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Development of a novel material flow simulation model for the integration of spatial and process relevant information

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Abstract – Simulation techniques are almost indispensable in the analysis of complex systems. Materials- and related information flow processes in logistics often possess such complexity. Further problem arise as the processes change over time and pose a Big Data problem as well. To cope with these issues adaptive simulations are more and more frequently used. This paper presents a few relevant advanced simulation models and introduces a novel model structure, which unifies modelling of geometrical relations and time processes. This way the process structure and their geometric relations can be handled in a well understandable and transparent way. Capabilities and applicability of the model is also presented via a demonstrational example.

[Keywords: production logistics, simulation, adaptive modelling]

1 INTRODUCTION

Material flows of products, parts and other goods in the production and in the associated logistic operations generally make up complex systems. In order to cope with the complexity during analysis and system control intelligent software system components are needed. Simulation software are more and more frequently used as a base platform for this purpose. These require implementation of a simulation model, which is digital mapping of the real material flow system. This digital model enables multiple tasks such as emulating the system, making predictions for the future operations and evaluating control strategies. This leads straightforward to the application of simulations for process optimization (see e.g.: [Mol05]). There are several application fields, a comprehensive overview can be found in [FRDF14], where the authors concentrate on the macroscale implementation of material flows – the logistic supply chains.

In the manufacturing industry, the process simulation model's structure is generally determined by the technology and the related material flow processes. The model's construction is always an individual task, however there is always an ambition to standardize it. Many see it the only way to analyze complex systems [MSHT10]. In production system simulations the material handling system is usually considered as a resource for which the technological workstations compete [SKC+13]. So the load/unload stations, although depending on the type of layout, are generally at the entrance and exit of the simulation model. In material flow simulations however the main focus is on the material flow system's capability of being able to handle the tasks given by the technological stations, which are in this case the sources and drains of material flow. It must be pointed out that neither the technological nor the material flow part can be omitted or neglected.

The simulation model's accuracy is fundamentally depending on the realism of the input data and the model's inner parameters. There is a significant problem in real industrial applications that the modelled system continuously changes over time. Causes for this can be introduction of a new product or capacity upgrade of some technological step of materials handling system component. As it is not realistically expected that these modifications can be real time implemented into the model by humans, adaptive feature for simulations are developed.

Adaptiveness has multiple implementation in simulations. There are three different features, which can be subject to adaption:

- Dynamical objects in the simulation (example: implementing various production programs in the model, the input tasks – dynamic objects are subject of changing)
- Adapting operational rules and parameters in the model (these adaptions are without changing the static structure of the model, example see [SE12]).
- Structural adaption (this means automatic reorganization or changing of the static DES model structure)

From the above various dynamic objects as input was one of the first problems applied in simulation research. Currently this feature is already implemented in standard material flow software. Parametric and operational rule

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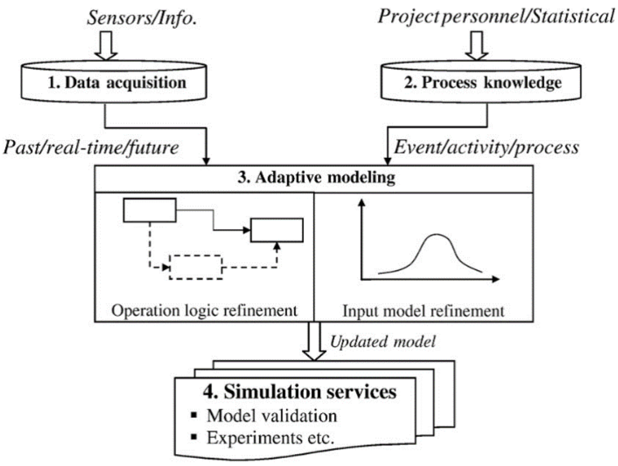
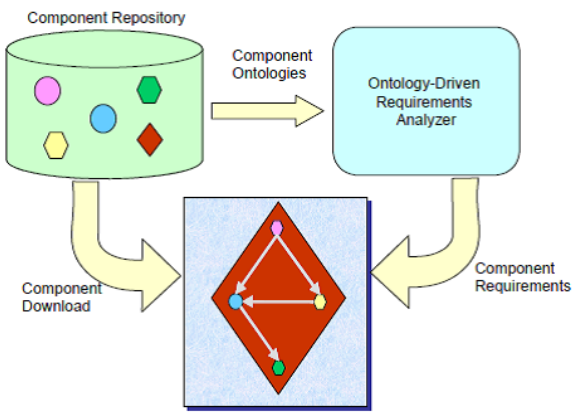
adaption is a more difficult issue. Lingguang Song and Neil N. Eldin in their paper [SE12] presents an adaptive real-time tracking and simulation algorithm for heavy construction operations of heavy construction operations. In this method construction data are continuously recorded by the means of different sensors. The framework presented in Figure 1. a) enables continuous adaption of the simulation by generation of the necessary empirical distribution functions. This implies that the simulation model itself has a special construction which enables adaptive features.



