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THE DESIGN AND ANALYSIS OF MATERIAL HANDLING SYSTEMS USING SIMULATION

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Abstract: The design of modern automated manufacturing and assembly systems is necessarily associated with the need to simultaneously develop the concept of efficient intra-logistics systems. Effective integration of production resources with intralogistics systems for transport and handling equipment requires, among others determining the layout of transport paths, the type of transport means, their capacity, number of actuators or number of containers, etc. In the process of solving individual partial problems and design, various methods and techniques supporting decision making are used, including mathematical methods, heuristics, or artificial intelligence methods. Due to the complexity, they are often approximate or suboptimal methods. Therefore, there is a need to verify the solutions obtained, especially in connection with other subsystems in the conditions of various data and parameters related to production orders. To this end, an approach based on the process of automatically generating simulation models is proposed. The integration of simulation systems with CAD systems based on data mapping with the proposed software solutions using internal programming languages allows the automation of the process of creating the designed handling system.

Key words: data mapping, integration, modelling and simulation, material handling, intralogistics, Industry 4.0.

1. INTRODUCTION

Intra-logistics systems deal with planning, realization, operation, and optimization of internal distribution processes, and may include information flow and material handling. According to (Tompkins et al., 2010, Gamberi et al., 2009) in a typical manufacturing company, material handling accounts for 25% of all employees, 55% of all factory space, and 87% of the production time, and represents up to 70% of the total cost of manufacturing a product. Additionally, more than 35% of system efficiency is likely to be lost as a results incorrect layouts and location designs (Hosseini-Nasab et al. 2018). Each of these aspects is associated with a number of problems that should be resolved before deciding to use a given type of solution with accepted parameters.

Material transport equipment as one of the main categories of material handling equipment includes conveyors (belt, roller, slat, chain, power and free, etc.), industrial vehicles (walking/riding, and automated, e.g. AGV), as well as monorail, hoists, and cranes. Their appropriate selection, estimation of parameters, and designing optimal routes or shapes are critical stages in the design of new or modification of existing logistics systems. The same applies to the design of the production system and its operation - planning and controlling the flow of raw materials or semi-finished products. This stage is obviously inextricably linked with the problem of manufacturing facility layout design and optimisation and should be solved at this stage. Facility Layout Problem is the subject of many scientific studies related to the search for effective methods in this area, both in relation to conventional systems as well as flexible and reconfigurable manufacturing systems (Maganha et al., 2019), especially important in the context of the new industrial revolution - the era of Industry 4.0. With respect to the intra-logistics systems, the main emphasis is placed on minimising material handling and relocation costs and maximising savings in material flow and inventory costs (Gamberi et al., 2009, Oke et al., 2011, Maganha et al., 2019). Due to the high complexity of this class of problems, depending on the type of problem, various methods are proposed to support the layout design and selection of material handling system elements. The proposed solutions are based on, among others, genetic approaches, simulation approaches, mixed integer or linear programming, heuristic models, simulated annealing algorithm, particle swarm optimisation algorithm, branch and bound procedure (Reddy Gutta et al., 2018, Maganha et al., 2019, Ren et al., 2019, Chen et al. 2019). Most of this class of problems are NP-hard and it is not possible to apply exact methods and search the entire range of possible solutions, so the obtained solutions may not be optimal, but only some their approximation.

In this context, there is a need to verify the solutions obtained, especially in connection with other subsystems in the conditions of various data and parameters related to production plans. Designers also need flexible tools to create an appropriate model of a material handling system that efficiently and quickly verifies the assumed indicators.

