers on questions like how the system under test will behave in a particular situation and what will be the consequences of decisions made under certain conditions. The simulation method should be used when it is not possible to use analytical methods. Simulation methods are therefore particularly useful in the study of complex systems, including logistics systems.

However, the typical goals of constructing simulation models of logistic systems are (Brzeziński, 2007):
- qualitative / quantitative determination of the influence of selected factors on the system,
- determination of the values of certain functional characteristics of the system,
- comparison of alternative systems (variants) in specified operating conditions or selection of the best variant of the system from a set of variants.
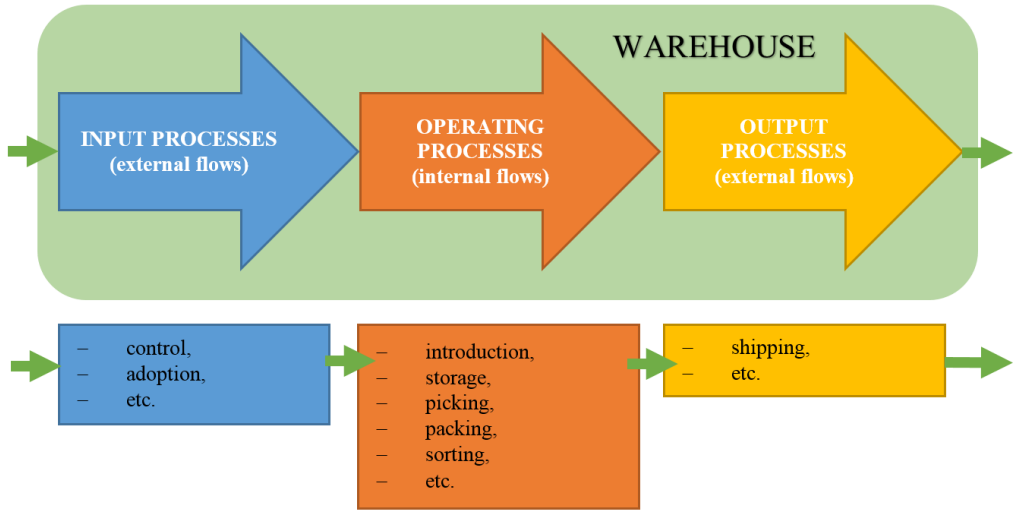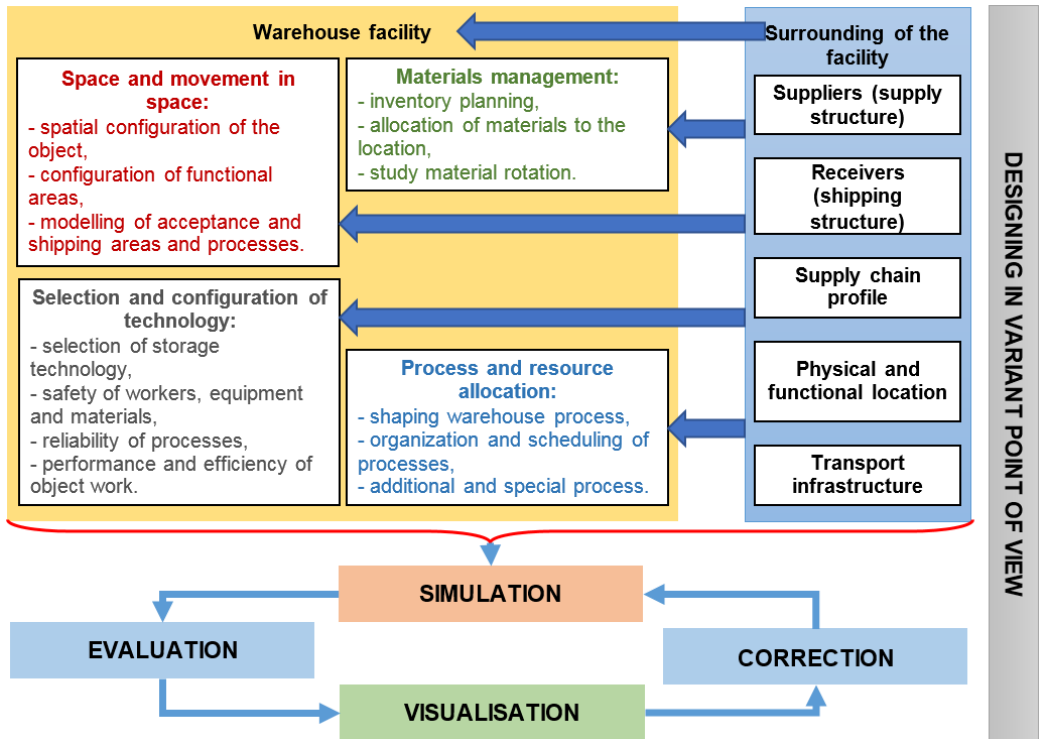
Fig. 2. Division of warehouse processes

Fig. 3. Comprehensive approach to the designing of storage facilities

In the literature of the subject, there are many proposals for the use of simulation studies for the designing of logistics systems (for example Ambroziak & Jacyna, 2002, 2003; Leszczyński, 1973; Wasiak, 2007). These studies allow for observing the impact on the performance of systems, adopt resources of them, the organization of their work, and thus allow for a rational selection of their equipment.

