HOLISTIC PLANNING OF PRODUCTION AND INTRALOGISTICS SYSTEMS THROUGH AUTOMATED MODELING WITHIN AND AMONG THE TOOLS OF THE DIGITAL FACTORY

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ABSTRACT
The automated and semi-automated model generation has been discussed and developed for decades. With AutomationML (AML), an open, object-oriented, XML-based storage and exchange format is provided, which should also allow an exchange among visualization, construction and simulation tools. Separate cross-section functions and proprietary software solutions of the individual tools make it difficult to define a common transfer point. The presented concept and tool describes the development of an application-oriented and source-open middleware. The focus of the ongoing implementation phase is the development of these uniform, digital planning methods and tools by AML. The first prototype outlines the advantages but also the disadvantages of automatic model generation via AML. Up to now simple conveyor systems from straight, curved conveyor belts, rotary tables and single stations from the visualization tool Tarakos – taraVR can modelled automatically in the simulation tool Siemens – Plant Simulation and construction tool Autodesk – AutoCAD.

Keywords: automated and semi-automated model generation, AutomationML (AML)

1. INTRODUCTION
The versatility, speed and flexibility of the product creation process is increasing due to the ever-shorter product life cycles. This development has a direct impact on the participating logistics and production processes (Schenk 2014). The increasing digitization and automation accelerates the development of the continuity of available data models for the digital production and logistics. The use of digital tools in the areas of simulation, visualization and construction improve the quality of planning, increase efficiency and shorten the product development and launch (Schenk 2014; Daft 2016; Klepper 1996; Lüder and Schmidt, 2015). These benefits can only be fully used if it is enabled to translate all relevant and so far isolated digital methods and tools into an integrated planning system (Faltinski 2011; Schreiber and Zimmermann, 2011). Currently used tools cover only specific functional areas within the product lifecycle management (PLM). This focus on individual areas of application of PLM enables a high level of specialization. The tools include the possibility of simulation, visualization and construction. However, the significance of these functions is limited with respect to the specialization of the users (Figure 1). This limited solution spaces are created by a lack of interface integration. An exchange of data in a heterogeneous system environment is therefore limited (Faltinski et al. 2012; Rawolle et al. 2002). In practice, therefore, no holistic, neutral and IT-based approach has been developed for the integrated digital planning and control of intralogistics systems and production areas. It lacks a neutral exchange format for continuous availability and mutual availability of simulation data, geometric design points and visualization elements.

ability to: \ tool for:	simulation	visualization	construction
simulate		◐	○
visualize	○		◐
construct	○	○	

○ low ◐ medium ● high

Figure 1: Ability of visualization, construction and simulation in the different tools

The ongoing implementation phase discusses the concept and tool and first results of establishing continuous modeling between simulation, visualization and construction tools. The further course discusses the concept and tool for continuous model building on the example of the exchange direction of visualization to simulation and visualization to construction.

2. STATE OF THE ART AND SCIENCE
The standardization of systems, processes and their components is an essential element in the mastering of complexity as well as control and structuring of future, digital challenges (Drath 2010; Eigner and Stelzer 2009). The previous focus was the combined planning phases on a shortening in the time-to-market of products through the integration of product, process and production system planning, entitlement to use today is

