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A TECHNICAL CONCEPT FOR PLANT ENGINEERING BY SIMULATION-BASED AND LOGISTIC-INTEGRATED PROJECT MANAGEMENT

Thomas Gutfeld
Ulrich Jessen
Sigrid Wenzel

University of Kassel
Institute of Production Technology and Logistics (IPL),
Department of Production Organization and Factory Planning
Kurt-Wolters-Str. 3
34125 Kassel, GERMANY

Christoph Laroque

University of Applied Sciences Zwickau,
Institute for Management and Information
Chair for Business Computing

Scheffelstraße 39
08056 Zwickau, GERMANY

Jens Weber

University of Paderborn
Heinz Nixdorf Institute
Business Computing, especially CIM – Simulation and Digital Manufacturing
Fuerstenallee 11
33102 Paderborn, GERMANY

ABSTRACT

Customized planning, engineering and build-up of factory plants are very complex tasks, where project management contains lots of risks and uncertainties. Existing simulation techniques could help massively to evaluate these uncertainties and achieve improved and at least more robust plans during project management, but are typically not applied in industry, especially at SMEs (small and medium-sized enterprises). This paper presents some results of the joint research project *simject* of the Universities of Paderborn and Kassel, which aims at the development of a demonstrator for a simulation-based and logistic-integrated project planning and scheduling. Based on the researched state-of-the-art, requirements and a planning process are derived and described, as well as a draft of the current technical infrastructure of the intended modular prototype. First plug-ins for project simulation and multi-project optimization are implemented and already show possible benefits for the project management process.

1 INTRODUCTION

The customized plant engineering and construction is distinguished from the stationary series production. Generally, the engineering and construction of a plant (like a windmill-powered plant, a biogas plant or a power plant) is the realization of a single product at various locations in terms of a make-to-order production and an on-site fabrication. The planning and implementation of these plants always depends on technical and structural boundary conditions. Further important points are organizational project specifications (for example, production steps, construction phases or resource disposition) and logistical constraints.

Temporal feasibility of the design, construction and production, the robustness of project plan together with the customized constraints have crucial importance for the competitiveness of each participating company. Before and during the project, its schedules have to be evaluated, so that the companies have a better chance to re-act when the constraints change with regard to the product (the plant) or the production. The companies must consider logistics processes in the definition of project schedules, because of the uncertainty of delivery dates, which often depend on local conditions at the customer´s site and the resulting implementation risk at the end.

Comprehensive tool support is primarily found in customized plant design (for example CAD, CAE or FEM-applications). Optimization, visualization and simulation are possible with the help of these programs with regard to design, assembly and production. The project planning and implementation of a plant is done with simple methods of project management, for example (DIN 69901-3 2009). However, these project management methods are inadequate, because they do not reflect temporal uncertainties of logistics and project schedules. Critical points of the total project cannot be detected and the robustness of the project schedule cannot be evaluated. The considered projects in the field of plant construction due to their individuality have the problem that they are built directly at the location of the customer under specific logistical conditions. In addition to these special cases, the time for planning, construction, design and implementation is continuously reduced so that the customer can realize a faster return on investment costs. Improving the logistical aspect, specifically in the areas of planning and implementation of the plants, makes a much higher optimization potential possible. The complexity of the planning is additionally increased as the project managers have to organize several projects in parallel, making it challenging to manage, plan and coordinate the bottleneck resources of their team, employers and departments.

Therefore, the University of Paderborn and the University of Kassel started a joint research project *simject* in April 2013. The aim is to minimize the described problems and deficits of project management and to develop a demonstrator for simulation-based and logistic-integrated project management in plant engineering. In this paper, starting from “related work” in Section 2, the already achieved results of the joint research project will be presented. In Section 3, we will discuss the concept and the utilization process for the technical demonstrator of the project. In Section 4, its technical structure will be explained, focusing on the IT-architecture and the needed plug-ins. Section 5 deals with a first use case, showing the benefits of the use of simulation in project management. The paper closes with a conclusion and outlines the remaining project work.