The answer to these needs is the use of modern discrete modelling and simulation systems, supported by data-driven methods of automatic generation of complex models of production and logistics systems models (Bergmann and Strassburger, 2010, Wang et al., 2011, Krenczyk et al., 2018). Thanks to this, it becomes possible to verify many of its possible solutions and to analyse their work results. This, in turn, gives the opportunity to make the right decisions and choose the solution that guarantees the best fulfilment of the requirements imposed by the customer. The original contribution of this work is the development of the proprietary methodology of automatic simulation models generation with the concept of integration of CAD and simulation systems using the method of geometric data transformations directly into internal program code creating objects in the simulation system. For this purpose, a specific module in the FlexSim simulation system has been developed. The proposed approach was illustrated by the example of generated models and analysis of obtained results in the FlexSim system. The process of obtaining data and their transformation is also shown. Generated models, in addition, can be freely modified and supplemented with other subsystems or cooperating objects. It can, therefore, be an effective tool, in the form of a digital copy (digital twin), in the operational management of the future real manufacturing system, while supporting the digital transformation and supporting the process of implementation of Industry 4.0 concept.

The paper is organized as follows: In section 2, the modelling and simulation in implementation of digital twin concept is described. The proposed semi-automatic generation of simulation models method is also provided. Section 3 presents a CAD and simulation systems integration concept. Section 4 is devoted to presenting a practical implementation of the proposed approach. Finally, section 5 concludes the research with directions for future work.

2. MODELLING AND SIMULATION IN IMPLEMENTATION OF DIGITAL TWIN

The answer to the growing global market demand is the fourth industrial revolution (Industry 4.0), based on cyber-physical systems technologies - including production resource, transport and storage systems. Production equipment should be able to autonomously exchange information in order to achieve greater flexibility, especially at the management, planning and flow control levels. Industry 4.0 is based on digital integration of technical and network aspects of manufacturing systems. In this context, computer modelling and simulation play a key role in managing the increasing complexity of production systems and can act as an integrator of solutions obtained in the process of optimizing existing or newly-designed subsystems (Rashid and Tjahjono, 2016, Rosen et al., 2015). From the point of view of computer simulation, the cyber-physical approach (digital objects, with their structure, connections and existing meta-information and semantics) is the next phase in the development and application of modelling, simulation and optimization technologies (Figure 1) (Rosen et al. 2015). However, the current modelling methods and tools still rely on manual data entry and analysis of the results in many cases. This makes the application of these methods very difficult, especially in the context of modelling and simulating larger and more complex systems, which is one of the main challenges in this area. (Crosbie, 2010). The research works related to the methods of semi-automatic and automatic generation of simulation models are a response to these needs. (Crosbie, 2010, Bergmann and Strassburger, 2010, Krenczyk et al. 2018). They are based on approaches to creating simulation models from external data sources using data exchange interfaces with simulation systems or model-building algorithms. The simulation model is not built in a standard way, using functions or visual simulation tools. This means that planners/engineers using automated tools should be able to prepare simulation models and conduct experiments only by changing or

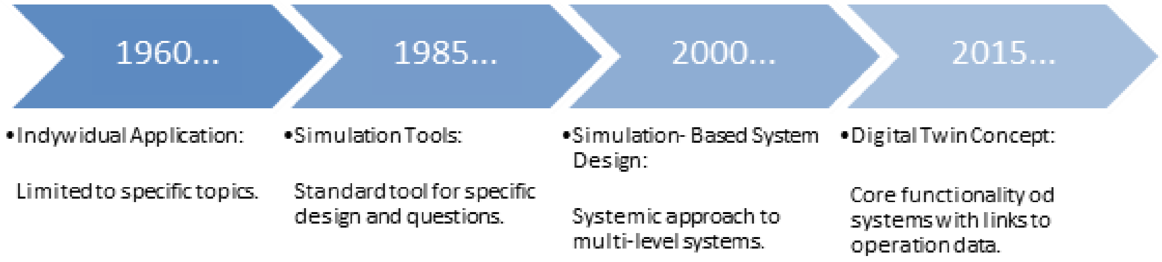


Fig. 1. Development of simulation applications (Rosen et al. 2015)

selecting input data that automatically updates the entire simulation model. The semi-automatic model generation methods developed so far can be divided into three main categories (Bergmann and Strassburger, 2010, Krenczyk et al. 2018):

- parametric approach: models are generated based on existing building blocks (atoms) stored in libraries, selected and configured based on parameters from other systems,
- structural approach: models are generated based on data describing the structure of the production system (usually in the form of data on the arrangement of devices in the production floor),
- hybrid approach: combining AI methods (expert systems, neural networks, etc.) with the two presented above.