at an early stage of reliable data from the product development process (Schenk 2014; Schenk and Schumann 2008). The idea of combined planning phases is described for years by modern and powerful tools (Dangelmaier 2013). These special cases are made of individually designed solutions. It lacks the holistic planning approach to take part in processes to promote an integration of all. First approaches for generating layout-based models can be found at Lorenz and Schulze (1995). First approaches to use structural as well as system data from a production planning and control system (PPS) to create models can be found at Splanemann et al. (1995). A first classification of automatic model generation approaches was provided by Eckardt (2002). The author distinguishes between parametric, structural, and hybrid approaches. Another way to classify approaches of the model generation makes the classification of model generation approaches to Straßburger et al. (2010). Early developments through digital planning and control was designed by the enterprise application integration (EAI) and service-oriented architectures (SOA) (Aier 2006; Kaib 2004; Bieberstein 2008). The EAI represents integrated business processes along the value chain. Enterprise applications of different generations and system architectures can interact in this framework over a common network. The SOA describes a method that encapsulates from existing IT components and coordinates. This existing services will be consolidated and summarized to a higher service. The objectives of EAI as also SOA are reducing costs in the development of production processes and increase the flexibility of business processes in the long term. The reason for the low acceptance and development of the methods is the high demands on insecure systems, data security, continuity of the tool development and product development process (Fay 2006; Raupricht et al. 2002). The interaction of different digital planning tools within the product life cycle is summarized often under the term "Digital Factory". The term describes a comprehensive network of digital methods and models, including simulation and 3D visualization. Its purpose is the integrated planning, management and implementation, as well as a steady improvement in all key factory processes and resources (VDI 2008; Wenzel et al. 2003). Also here is a link of different planning tools. However, the use of continuous planning tools is missing. Weigert (2015) describes the first opportunity of an implemented middleware for the automatic data exchange among different tools of the digital factory by AML. The motivation for the use of a common concept and tool can be reducing costs for the planning, control and operation and maintenance of plants and factories. First options for the automatic generation of the model are described. However, no procedure is known to reach the current level which combines three essential tools for the digital factory by an open interface.

2.1. Storage and Exchange format

For the semi- and fully automated model generation is the origin and use of the data and information utmost importance (Bergmann 2014). The currently most popular standards for the automatic model generation are the data formats simulation data exchange format (SDX) (Sly and Moorthy 2001) and Core Manufacturing Simulation Data (CMDS) (Lee 2015; Bergmann et al. 2010). The hierarchically structured SDX format is used to exclusively provide layout information. With the open-source, XML-based format of CMDS can both layout - as also process-related information transmitted. The problem of implementation of comprehensive control and routing strategies and complex system behavior is not completely solvable but manageable with these data formats (Bergmann, 2014; Bergmann et al. 2010). By AutomationML (AML), an open source, free available, object-oriented, XML-based storage and exchange format is being developed. After initial evaluations of different exchange formats, Daimler AG initiated the development and standardization of AutomationML as an intermediate format of the digital factory together with ABB, KUKA, Rockwell Automation, Siemens, netAllied and Zühlke, as well as the University of Karlsruhe and Otto von Guericke University Magdeburg in October 2006. In 2009, the previously closed industrial consortium opened by establishing an association. The first new member was the Fraunhofer IOSB. It becomes clear that the efforts to use AML are driven by the industrial and scientific location of Germany. AML owns the technical requirements for the modeling of production, intralogistics and robotic systems that is used but so far mainly in the area of virtual commissioning. Fundamentally AML linking role profiles (Hoernicke et al. 2016; Hundt et al. 2009; Lüder and Schmidt 2015). So far, topology, geometry, kinematics and behavior of system components can be described with AML. The hierarchical picture of the topology of the subject of the planning is carried out by means of Computer Aided Engineering Exchange (CAEX). The CAEX library concept includes three types of library (Drath 2010):

- The **SystemUnitClass** library is a catalog of concrete physical or logical system objects or their combination. Attributes, interfaces and nested internal elements and their compounds are assigned to the elements
- The **RoleClass** library defined abstract physical or logical system objects, regardless of the actual technical realization. Roles describe the functioning of investment properties
- The **InterfaceClass** library describes the kind of interfaces between the system objects. The relations between investment objects are mapped

Geometry and kinematics can be associated with individual system components through COLLADA files. The control is defined by PLCopenXML and describes the system behavior. AML is adaptable and flexible, it offers the possibility to include other XML formats (Hundt et al. 2009). In addition, the AML format has an inherent distributed data structure. The information is instead of a monolithic XML document, saved as separate documents. The reusability of individual system components and the development of element libraries will be easier (Lüder and Schmidt 2015).