2 RELATED WORK

In order to represent the state-of-the-art and related previous research work, simulation tools and methods from civil engineering, shipbuilding, series production and plant engineering have been taken into consideration. Moreover, in this section, the results of a requirements analysis are described.

2.1 State-of-the-Art

Today, software tools exist in the field of civil engineering, where they simulate project scenarios and visualize the results in order to support the planning and controlling of large construction sites by viewing different events on location plans depending on temporal sequences. One example of this kind of software is the Afinion Project-simulator (Afinion 2012). This simulation tool considers the precedence of a combination of location plans and schedules for the visualization of portable processes measured over time without handling or viewing logistical processes. However, other simulation tools offer distance-time planning capabilities and show construction processes in respective distance-time-diagrams (TILOS 2012). This kind of simulation software is often used in road, rail and pipeline or tunnel construction. A process-oriented approach is offered by the tool “OTD-PM” (Fraunhofer 2012). This process-chain model enables the simulation and visualization of the project steps. It is furthermore possible to consider logistical supplier processes. In addition, a project simulation tool based on ProModel can be used to simulate and analyze different project scenarios (ProModel 2013).

In the field of building construction and civil engineering, there have been industry co-operations for simulation-based construction processes of a “Metro stop” (underground public transportation). The simulation program used was “Plant Simulation” from Siemens AG (Günthner and Kraul 2008). All construction and logistical processes were simulated and the results were transferred into a project plan. This cooperative project was later developed into a block library for civil engineering. This further development was accomplished during a research project by (Wimmer, Horenburg and Günthner 2010).

The Ph.D.-Thesis of (Weber 2007) focused on the modeling and simulation of logistical processes in the field of building construction. The used software tool was “Enterprise Dynamics” from INCONTROL Simulation Solutions. (Kugler 2012) wrote another thesis in the same field. The topic is about the review of the usage of multi-agent-simulation in combination with CAD models. (Chahrour 2007) analyzed earthwork processes via CAD models and “PACE”, a Petri net-based simulator of the company IBE Simulation Engineering GmbH. Thereby the logistical process of earth removal was also considered.

In shipbuilding, the simulation tool STS (Simulation Toolkit Shipbuilding) was used and since the 1990s it has been adjusted for unique production in the area of shipbuilding (Steinhauer 2008). This tool was integrated in the software “Plant Simulation” and contains parameterized and re-usable blocks for modeling production (Steinhauer 2008). In addition, the influence of weather data was mapped and developed for discrete event simulation (Steinhauer 2011). Since 2006, the research foundation between shipbuilding and civil engineering called ‘Simulation of Outfitting in Shipbuilding and Civil Engineering’ (SIMoFIT 2012) has developed a constraint-based simulation approach (Steinhauer, König and Bargstädt 2007). The aim of this project is a simulation-based planning tool, which considers the individual project participants, suppliers, different execution variants, order dependencies and the dynamic production environment. The described constraint-based simulation approach, a so-called “ConstraintManager”, will be integrated into the STS simulation tool so that dynamic conditions respecting predecessor and successor relationships will be able to visualize the construction process and work steps. Furthermore, it should be possible to visualize dependencies of time and resource availability, for example, materials or human resources (compare to Beißert, König and Bargstädt 2010, König and Beißert 2008, König et al. 2007).

The collaborative research project “Mon²Sea” focuses on production and logistic processes for series production of plants, especially offshore-projects and wind energy plants. The research goal is a conceptual development of an IT-research platform for material supply and general supply chains. Additionally, the platform should enable a stochastic planning model for the weather-dependent planning and installation of wind energy plants, an infrastructure for innovative information and communication technologies for the tracking and tracing strategies as well as identifier and automatic localization functions (Mon²Sea 2012).