As part of the research work on the methods of creating digital twins with the use of simulation systems, the authors develop a method of semi-automatic generation of simulation models based on a hybrid, structural-parametric approach. It is briefly described in the next section because it is the basis for the integration process with CAD systems for the modelling of material handling systems.

2.1 Semi-automatic generation of simulation models

The developed data-driven method for semi-automatic model generation is based on hybrid parametric-approach, data mapping and transformation methods in combination with the concept of a neutral data model that makes it possible to increase the versatility of the approach compared to the presently used. Data are obtained from IT systems supporting company management at various levels and in various functional areas (ERP/MRP/MES/APS/SCADA). The architecture of such a solution is shown in Figure 2.

Achieving the set goal requires the implementation of four main stages. The first stage is related to obtaining complete data required to prepare a functional simulation model. Data representation methods using the Extensible Markup Language (XML) (which is a data neutral format) and data mapping/transformation methods are applied. Of course, depending on whether the operated or designed system is modelled, the data will be obtained from various sources (ERP/MRP/MES/APS/SCADA). These systems, apart from the data entered by users (e.g. planners, designers), are supplied with data in accordance with the traditional vertical communication (vertical integration), from the control level, through SCADA and MES systems, to the ERP system level (this flow has been symbolically shown in left-side of Figure 2 as directed data flow 01010100...). Examples of PPC/ERP class system modules that allow for obtaining data in the form of XML documents are: NetWeaver of the SAP system or IFS Connect of the IFS Application system, which allow for integration with other systems or Electronic Data Interchange (EDI) programs. In the next stage, the processes of data exchange between the source data representation and the neutral intermediate data model are carried out. They contain both the data required in the next stage to generate the components of the simulation model, describing the resources of the production system, the production order, and the material flow procedures - organizational data required to define the control logic of the system actuators.

The proposed solution uses XSLT and XML style-sheet languages. The XSLT processor takes one or more XML source documents containing data from the above-mentioned input systems, and based on XSLT stylesheets processes them to produce an output document. The output document aggregates the data required to create the model. It is referred to here as a neutral data model because the data schema is no longer related to either the input systems or the simulation system. An indirect, neutral data model has been introduced so that it is possible to use the generator with virtually any simulation system - adapting the solution to a specific system does not require modification of data exporters, but only the definition of transformation into the internal programming language of the simulation system. XSLT processors are also used at this stage, thanks to