3. APPLICATION GOALS AND CONCEPTUAL DESIGN

A continuous model generation between simulation, visualization and construction tools for the integrated planning of production and intralogistics systems describes the linking of the three digital tools. The expertise in dealing with the tools than the substantive complexity of each tool is highly classified. The presented concept and tool describes the development of application-oriented and open source middleware. The goal is to develop of uniform, digital planning methods and tools for a consistent design. The lossless and accelerated conversion and modelling within the various tools is in the focus. On reason of the different core functions of each tool, as well as their proprietary interfaces, the goal is to develop an open source automated import and export solutions (Figure 2).

Following advantages arise from the use of an automatic exchange system:

- Existing simulation, visualization, and construction tools in the company remain in place, preventing costly new investments
- Productivity and cost reduction can be achieved by the use of development, combining the individual benefits of the tools
- Visualization, modeling, and simulation of real-world intralogistics systems accelerates, reducing the largely manual and costly effort in creating a new model

At present, many software solutions have only limited access to the ability to offer planning data in a heterogeneous system landscape.

This fact is due to the lack of conformity of the interfaces and the resulting lack of integration of all necessary planning data. The reasons for these so-called insellations have been and are the efforts of machine manufacturers to exclude competing products by means of ever new proprietary interfaces in favor of their own "complete solutions". A circumstance that today is hardly accepted by customers. Furthermore, the lack of networking between the planners and partners involved in the process contributes to the existing problem. In order to support the definition of the mapping rules, a graphical interface is developed which contains the following features:

- Visualization of the data model of the source system in a tree structure
- Selection of pre-made rule templates for repetitive application forms:
- *1:1 mapping* (Due to a type attribute; On the basis of a checked attribute value)
- *m:1 mapping* (Illustration of a group with the same or similar attribute value; Illustration of a group by means of object relations (parent-child, Sibling)
- *0:n mapping* (Creating new node with no equivalent in the source model)
- Memory function for the created rule sets with additional information:
    - Author
    - Version
    - Description
    - Source-Tool
    - Target-Tool

The exchange system is not limited to the generation of exchange files but can also be used for exchanging data between current network instances if the tools involved permit such an integration. The concept and tool for the continuous and comprehensive model building is appropriate on the example of the simulation tool Plant Simulation – Siemens and construction tool AutoCAD – Autodesk. The visualization tool taraVR – tarakos serves as a starting point for the investigations.

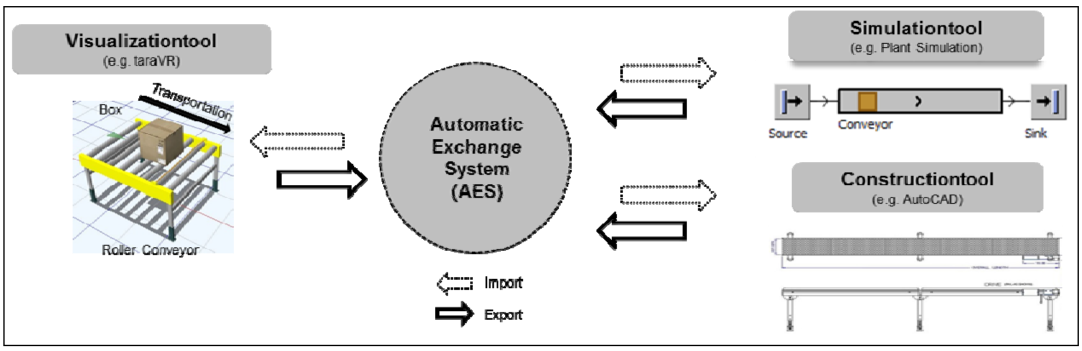

Figure 2: Overall concept of development

4. CONTINUOUS MODELING BETWEEN SIMULATION, VISUALIZATION AND CONSTRUCTION TOOLS

The Automatic Exchange System (AES) forms the basis for the common data and information exchange. The AES is defined by a system of mapping rules and an associated user interface. The model item get its role profiles from the developed AutomationML roll library within the Exchange System. In addition to the transmission of model elements it is important to transfer their attributes such as capable of taking over transport direction, speed, and more state descriptions. Furthermore, the relationships between the elements must be transferred. The approach of an open source standards about the AML function narrows the existing interface packages and fee-based libraries in the commercial product suites for the exchange of data. Goal is to realize independent modeling of closed software packages. Based on the classification ability of model generation approaches to Straßburger et al. (2010) the represented development can be classified as follows:

- Application: parallel (tactical) planning
- Focus: conveyor systems
- Degree of automation: semi-automated
- Approach: direct generic structure
- Support creation of model
- Interfaces: Text - and XML-based

Before models can be automatically generated it is necessary that the modules and elements of different tools are mapped. Data mapping is the process of mapping data elements between different data models and thus constitutes a fundamental step in the information and data integration (Alexe et al. 2008). A so-called rule interpreter is designed to enable this mapping. From the respective visualization, construction, simulation tools the libraries with all modules and their parameters are exported and mapped. This manner defines rules for the transfer. If current rules exist, the import file for the target tool can be generated by the rule interpreter emanating from an export file of source tool automatically.

The import file is loaded using the created interfaces or corresponding data interpretation in the target tool and interpreted. To integrate the relevant elements of the model and to interpret is a systematization of elements of importance for further processing. After the reduction for the respective tools it is important to define the requirements for the interfaces. The needs and situations of the interfaces between the designed EAS, the simulation tools as well as design tool have been analyzed and defined.

4.1. Automated model generation – Construction

The Autodesk AutoCAD tool has considerably more modification options in the area of the interface creation. Through the import of other CAD tools with the formats 3D Studio (.3ds), Autodesk Inventor (.ipt; .iam), SolidWorks (.prt; .sldprt; .asm; .sldasm) and step (.stp; .ste; .step) is there quite a broad base. For the development and integration of and into the EAS is the variety but not of importance. The neutral exchange format AML forms the basis of the development. For this purpose, separate commands are developed for import and export. The goal of consistency to the visualization tool ensures that the interface in the format programmed .net and used. Determined at a minimum for the required parameters of the construction tool for the communication with the AES include:

- Object information: name, geometry
- Layout information: location (connection are not necessary)
- Detailed information on geometry are not needed, can be optional attached in an AML file through the COLLADA format

A direct import AML files is not possible and is not supported by the Autodesk software suite. AutoCAD is used within the development as a two-dimensional representation of intralogistics planning and construction data.

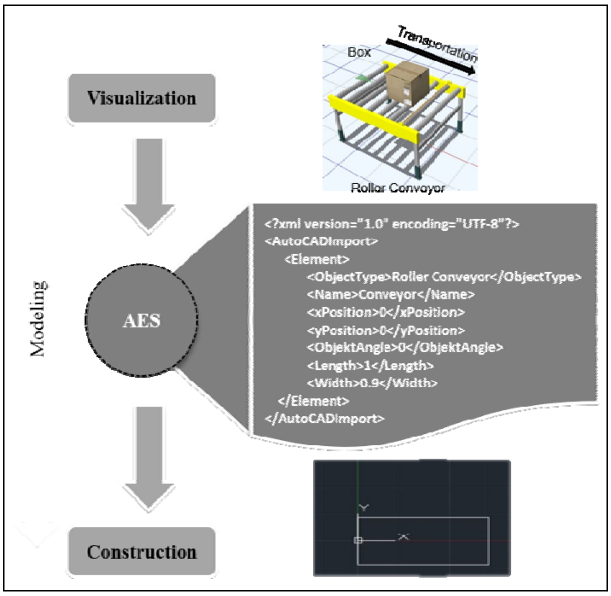

Figure 3: Model generation between visualization and construction tools via AES

Not only static blocks are addressed within the tool. The blocks are predefined two-dimensional body by the user. They are stored in a block table. Hereby the purpose a dynamic adaptation of the body within the construction tool to get.