In the literature, among the specialized applications for simulation research are listed among others (Korzeń, 1999; Turban & Meredith, 1991):

- DYNAMO (DYNAmic MOdels) – Simplified graphical simulation language developed based on SIMPLE by Phyllis Fox and Alexander Pugh under the direction of Jay Wright Forrest for the design and research of production processes. It was developed in the years 1959-1986 (Clark & Kurono, 1995);

- EXTENDSIM (earlier Extend) – developed in 1987 by Bob Diamonds program to simulate discrete events and continuous processes with animation in 3D. This application as first introduced interactive drag and drop modelling and offered a development environment for creating unique, reusable components (Krahl, 2012). This program is still being developed [http://www.extendsim.com (access 13.10.2016)];

- GPSS (General Purpose Simulation System) developed around 1960 by Geoffrey Gordon programming language used for computer simulations. The most common use of this language is simulations of the railway system. This program is still offered [http://www.minutemansoftware.com/ (access 13.10.2016)];

- SIMPLE (Simulation of Industrial Management Problems with Lots of Equations) – first programming language for converting of model equations on machine code developed in 1958 by Richard Bennett (Forrester, 1989);

- SIMSCRIPT – developed in 1963 by Harriet Markowitz and Bernard Hausner program for building simulation models for decision support systems in a variety of applications (including transport and logistics). This program is still being improved [http://www.simscript.com/about/about.html (access 13.10.2016)];

- SIMULA (SIMUlation LAnguage) – developed in 1962 by Ole-Johan Dahl, Bjørn Myhrhagen and Kristen Nygaard, the first object-oriented programming language (Simula I, Simula 67). It was made with the intention of creating computer simulations. This language was developed until 1967, although it is still used today primarily in academic circles (Krogdahl, 2003);

- SIMULINK – used to perform computer simulations part of the MATLAB numerical package. Simulink uses the graphical interface to build simulation models with discrete and continuous time [https://www.mathworks.com/products/simulink/ (access 13.10.2016)]. Its application is primarily signal analysis and modelling of control systems;

- SLAM (Simulation Language for Alternative Modeling) – offered since 1979 by Pritsker & Associates, Inc. (now Pritsker Corporation) universal language of simulation systems (including production, transport) (O'Reilly, 1995);

- STELLA (Systems Thinking, Experimental Learning Laboratory with Animation; known also as iThink) – developed in 1985 by Barry Richmond, a visual programming language for modelling the dynamic systems. In addition to sources and graphical functions, four basic graphic elements are included: storage, relocation, transformation, merging (Clark & Kurono, 1995). STELLA language is constantly being developed [http://www.iseesystems.com/store/products/stella-architect.aspx (access 13.10.2016)];

- VENSIM – developed in 1990 by Ventana Systems Inc. Visual programming language for building simulation models with continuous time and discrete time. Models created in this environment can be calibrated, among others using data from the optimization and Monte Carlo methods. This is a general-purpose modeming language [https://vensim.com/ (access 13.10.2016)].

- The DOSIMIS software (e.g. Karkula, 2008) or even Flexim (e.g. Zhu et al., 2014) are also well known for simulation analysis tools used in logistics systems analysis. In addition, many other tools for simulating of logistics processes with an enhanced graphical interface are available. One of the modern tools of this class is eM-Plant. This package enables the construction of a simulation

model for any logistics facility based on fully configurable components representing load stations, single processes, assembly and packaging, business processes, routing and transport equipment, storage buffers and human resources (Borowski, 2005).

Among modern simulation tools that can be used in logistics research, the Enterprise Dynamics package (formerly known as Taylor II) also deserves attention (Korzeń, 1999). It is a powerful program for simulation and advanced visualization of processes in 3D. It can be used for testing production, logistics and other systems (Dobrzańska-Dankiewicz & Krenczyk, 2008).