a) Parametric adaptation [5]



b) Building from components – structural adapation [8]

Figure 1. Examples on simulations‘ adaptivity

The adaptive simulations have generally more complex functionality than the conventional ones. As complexity increases, it becomes attractive to employ a formal system for decision making during system operation. Example for this can be application of an 'expert system' that generalizes 'IF' statement logic in a way that can be easily specified and adapted [Cly95]. The later belongs to the artificial intelligence methodology. Another way to make the simulations more intelligent is the application of neural networks. Our former research was focusing on the approximation of travel times using a feedforward neural network, and its applicability in simulation models [BGR12].

Structural adaptation of a simulation model is a novel area in logistics simulation modelling. The proposed paper will therefore focus on this problem area. One of the main challenges here is that the model's own structure and operation should be modelled automatically. This problem can be solved preferably by the use of ontologies. Using ontologies to set up simulations is described in [BPM06], where predefined components are used for the construction of the simulation model. We point out that the proposed simulation model's process descriptive part in section III. could also be automatically constructed this way. More on adaptive simulations supplemented by a material flow example is presented in [GB15].

Adaptive techniques are despite the latest achievements not yet the mainstream of simulations, because of the complexity. Wenzel in his paper [Wen09] presented development areas in the areas of production and logistics using the "Gartner Hype Cycle". The phase "technology trigger" characterizes an event that attracts the interest of the professional public in coming. With the phase "peak of inflated expectations" enthusiastic expectations for technological development are created. The "trough of disillusionment" highlights the fact that the expectations associated with the development, cannot be satisfied. Publications on this phase are rare. In the "path of illumination" (slope of enlightenment) realistic estimates lead to a new understanding of the developments. The last phase of the Gartner Hype Cycle "plateau of productivity" is achieved when the benefits of development are widely accepted. The technology developed in this phase in the second or third generation. Adaptive simulations are closest to the category in Fig. 2 called „Automatic model generation“. As seen there have already much research in this area, however next a period of disillusionment is expected. Therefore actually research in this area should much concentrate on practical applications, in order to prove usability.

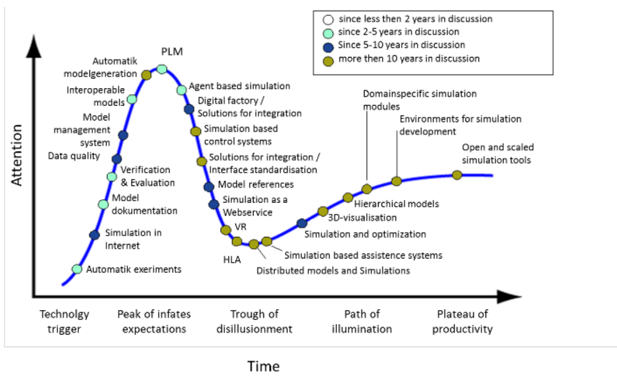


Figure 2. Positioning of the development areas in the areas of production and logistics using the "Gartner Hype Cycle" [Wen09]

Current research is a part of our research ambitions to achieve new advancements in Production Informatics and Control. In its thematic the paper is part of our H2020 financed project EPIC.