A pure one-to-one relationship of modules is no longer necessary. Blocks to dynamically build and parameterize the interface with c#.NET was programmed and encapsulated in a Dynamic Link Library (.dll) file. The enclosed program environment is performed as AES.dll.

Algorithm 1: Pseudocode for Modeling – Construction

```
define fcn = rootnode.childnodes and
        scn = FCN.childnodes
open xmlfile
while rootnode has fcn
    read SCN.objecttyp, SCN.x–pos, SCN.y–pos
    create object from blocktable.objecttyp at
            x–pos.,y–pos.
    if object is dynamic
        for i = 1 to SCN.parameter.count
            read SCN.parameter(i) and
                parameter(i).value
            set object.parameter(i)=parameter(i).value
        next
    end if
end while
close xmlfile
```

After the call of the encapsulated .dll file it is possible to run various commands. The pseudo code describes the reading and processing of the XML file in the construction tool (Algorithm 1). The XML file is created from the AES and read in the target tool. In contrast to the simulation tool, the structure can be an XML file because the tool can work with XML and .dll file to process the models (Figure 3). The file is built in a common XML format. The linking of several objects is ensured by the updating of the source code. By working with dynamic blocks, the parameters can be arbitrarily varied according to the read-in to the construction tool. This is the processing of dynamic blocks. The blocks are user-defined two-dimensional bodies. They are stored in a block table. The aim of the invention is to obtain a dynamic adaptation of the bodies within the construction tool. For a static block, the dimensions are invariable. It is therefore stored with fixed dimensions in the table and can only be generated with these dimensions again. In a dynamic block, the user defines individual elements of the block as variable.

4.2. Automated model generation – Simulation

For the development of the simulation tool, event-oriented simulation approach from Plant Simulation by Siemens has been used. “Plant Simulation” has a variety types of license and fee-based libraries. Costly licenses such as “Professional” in combination with the “Interface Package” have been avoided for the development of a common data interface. The selection would not meet the main goal of an open-source and neutral communication interface. The license type of "Standard" forms the basis for the interface between the EAS and the simulation tool. An advantage is the upward compatibility of the simple data structure (.txt file). A disadvantage is the complex data processing in the AES before import and export in the simulation tool. The strings must correspond to a given form can be accurately encoded and decoded. As a result is a text file as opposed to a binary file without the use of special programs to read and can be viewed with a simple text editor and edited. Determined at a minimum for the required parameters of the simulation tool for the communication with the AES include:

- Object information: name, type, geometry
- Layout information: location and connection to other elements
- Material flow parameters: time usage, routing

A direct import of AML files is not possible and is not supported by the selected simulation tool. A master file was developed for the simulation tool, which contains all requirements needed for the model creation. The system works according to a hierarchical management of access to a common resource as a master/slave system. The master file allows only the backup model derivatives and contains all the required methods to model creation, export model, library export and import of the modules. A new generation section of source code is generated for each previously mapped module. Sections for identical statements, for example the combination of elements, can be applied. The text file is read from the AES into the simulation tool.

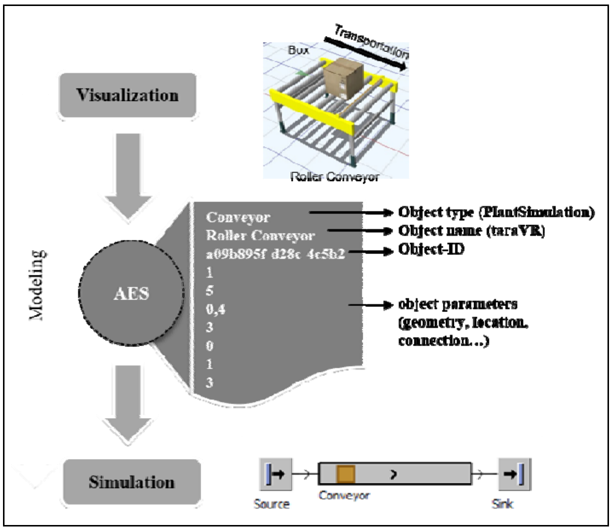

Figure 4 Model generation between visualization and simulation tools via AES

The file contains a hierarchical structure, which allows to process all objects equally. Changes to entire model elements or parts thereof can thus be easily incorporated. The file is integrated by the integrated data interface. This has resulted from the use of general interfaces.