Described examples of simulation tools usually offer the possibility to generate cause-effect diagrams and structural diagrams that are more or less tailored to the specifics of the processes carried out in the storage facilities. However, there are no commercial tools that fully replicate real-world processes and, above all, allow them to be optimized for the efficiency of their processes. At most, it is possible to investigate by trials and errors method from the pre-determined by analytical methods solutions in the area, to solutions which meet all given criteria for efficiency. Often, due to the varied substantive conditions, complex logistics systems can only be designed piecemeal - the selected part of them is chosen because of the chosen conditions. In addition, with the exception of the Flexsim version available from 2016, integration of the simulation tool with WMS warehouse management applications is not assured. These barriers were a prerequisite for developing the SIMMAG3D tool, which covered the most important issues in the design of complex logistics systems ranging from supply chain configuration and warehouse location selection through spatial and functional design of these objects to the simulations and visualization of their processes. The developed tool enables in this scope, among others visualization of inventory and the full integration of WMS systems, including both import actual configuration data space and resource inventory, also export of design obtained solutions for a storage facility.

4. SIMMAG3D system and its functional possibilities

4.1. General remarks

SIMMAG3D is a system for 3D modelling and visualization of warehouse facilities, which was built based on developed mathematical models, computational algorithms and functional dependencies necessary for the designing of storage facilities. It also takes into account the different types of warehouses and design methodologies as well as the location of warehouses in the logistic network.

It should be emphasized that this system is a tool to assist in the designing of warehouses by enabling of preparing models to interact with WMS systems or simulation systems, providing presentation and visualization of material flow and freight flow processes. It also enables analysis of the effects of the implementation process improvements implemented in the storage facilities.

As mentioned earlier, designing of storage facility due to the shape of the building is difficult because of the variety of issues which should be taking into account (fig. 4). The answer on these problems is the SIMMAG3D system. Because it is designed for modelling and visualization of 3D warehouse objects, it is very important for implementation, education and research. Its architecture and module descriptions are described in section 4.2. It should be mentioned about the functions of the SIMMAG3D system, among which the basic are:

- modelling of warehouse facilities in 3D,
- designing of warehouse facilities in 3D,
- visualization of warehouse processes in 3D
- optimal placement of objects in the logistics network,
- designing of supply chains in different planes,
- shaping and dimensioning of warehouse facilities,
- scheduling of internal transport process,
- multi-criteria evaluation of proposed solutions,
- simulation of the flow of materials in different functional areas of warehouse facilities.

The model thus allows the preparation of a storage facility in 3D, visualize, plan and evaluate the processes taking place in it, as well as propose a location of the object in the logistics network.
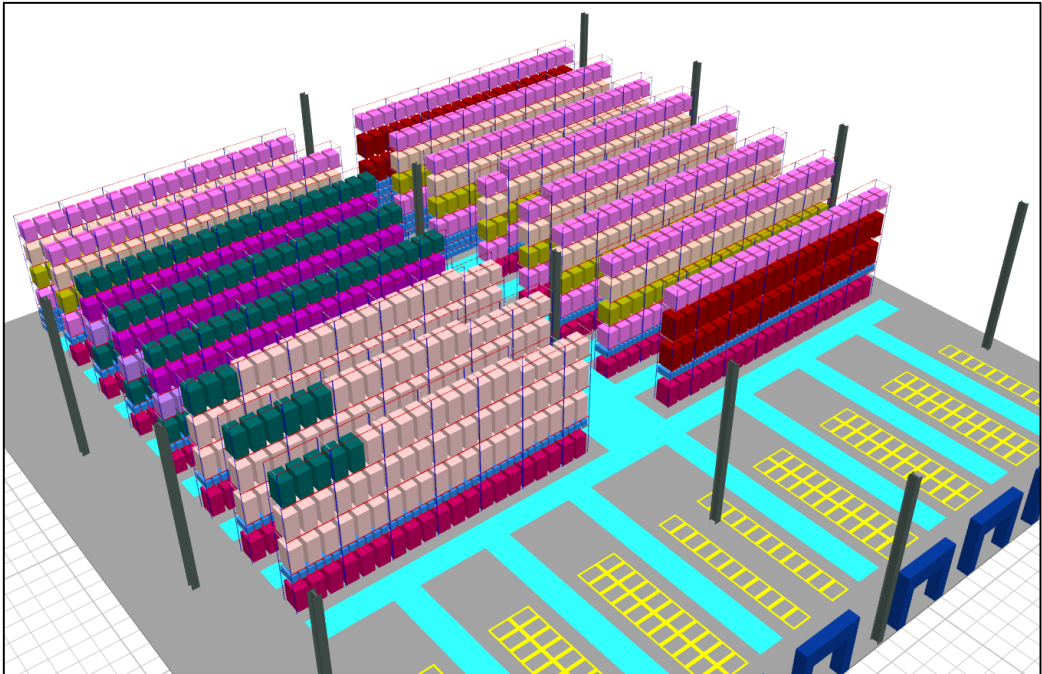
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Fig. 4. Visualization in 3D of warehouse solid (source: own work using SIMMAG3D system)