The various research projects, foundations and tools show that the considerations of logistical conditions in combination with project plans are not new and innovative. However, these occur only in shipbuilding and civil engineering via case-by-case-simulation. The simulation-based project planning methods relate only to individual applications or general research projects. In contrast, many years ago, the discrete event simulation was applied for the hedging of risks in logistics for series production (VDI 2010; Wenzel et al. 2008; Scholz-Reiter et al. 2008; Kuhn and Wenzel 2008; Spieckermann 2005; Bayer, Collisi and Wenzel 2003; Kuhn and Rabe 1998; Kuhn, Reinhardt and Wiendahl 1993). Today planning tasks in series production, for example, the automotive industry will be solved via complex optimization models (Günther and Tempelmeier 2005). The optimized project plans, just like handmade plans, contain risks and need to be regularly adjusted to new situations. In the future, the use of existing simulation methods for analyzing the resulting project plan and evaluating it in terms of its robustness may be considered (Fischer et al. 2012, Laroque et al. 2011; März et al. 2010;).

According to Steinhauer and König 2010, simulation-based analysis, which is normally used in series production, might be used to evaluate the safety of the planning of unique and customized plants and increase the efficiency of plant production. In this way, potential improvements in plant engineering for smaller companies are also possible.

In short, it can be stated that there is no standardized solution of simulation-based and logistic-integrated project management, usable for SME. During the project, particularly the development of the demonstrator, an additional requirements analysis has been performed with possible application partners in order to identify the specific requirements of SMEs. Its results are described in the following section.

2.2 Practical Requirements Analysis with Application Partners – Short summary

In the beginning of the research project, the University of Kassel and the University of Paderborn performed a requirement analysis for a simulation-based logistic-integrated project management tool together with plant manufacturers from SME within the scope of environmental technologies. For this reason, interviews were conducted for analyzing project management restrictions in this field. The aim of the analysis was to determine the type of project management plans, which project run times, exist, which tasks and processes are involved or which project volumes are available on average. Furthermore, it was analyzed how change management is done, in particular adjustments of project plans, project documents and employer information, and the combined expenditure was determined. In addition, the reasons for the adjustments were surveyed. It was analyzed, what kind of tools would improve the actual change management situation. One important point was the information about individual considerations of uncertainties. Whether and how simulations are used in the project processes, in particular for logistical processes were also surveyed.

The results of this analysis reflect in particular that a simulation-based logistic-integrated project management tools should have an interface to project planning tools like Microsoft Project, or to an enterprise resource planning (ERP) system. In addition, there is the requirement that weather information and the influence of weather on the logistics processes should be include in a simulation model as well as the consequences on the project plan. As another important point, geographical information system data (GIS data) have to be represented in the simulation model of such a tool.

With regard to the simulation tools used today, there are frequently no simulation analysis of logistics processes within project planning and no simulation-based analyzing of project plans. Only technical solutions for the simulation of the plant construction and optimization (CAD- or FEM-applications) process are used. It has been found that, on average, the absence of resources, for example caused by illness of employer, delivery bottlenecks of materials or administrative procedures are responsible reasons for the scheduling uncertainties of projects. Scheduled buffer offset these uncertainties and there is a high communication effort between the responsible departments and the supplier. In this way, it became clear that between unforeseeable events, information gaps and deficits originate and the consequence on the projects are the project delay or in worse case the failure of the project. For that reason, there are the requirements to simulate and visualize project plans including a construction progress visualization (2D and 3D) and generate measures to minimize information deficits.

3 CONCEPT

3.1 Project idea

Section 2 has already depicted existing forms of simulating uncertainties in project planning (e.g. date of delivery). Nevertheless, in today's plant engineering uncertainties are still almost exclusively taken into account through manual integration of additional buffer times. One of the reasons is the absence of simulation software for project simulation that meets the demands of SMEs in the field of plant engineering. It would be desirable to compare multiple project planning alternatives and additionally integrate logistical processes through a simulation of the sequence of events. More apt planning of uncertainties, due to the presented attempt, should fill this gap. Today's manual planning of buffer times in project schedules cause high buffer time stocks. These buffer times are often not bound to the events of highest risk, but are scattered throughout multiple processes. If these time buffers are not taken up during project completion, it usually does not lead to positive effects. Necessary buffer times should therefore be concretized for logistical tasks through the integrative attempt. They are first to be determined based on logistical simulation and then to be put down to the project schedule as restrictions (cf. Figure 1). Logistical processes determine the basis of logistical simulations for SMEs in the field of plant engineering, which are used to generate models of logistics into tangible projects. Afterwards the determined project schedule can be subjected to a simulation and according to that be improved. As changes to the project schedule are set into practice, those can again be subjected to the logistical simulation (cf. Wenzel & Laroque (2013)). In the future this process could not only be used in project planning, but also in project controlling and for steering measures. The idea of a simulation-based project management with integrated logistics could be forward-looking. It is based e.g. on the development and utilization of reference plans as well as project- and logistic-scenarios. Thereby, systematic experience and process improvements can be integrated (Wenzel et al. (2014)).