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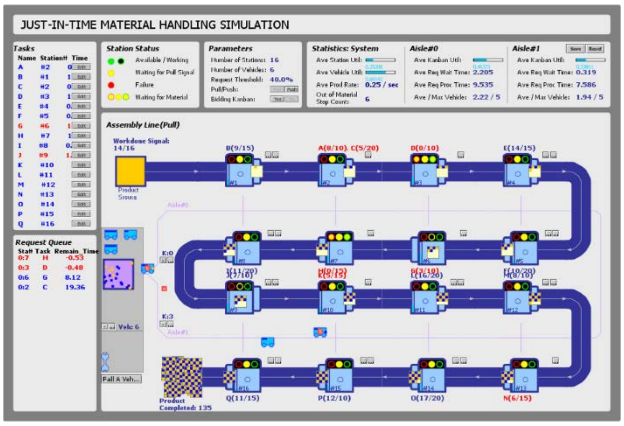
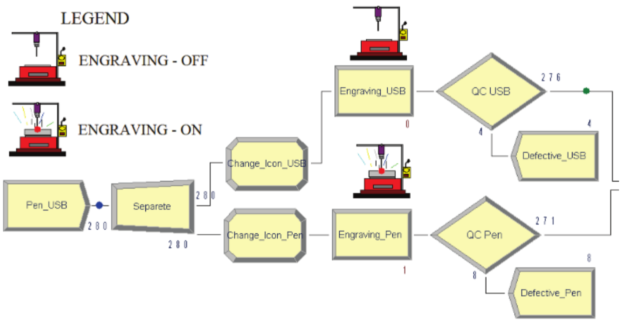
2 SURVEY OF RELEVANT MODELS FROM SCIENTIFIC WORKS

Building up a comprehensive classification of simulation models goes far beyond the extent of a single publication. Because it is not a main issue of this paper a simple classification will be presented. Accordingly we distinguish ”layout type” and “process type” simulations.



Layout type simulation [HS08]



Process type simulation [Ros14]

Figure 3. Examples for layout type and process type simulations

In layout type simulation models the central part of the simulation [HS08] is the simplified model of the system from bird view. Here, main components are modelled, distance between the nodes can easily be judged. However the processes are not seen initially, in order to see them the user should go into further sub-windows or coding sections.

Process type simulation models (e.g. [Ros14]) concentrate on the demonstration of process dependencies. In this case correspondence of processes and related locations is not obvious.

There is no preference between the two model types as each has advantages. In some cases there have been attempts to combine the two modelling ways, but there is no unified schema to do this.

3 DESCRIPTION OF THE “JELLYFISH” MODEL

The developed and proposed “Jellyfish” model is first and foremost a new art of representation in simulation modelling. The name comes from the structure of the model as it is composed of two main parts like the marine animal. The upper “bell” represents the physical layout of the modelled system with all the machines, transporters, buffers; the technological and material flow components. This is a realistic model of the real system, handling alone all the mechanical and logical constraints. It can also include complex algorithms for path planning such as the one shown in [BGR16]. Thus this part is a layout type simulation model. Comparing to the latter, the main difference is that in former models the processes are defined in codes, databases or when it was necessary were modelled by separate modelling objects, which were placed in the same modelling plane. The example shown in Figure 4. has been implemented in Plant Simulation [Sie16], but it can be constructed in other software environment, provided it is able to handle 3D position of simulation objects.

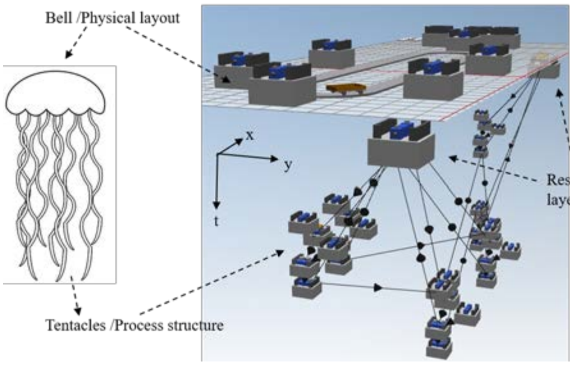


Figure 4. General construction of the “Jellyfish” model

In our approach the processes are represented in the 3D space of the downwards projection of the layout. That means the model is interpreted in a (x,y,t) coordinate system, which is common for the description of planar motions. As later processes are located more distant from the plane of the physical layout the axis “t” points downwards.

Between the physical layer and the processes the resource availability layer is located. It helps controlling the processes from executing parallel multiple processes which require the same resource.