4.2. Functional capabilities of the SIMMAG3D system

The SIMMAG3D system provides a comprehensive approach to all aspects of warehouse designing as a result of (
fig. **3**):
1) Shaping of the warehouse process, including:
- determining the stages of the storage process,
- sequencing of warehouse process elements,
- separation of sub processes due to special requirements e.g. customer,
- mapping of warehouse processes,
- selection of material transfer strategy by warehouse,
- estimating the reliability and effectiveness of warehouse processes,
- determination the cost of the warehouse processes.
2) Organization and scheduling of the warehouse process, including:
- shaping the flow of information and decision patterns in the organization of work,
- allocation of resources to warehouse tasks (scheduling),

- allocation of time to warehouse tasks (scheduling),
- technological limitations of the implementation of warehouse operations,
- wave-picking - wave organization of the warehouse process.
3) Taking into account the additional and special processes such as:
- cross-docking,
- planning and organization of value-added services (VAS).
4) Selection of storage technology (storage and movement) for logistic tasks (functional configuration), and especially allows:
- selection of storage technology in the reserve areas and others,
- selection of materials delivery technology in picking zones,
- selection of inter-zone internal transport technology,
- selection of intra-zone internal transport technology,
- selection of information technology.

Implementation of the specified steps using SIMMAG3D system, allows for developing storage facility project. Utilization of such comprehensive tools equipped with visualization and simulation of the work of the object allows to avoid many design errors, and their consequences in the real object.

Utilization of tools such as the SIMMAG3D system is not only aimed at minimizing the cost of operating the storage facilities or improving the quality and reliability of services, but also minimizing errors both qualitatively and quantitatively.

Simulations and multivariate analysis of interference allow to improve warehouse's performance in terms of space and resources, improve workplace safety, and reduce operating costs in the supply chain by inventory minimizing.

The architecture of the SIMMAG3D system is shown in fig. 5. The developed system is divided into functional layers. Among them they were distinguished:

- user interface (GUI),
- WMS>SIMMAG3D interface,
- database (catalogues and 3D libraries),
- data generator,
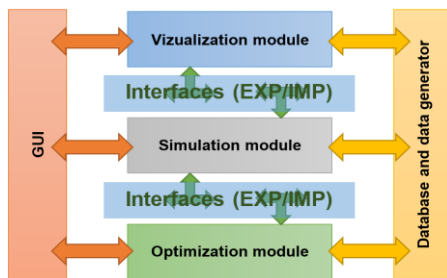- 3D visualization,
- optimizer with simulator.

Fig. 5. SIMMAG3D architecture

The graphical user interface is an application layer that allows communication with the system. It consists of two parts, the first one concerns visualization for object management and modeling. The second part concerns the operation of additional elements of the application i.e. optimizing and simulating the work of the object (after saving the result in the database it is possible to present them in 3D).

Interface WMS>SIMMAG3D – It is responsible for the communication between the WMS systems and the SIMMAG3D system. Data exchange tables are used to import information about the storage facility (existing). Downloaded data to the database include, but are not limited to, master data, release orders, states, alerts, as well as data from the WMS configurator of processes, spaces and units.

Database – it consists of three main layers that store and process data for the SIMMAG3D system. In the database, the part for the 3D models of architectural equipment and solutions, the part for the catalogs for optimization and simulation, and the part for the visualization of the object and inventory in 3D are separated. The database was developed in the Microsoft Azure cloud, allowing easy data access and simple management and modification.

Data generator – module which gives the ability to generate random data for design and optimization. For the design of new objects and upgraded objects it is often necessary to obtain additional data that the designer does not always have. It was therefore possible to generate data, for example, based on historical data or forecasts, and randomly based on the distribution.

3D Visualization module of SIMMAG3D system offers the user an opportunity:

- carry out analysis and selection of characteristics - within this possibility the user can select individual characteristic values, change their values and perform analyses,
- modelling objects and their graphic design - within this possibility, a user after entering a series of data can build a warehouse object from the finished elements using their graphical representation.

The 3D visualization module can use the database developed within the SIMMAG3D project for:

- data about the object and its configuration,
- equipment catalogs
- object libraries in 3D.

In addition, the database can be updated with data from the WMS (Warehouse Management System) in the area:

- basic data,
- order data,
- stock data,
- schedule data,
- data necessary to configure the space, process and storage units.