The content of the text file is deliberately simple. The file is divided as follows. The object type is determined by the target tool and is part of the library in the simulation tool. The object name describes the name of the object in the source tool. The identification number of the object is a one-to-one number sequence that identifies the object in the model. Further details describe object parameters such as geometry, location, connection and speed. For multiple objects, the ID also describes the auto-linking points in the model. After conversion from the visualization tool into the AES, a text file is created (Figure 4). This is read in the simulation tool by a simple data interface. The necessary intelligence of the simulation tool is generated by the programmed interpretation of the source code (Algorithm 2). The programmed method reads the text file and checks whether the object exists in the simulation tool library. If the response is positive, the method begins to link the object to the element from the simulation library. After this, the method parameterizes the created object according to the specifications of the text file. Because the entire intralogistics system is present in a text file, the objects are separated by a separator. The unique ID knows all objects predecessors and successors. If the predecessor or successor is missing, the source or sink is created.

Algorithm 2: Pseudocode for Modeling – Simulation

```
open textfile
while not textfile.end
read bibliothek, objecttyp, x-pos., y-pos., name
create object from bibliothek.objecttyp at x-pos.,y-pos.
    if next textfile.line ≠ seperator
        do
        read parameter and parameter.value
        case parameter of
        case "input-id"
            if object.exists(input-id)
            connet object with input-object
            end if
        case "output-id"
            if object.exists(output-id)
                connet object with output-object
            end if
        else
            set object.parameter = parameter.value
        end case
        until next textfile.line ≠ seperator
    end if
endwhile
close textfile
```

The flexibility of the model creation is given by scanning the entire simulation library in the master file at start. This long term causes that even individual building blocks of the end user can be read out and dynamically addressed.

5. SUMMARY AND OUTLOOK

The described concept and tool represents a comprehensive approach for the automatic and open-source modeling and data transmission between different tools. The development describes a possibility to repeatedly use individual AML libraries for simulation, visualization and construction. This can be ensured by an AML role library. First results show that the implementation is successful. Similarly, no proprietary software solutions are used. With the possibility to combine modeling within the different tools it can be possible to produce precise and fast models from a single source. As a result, costly, error-prone and time-intensive re-modeling is already avoided. The development level reached the basis for the transfer of the models into the corresponding target tool, described by simulation and construction. Further steps are the increasing detailing and standardization of the automated exchange system. In the future, the question about the implementation and transmission of the work plans and the accompanying control and the routing of the elements in the simulation tool will be explored. Up to now simple conveyor systems from straight, curve conveyor belts, rotary tables and individual stations from the visualization tool Tarakos - taraVR can be modeled automatically in the simulation tool Siemens Plant Simulation and construction tool Autodesk - AutoCAD. The use of cost-intensive and optional interface libraries can be dispensed. Due to the simplicity of the development it is possible to connect arbitrary tools. To this end, investigations are currently being carried out to prepare the interface to other vendors' tools. Similar advantages are promised. It was necessary to use only existing licenses throughout the development. Only the internal specifications of the tool were used. No license rights of the providers were infringed.

The cooperation with end-users from the practice makes clear what additional requirements on the range of functions the AES must solve in future. The question about the implementation and transmission of the work scheduling and the accompanying control and the routing of the elements in the simulation tool are also to be investigated. The repatriation of information and models of the simulation and construction tool in the visualization tool be made manually in the AES at the current time. Target is to process the data from the construction through renewed data mapping in the AES. Here, the AAS repeatedly assumes the role of the rule interpreter and plausibility auditor. The integration of the event log obtained by the simulation runs is conceived for the simulation. The described and planned scope and procedures are to be simplified and made more dynamic in the future. At the same time, a significant increase in the user-friendliness in handling the tool is planned.

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