Each process is composed of the following elements. The signals from the processes which are preconditions of the actual one arrive into buffer elements (1). If all preconditions are met, the process starts, if the physical resource is available (2). This logical information is stored in buffers of the Resource layer for each machine (see Figure 3). The process running element (4) is modeled as an assembly station as it collects signals (virtual objects) from the preconditions and from the availability of the resource. As soon as

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the physical system has executed the process it places a virtual object into the feedback on completion buffer (5). That enables flowing of the information further into the process completed assembly station (6). Finally the information forwarding on completion, which is a dismantle station leads the virtual objects to the precondition side of consequent processes. The processes are located in the (x,y) plane at a position where the process starts (e.g. starting point of a movement).

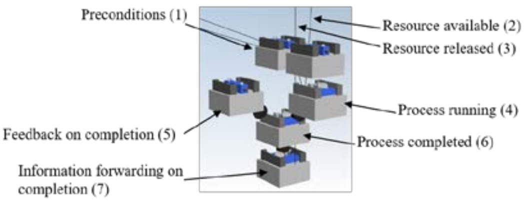

Figure 5. Model of a single process

After presenting the model's structure the question may arise, what benefits can be achieved by using it. Process control for example could also be implemented in coding sections, by simple search algorithms. So what are the advantages to use at least 5 simulation objects instead a simple code with variables?

First advantage is visual. Actual state of the system can easily be recognized by observing the process structure part.

Second, this representation can be generated automatically on the input database of process dependencies.

Third, this approach enables new possibility in the methodology of model analysis. Having a graph model of the processes such methodology like ontology matching [CMG15] could be applied. These methods enable recognition of typical process patterns in the actual process flow thus enhancing the analysis possibilities.

Fourth, the "Jellyfish" model supports simulation' adaptiveness as well. Structural adaptation is particularly supported. It is an important advantage as this is the most complex problem as written in the introduction. The proposed model can be adapted in similar way as Benjamin et al. [BPM06] described in their paper: the authors proposed a model construction method using a component library.

Summarizing the above advantages, the proposed model gives an easy to overview and standardized way for presenting complex material flow processes. It supports human analysis and adaptation without becoming over-complicated.

4 SIMULATION EXAMPLE

During this research phase a simulation model has been elaborated for the presentation of the „Jellyfish" concept. Though the modeled process was quite simple the development process revealed important details which should be considered in order to get a properly operating simulation.

The example material flow system's 2D view in Plant Simulation is presented in Figure 6. It is composed of 6 material buffers (Node 1-6), a transporter (Automatic guided vehicle - AGV) on an oval path and a machine at Node 4 for the processing of incoming materials.

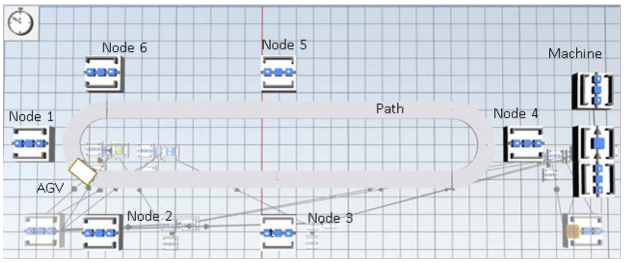

Figure 6. Example layout

The processes are described in Table 1. The materials are transported from Node 1 to the Buffers, and remain there until the machine is ready with the preprocessing. Afterwards, the materials are transported to Node 4. Finally, as each material arrived, the machine carries out the production. Even in the current version the model is very demonstrational: movement of AGV and the actual processes can be surveyed at a glance.

Table 1. Process description

Proc. ID	Precondition process	Description	Required resource
1	-	Material transport from node 1 to node 2	AGV
2	-	Material transport from node 1 to node 3	AGV
3	-	Preprocessing 1.	Machine
4	3	Material transport from node 2 to node 4	AGV
5	3	Material transport from node 3 to node 4	AGV
6	4,5	Production	Machine

5 SUMMARY

The presented new model's first tests were limited to the functionality, but even so, these are promising. Next steps of the research will focus on modelling more complex, real industrial processes and analyze them with ontology matching methods to obtain process features which are hidden from the methods used before.

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