Within the optimization and simulation module, the user can use the following components:

- Storage location and supply chain design tools, which will allow to determine the optimal location for project, based on a series of input data. The second functionality of the simulator will be the ability to design the supply chain - search for relevant links between the various supply chain links located in a specific space.
- Tools for designing and dimensioning storage objects which, based on a series of input data, including logistic tasks, will allow to spatial shaping of particular zones in the object and their dimensioning.
- Internal transport scheduling tool based on input data input, will allow to spread tasks over time and set up start-ups.
- Multi-criteria evaluation tools based on the data provided by analytical methods, will allow to find the most advantageous variant - e.g. in the assessment of the designed storage location variants.
- A material flow simulator in the functional areas of an object that, after entering a series of input data, will allow the distribution of the material stream in the functional zone and performing analysis.

As apparent from the above modules: *optimization and simulation, visualization in 3D* and *database module* are the basis for the functioning of the SIMMAG3D. User access to individual program modules is accomplished through a graphical user interface.

Data for the purpose of the above mentioned tools are stored in the internal database, which is accompanied by a data editor (for data to be edited), data importer (to be able to import data into it) and data generator (in the absence of relevant data can generate them). The database, in addition to being a data storage function, also functions as a data feeder, since, as mentioned above, the simulators and visualizers for correct operation require a series of input data.

The author's intention, the SIMMAG3D system is to be, as previously mentioned, a tool for designing a storage facility and for later managing of the development of this object. Support for Warehouse Managers in the form of a WMS integrated module, which is a graphical 3D visualizer with statistics and preview of inventory changes, will allow for more efficient work and identification of places and procedures where improvements need to be made. In addition, according to the authors, the SIMMAG3D system can be applied in didactics and training, where it is important to visualize the decisions made and their impact on the process in the warehouses.

Due to the fact that the SIMMAG3D system is intended to support the management processes, it was decided to introduce new design capabilities, including the ability to shape the supply chain structure and location selection. In order to shape an object, the graphical interface allows you to model the object using drag and drop.

Prepared catalogs of internal and external transport equipment and architectural solutions allow for simple shaping of individual zones in an object. Moreover, in order to simulate the work of the designed object, the system is enriched with a catalog of unit operations, which allows verification of accepted solutions. Directories are implemented as a database for the entire system.

These features are also of great value in object management as well as in teaching processes. The general scheme of the SIMMAG3D system is shown in fig. 6.
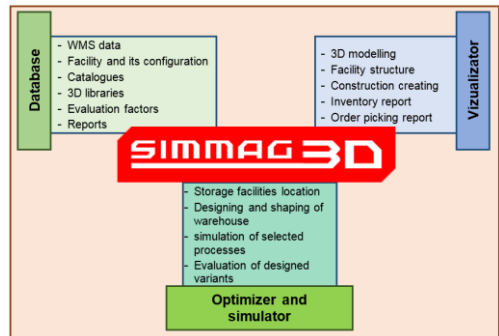

Fig. 6. SIMMAG3D scheme

5. 3D visualization of functional areas in SIMMAG3D system

The warehouse is in the form of a three-dimensional solid, mostly rectangular. Warehouse space is defined by the construction of the warehouse and equipment - pallet racks, shelving racks, space dividing systems such as mezzanines, walls, and platforms. Angles of straight and repetitive blocks of elements dominate, forming spatial arrangements defining the usable space for storage and transport space. This kind of storage system makes the 3D modeling of these facilities easier and more desirable.

The three-dimensional model of the warehouse, in the visual layer, essentially consists of following representation:

- structural elements of the building - floors, walls, columns of the supporting structure, doorways (gates), mezzanines and storeys,
- shelving structures - pallets, shelves, etc.
- storage units - pallets, cartons, etc.,
- continuous internal transport equipment (eg conveyors) and intermittent (eg forklift trucks)
- surface painting elements and other markings in the form of flat graphics.

One of the major modules of the SIMMAG3D system is 3D visualizer of warehouse facilities. The system depicts the physical and functional structure of the warehouse. The physical structure of a warehouse in a three-dimensional model consists of the following elements:

- rack - a set of storage slots connected to each other in one construction. Each rack has its own unique number or symbol,
- socket - shelf socket with physical dimensions and permissible load. Each nest is part of a rack,
- buffer - a separate area in a storage space having physical dimensions and a permissible load but not part of any rack,
- location - storage location with a unique address. Each slot or buffer can consist of any number of sites.

The functional structure of the warehouse, reflecting the course of the warehouse process in a three-dimensional model, consists of the following elements:

- Functional area - a part of the warehouse defined for picking up with a well-defined area and the way of management. It can consist of one or several storage areas.
- Functional zone - a part of the warehouse with a strictly defined area and capacity in the loading units eg Entrance Buffer or Pallet Reserves Zone. The zone must be homogeneous in terms of logistical processes taking place in it. Each zone may contain one or more sectors.
- Storage sector - a well-defined set of storage locations for organizing goods storage.