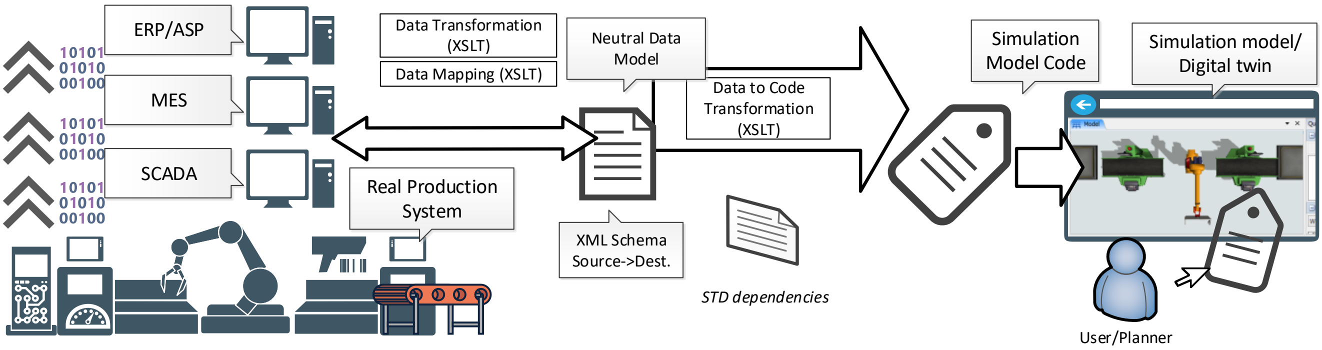


Fig. 2. Simulation model generator

string manipulation using regular expressions, functions and operators for data manipulation, generate complete code in the internal modelling language of the simulation system (which can be directly executed by the simulation system). Thanks to this, it is possible to easily adapt the proposed concept to work with any simulation system. In the next step, the data from the neutral intermediate model is transformed directly into the program code generated in the internal programming languages of the simulation systems. The last stage is the possible parameterisation of information about the procedures controlling the flow of materials on the shop floor (carried out by the system planner/operator), in order to conduct simulation experiments (Figure 2). The user is required to have knowledge of both the modelled production system and the operation (programming) of the simulation tool. Therefore, it is important to strive for a situation in which it will be possible to identify and map the largest possible scope of data from information systems (ERP/MES/SCADA).

Automatic code generation in the internal programming language of the simulation system, containing instructions that create a complete simulation model, is carried out with the use of Automatic Programming methods. Only the intermediate neutral data The proposed method uses the FlexScript language of the FlexSim simulation system (Beaverstock et al., 2018).

This section provides only basic information on the developed automatic simulation model generation method. Additional information can be found in (Krenczyk et al., 2018, 2018a, 2016).

3. CAD AND SIMULATION SYSTEMS INTEGRATION CONCEPT

The motivation for the development of the concept and method of automatic generation of simulation models, for integration with CAD systems, is related to some specific features of intra-logistics systems and their great importance as a subsystem of the production system, described in Section 1. These features are considered in relation to the method of modelling and parameterizing objects and their behaviour in the simulation model, which they enforce.

Contrary to production resources, for which the only geometrical features in the model are their dimensions and position coordinates in relation to the layout, resources from the material transport equipment group require the introduction of a series of data on shapes that make up transport paths (or conveyor routes), coordinates of loading and unloading places, or changes in orientation - often in three dimensions and on different floors of factory departments (Figure 3).

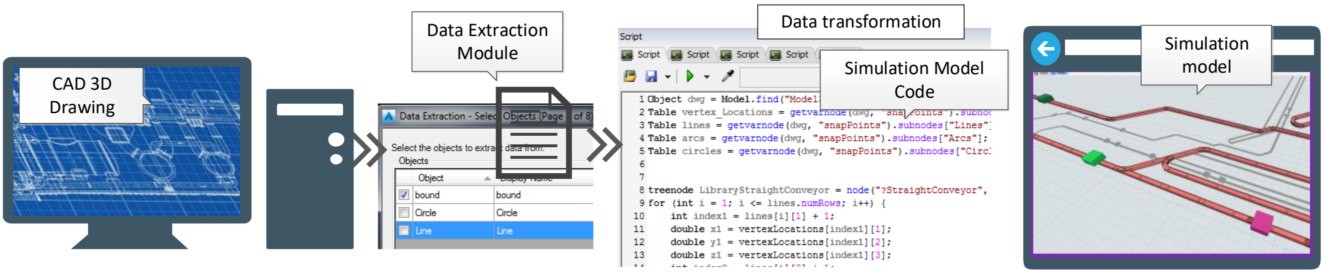
It should also be noted that their configuration and shape may change many times during the design, development and optimization stages of intra-logistics solutions. The above-described features significantly affect the time-consuming process of creating the model, especially the last phase (manual parameterization of the simulation model) described in the previous section.