In the SIMMAG3D system the basic element of modeling and visualization of warehouse structure is the structural module. There are three types of construction modules that are connected with the previously described structures of space division (SIMMAG3D REPORT, 2017).

- Plain module - frame construction module. For simple type, it is required to specify the dimensions of the module and optionally the width and color of the frame.
- Compounded module - a nine-element construction module. Each item must be saved in obj format and included in the system when adding a compound module.
- The other modules - a module in obj format, attached to the system in one file.

The defined construction modules (fig. 7) are used to create storage structures (e.g. racks fig. 8). Each unit construction is assigned to the appropriate construction group.
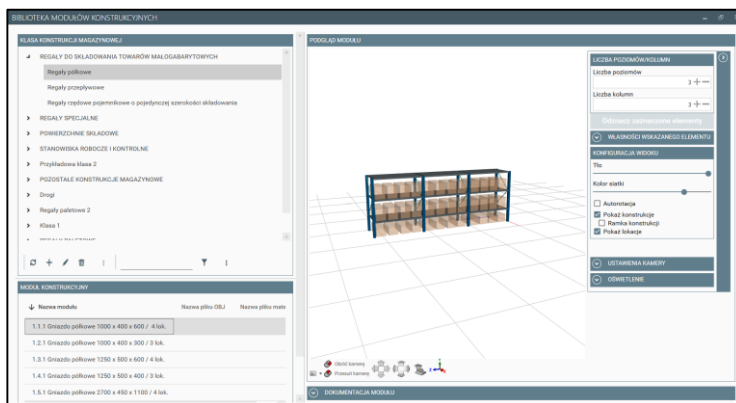

Fig. 7. The construction modules in SIMMAG3D
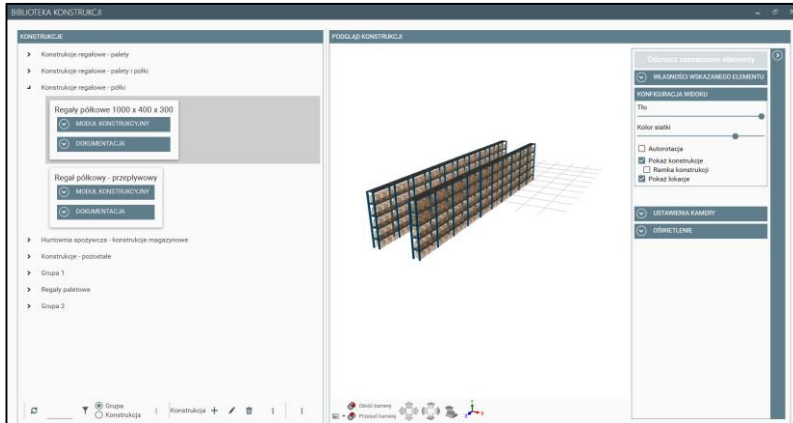*Source: own work based on the SIMMAG3D system.*

Fig. 8. Examples of storage construction made of structural modules
Source: own work based on the SIMMAG3D system.

6. Application of visualization module of SIMMAG3D system - case study

Using the SIMMAG3D visualization module, the model of the 3D warehouse model was visualized and inventory reports were prepared, along with the location of products in individual storage and picking locations by showing the storage locations where the picking were made within a specific time period according to the specified parameters for a particular industry. FMCG. The object of the analysis was one of the distributors of foodstuffs, tobacco products, dairy products and household chemicals. Source data on inventory as well as picking process are generated as reports in WMS (Warehouse Management System).

Detailed analysis was carried out for the following assortment types: chemistry, dairy, beverages and water, cigarettes and alcohol. Products were stored on pallets of 1200x800 mm and 1200x1000 mm, as well as in various types of boxes. A virtual storage entity has also been introduced to map batches of goods that are not presented in the form of other packaging units.

The following material flow rates are defined for an object:
- average daily number of picked goods in the pieces: 29644,
- average daily number of picked goods in the package: 15575,
- average daily number of picking order lines: 6514,
- average daily number of completed orders: 413,
- average daily number of completed dispatch units: 440,
- average daily number of advice note lines: 1168,
- average daily number of deliveries: 798.

The technology of the work of the object is to execute the order of releases by picking products from the pallet and pallet picking zones and put-out pallet load units from the pallet reserve area. The object is divided according to a functional and physical structure. Within the functional structure one functional area, four functional zones and ten sectors of storage were separated. Within the physical structure, storage locations and storage slots were set up, which were appropriately parameterized.

The warehouse divided into functional zones is shown on fig. 9.

Each of the separated zones can be shown individually. The picking zone from the pallets is shown on fig. 10. The pallet locations on the floor assigned to the picking zone from the pallets are marked in green.