Fig. 3. Industry conveyors examples

Due to the above, the possibility of shortening this time-consuming and costly modelling process was searched. The solution was sought in the long-used extraction of data and features from CAD models (3D). The developed methods were related, inter alia, to the automatic feature recognition (AFR) in the integration of computer-aided design (CAD), computer-aided manufacturing (CAM), and Computer-Aided Process Planning (CAPP) to achieve generative process planning and enhance the productivity. AFR provides abilities to recognize high-level geometrical features, and the most applied methods by researchers' works were edge boundary classification, slicing method, intelligent feature recognition methodology, or ontology (Kataraki and Abu Mansor, 2019, Babic et al., 2008, Brousseau and Dimov, 2008). At the same time, the development of CAD formats (also ISO standard format) made it possible to easily access geometric data (Han et al., 2019). Also, producers of CAD systems introduced Data Extraction modules, which automate the process of extracting, e.g. geometric data directly from CAD documents. An example would be "Data Extraction Wizard" in AutoCAD allowing selecting the data source, filtering objects are extracted, organizing and refining the extracted data and choosing an output format for the data. Moreover, similar solutions in the form of data extraction modules are implemented directly in simulation systems. In the previously mentioned FlexSim simulation system, built-in tools allow to directly import information about vertices, lines, arcs circle and other elements from an AutoCAD drawing (or selected layers).

The use of data extraction modules seems to be a natural choice due to the fact that CAD (3D) drawings are usually created in the process of designing and analysing material transport system solutions. In many cases, during the designing and development process of conveyor systems, configurators are used that are able to automatically generate CAD documentation for each variant (Mauger, Zona, 2010). A CAD drawing can thus be obtained with little time investment, with the extracted layer containing the conveyor travel axis or the transport path.

The implementation of the integration process required the design of an additional data transformation module obtained from a CAD drawing into an internal programming code that creates appropriate objects in the simulation model (additional data transformation step) (Figure 4).



```
Object dwg = Model.find("Model
Table vertex_Locations = getvarnode(dwg, "sna oints").subnoc
Table lines = getvarnode(dwg, "snapPoints").subnodes["Lines"
Table arcs = getvarnode(dwg, "snapPoints").subnodes["Arcs"];
Table circles = getvarnode(dwg, "snapPoints").subnodes["Circ


treenode LibraryStraightConveyor = node("?StraightConveyor",
for (int i = 1; i <= lines.numRows; i++) {
    int index1 = lines[i][1] + 1;
    double x1 = vertexLocations[index1][1];
    double y1 = vertexLocations[index1][2];
    double z1 = vertexLocations[index1][3];
```

Fig. 4. CAD and simulation systems integration concept

In practical implementation, the Data Extraction Module of the FlexSim system was used. The drawing of the centerline of the conveyor obtained from the CAD file is subjected to the process of automatic data extraction, from which a set of straight lines and 3D arcs describing individual sections of the transport system is obtained. The data is then written directly into FlexSim's tree nodes. In turn, they are input data of prepared program modules (data transformations) that create corresponding simulation model objects, such as, for example, straight and curved conveyors, straight and curved path, control and decision points, or transportation networks nodes. The scope of their applicability (the possibility of mapping the types of transport means) generally depends on the scope of the library of objects of the simulation system used and the corresponding prepared modules transforming data into code. In most cases, this range is sufficient (various types of conveyors, manual and automatic vehicles). Of course, depending on the needs, it is possible to prepare special modules describing non-standard means of transport used in a given enterprise. The next section shows a practical implementation of using the above-described concept of CAD system integration with the simulation system.

4. PRACTICAL IMPLEMENTATION

Using the concept presented in Section 3, the process of automatic generation of a simulation model was carried out for a fragment of the overhead conveyor system used in companies from the automotive industry in the CAD system, a layer has been prepared with a simplified drawing of the geometry of the designed overhead conveyor. The layer contains only the centerline of the conveyor rollers. The remaining geometry has been moved to other inactive drawing layers (Figure 5).