The SIMMAG3D visualization module also enables visualization and analysis of reports generated by WMS (Warehouse Management System) in a developed warehouse model. The system allows to preparing a inventory report and a picking report.

The purpose of the inventory report is to visualize and show the products in storage locations. The report presents data on product quantities in storage locations, product names, SKUs, and commodity product groups. In addition, it displays inventory

and product placement in individual storage locations. Pallet locations are displayed in green, while shelf locations are in blue. Empty storage locations are not shown. The height of the storage

location is displayed depending on the number and volume of products. Storage locations for "Milk" products are shown on fig. 11.
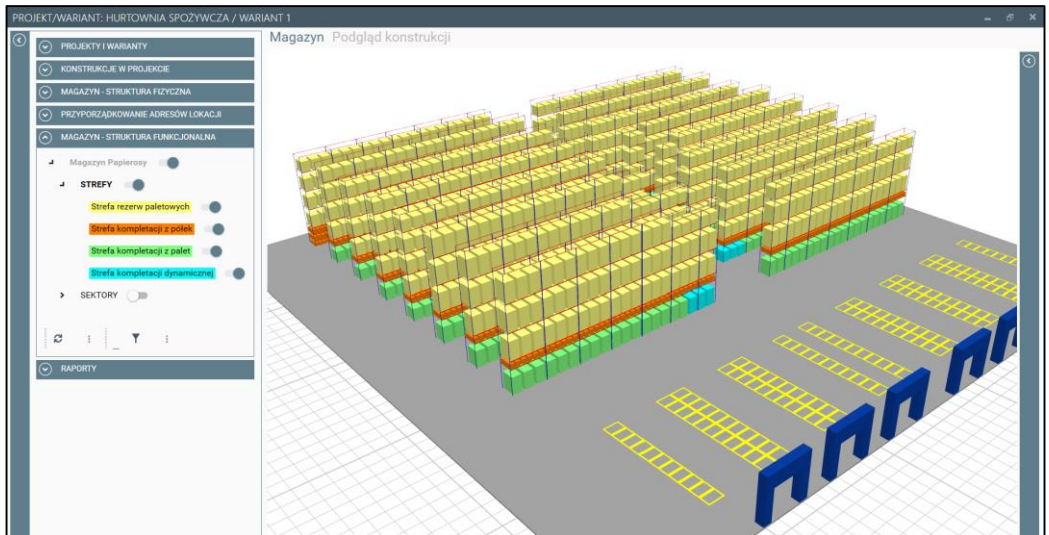

Fig. 9. The warehouse divided into functional zones
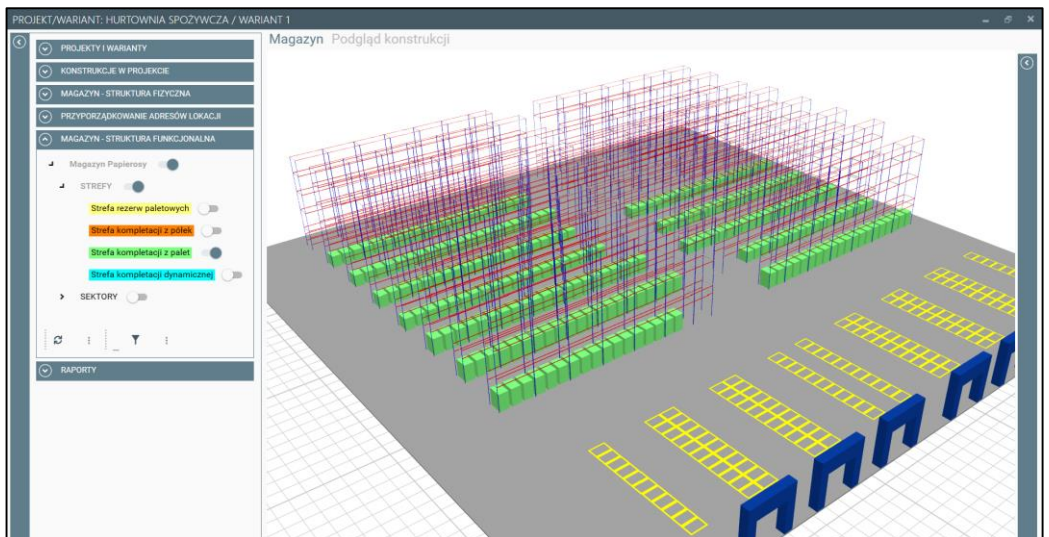*Source: own work based on the SIMMAG3D system.*

Fig. 10. Picking zone from pallets
Source: own work based on the SIMMAG3D system.