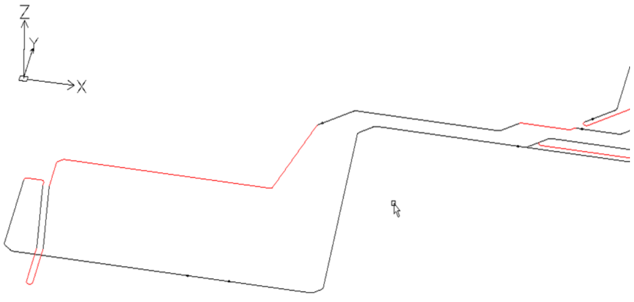


Fig. 5. Simplified CAD drawing of conveyor

The file with such prepared geometry was saved and automatically loaded in the FlexSim simulation system. As mentioned above, transformation modules have been implemented in the FlexSim system using the native data extraction module from AutoCAD drawing files. Then, in the FlexSim system, an automatic data transformation was performed into the code creating simulation objects (in this case, straight and curved conveyors). The process of creating a simulation model is shown in Figure 6. The generated model is fully functional and can be used to carry out verification experiments in a short time. However, during the verification of the model, a certain limitation was identified that should be taken into account in the data transformation process. It is related to the direction of the created conveyor modules and transport paths, both straight and curves. This direction results directly from the data from CAD drawings and corresponds to the direction of the created lines and arcs. Therefore, it is necessary to verify the obtained simulation model in this area. It is planned to prepare a software module supporting the automatic process of model verification in this area and supporting the engineer/planner as part of future works on the development of the method described in this paper.

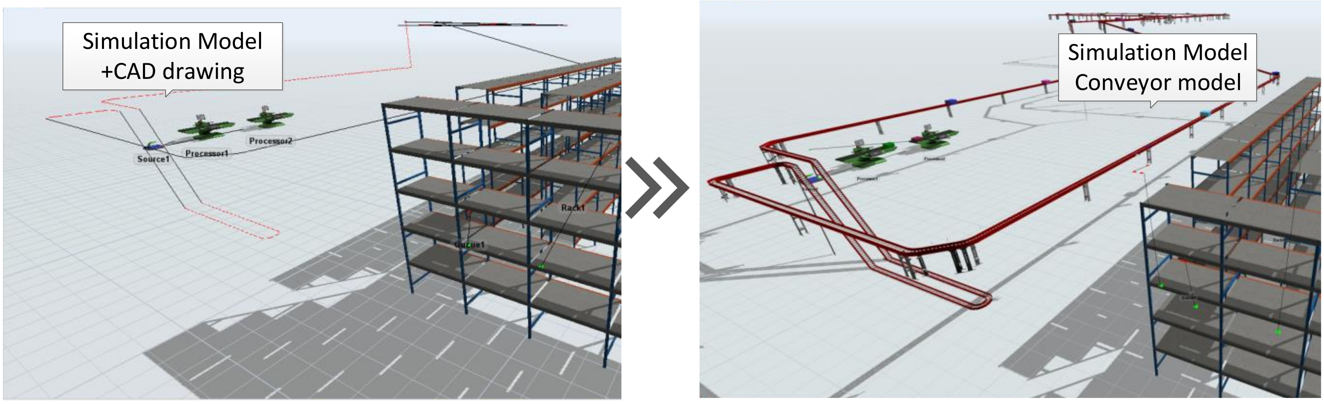


Fig. 6. CAD and simulation systems integration

The presented example of creating a simulation model exposes the usefulness of the proposed solution in supporting the process of verification of production flow plans. In addition, it can be a valuable tool to optimize the parameters of the production system, depending on the adopted criteria for assessing the solutions sought. The simulation models shown in this paper are available on http://imms.home.pl/dka/modtech2020.

5. CONCLUSIONS

Effective integration of production resources with intralogistics systems requires, among others, determining the layout of transport routes, the type of transport means, their capacity, number of containers, etc. The method of integration of CAD and simulation systems based on data-driven method of automatic generation of simulation models eliminates the disadvantages associated with cost- and time-consuming process of building simulation models, and can become an efficient and effective tool to support the planning and verification of production subject to the material handling system constraints. This in turn gives the opportunity to make the right decisions and choose the optimization solution. It can, therefore, be an effective tool, in the form of a digital copy (digital twin) of the real manufacturing system, supporting the digital transformation and the process of implementation of Industry 4.0 concept.

The subject of further work in the discussed area will be related to supplementing indirect data models with information that can be obtained from other computer systems, concerning other subsystems and production limitations.

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