The purpose of the picking report is to show the storage locations where the collecting took place over a certain time period. The report presents aggregate or average data: the number of completed items, the number of products collected in units of measure, the SKU, the order number, etc. It displays the inventory in the appropriate colors of the locations where the picking was performed according to certain parameters such as relative or absolute, period, goods to be analyzed, users, shipping items, analyzed data or time interval. Each place where the picking has been completed is displayed in the same percentage of fill (100%). The colors mark the individual locations map where the aggregate or average quantities of data were analyzed. The entire range of completed items is spread evenly into five groups containing 20% of the number of items. Each group has a different color. Sample picking report is shown on fig. 12.
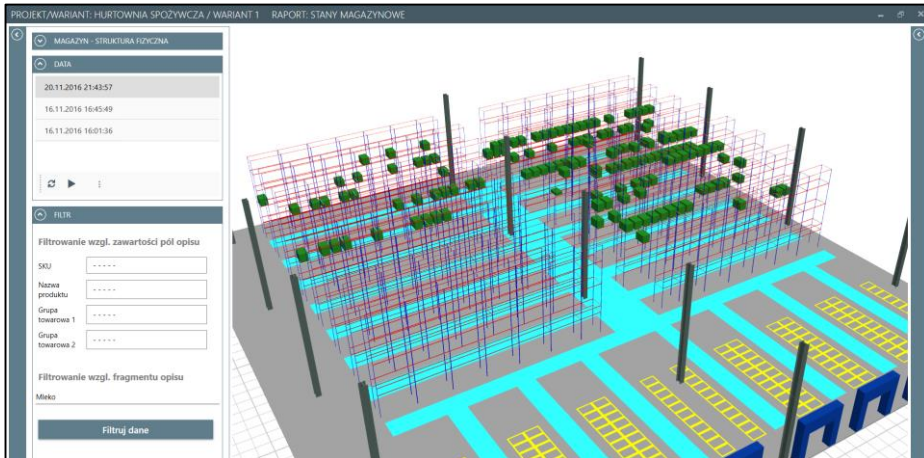

Fig. 11. Storage locations for "Milk"
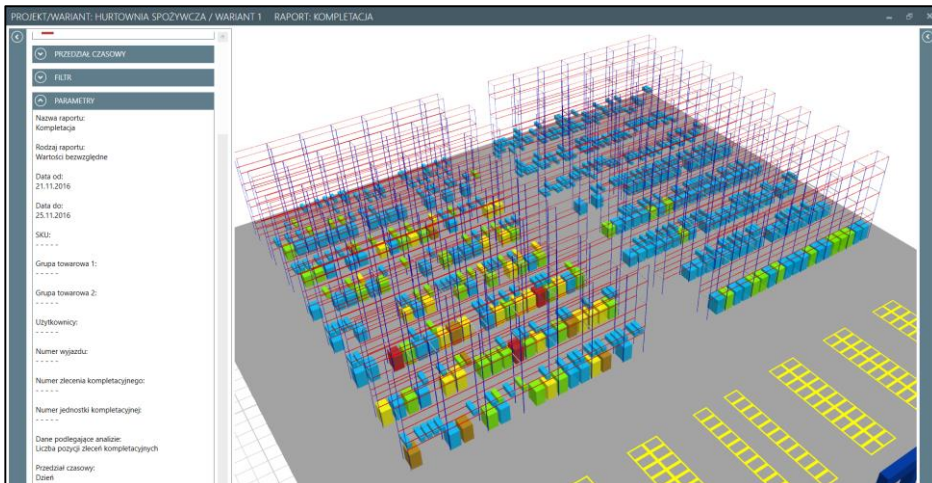*Source: own work based on the SIMMAG3D system.*

Fig. 12. Visualization of the picking report
Source: own work based on the SIMMAG3D system.

7. Summary and conclusions

The SIMMAG3D system can have many applications in the management and design of storage facilities. Basically, it is support for WMS, as well as a tool for the designing storage facilities.

The SIMMAG3D system architecture allows for decision support based on:

- dedicated mathematical models, algorithms and optimization modules (e.g. for storage facilities locations);
- dedicated simulation modules (for simulation and analysis of selected storage processes);
- integrated database with available on the market various internal transport and storage technologies,
- graphic presentation 3D module in a warehouse object - facilitates the identification of sensitive areas of storage facilities.

Among the main applications of the SIMMAG3D system can be indicated:

- preparation of design variants of storage facilities,
- pre-implementation analysis of logistics solutions,
- analysis of short-term operational objectives (change of material transfer strategy, distribution of products, prevention of seasonal phenomena),
- current logistic control when integrated with WMS,
- solving selected optimization problems,
- simulation and analysis of warehouse processes,
- graphic presentation in 3D designed solutions and inventory.

It is therefore applicable in the business operations of companies, testing of certain solutions in the design phase of storage facilities as well as in didactics and training.

Acknowledgements

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