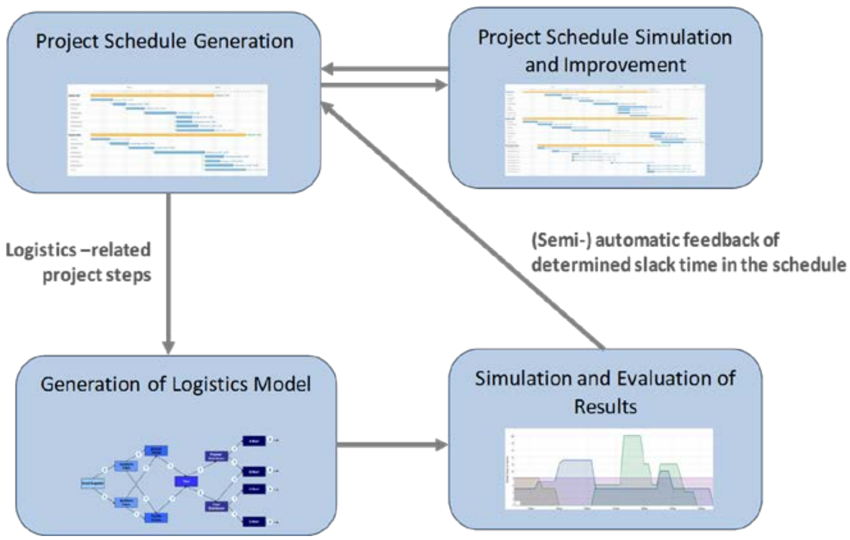

Figure 1: Project idea for *simject*

3.2 Utilization process

A simulation-based project management with integrated logistics has to support the process of utilization shown in Figure 2. Starting with a deterministic scheduling, this process describes the different steps of probabilistic planning, the subsequent plan-simulation updated during the realization of the project as well as, finally, the plan analysis. The following figure shows the process steps in detail.

- *Deterministic Planning:* The deterministic project planning can be done from scratch or be based on existing plans. These schedules are mainly the results of a detailed analysis of finished projects. In this way, the analysis is able to offer specifications for principal project operations and workflows as a template and provide the first timelines for specific work packages.
- *Definition of Probabilities:* To prepare the project plan simulation, unknowns and uncertainties of the project (e.g. duration of specific tasks, risk of delay by weather condition) are assessed with corresponding probabilities. If applicable, a corresponding probability function, which may affect the variation of the duration or delay of the start and end time points of individual work packages, may be used. The project planner may select from several statistical distributions that are available. However, at this stage of the research project, there is no information about which distribution may best cover which risk. If empirical values of work packages from the past are available, the probability function will be determined from historical data by distribution fitting. For the illustration of logistics processes in the context of work packages, the discrete event simulation is suitable, because individual influence factors can be considered, from the selection of transportation routes to a construction site up to the dispatching of motion tasks, transport

orders and resource utilization. The deviation in the logistics process, identified by the simulation, can lead back into the total project plan as a set of probabilities.

- *Project Schedule Simulation / Visualization:* The simulation allows one to take into account the probabilities of the individual work packages in the overall planning in order to generate final, assessable statements about dates and duration. The results are not deterministic planned events, but rather a spectrum that is described by a corresponding probability function. This includes, for example, the indication of earliest and latest end time point and the probability of individual dates in the given interval. The results of the simulation are visualized as an extended project plan, a Gantt chart, where the deviations are displayed. A subsequent optimization process allows corrections starting from the simulation result as well as tracking the effects in following simulation runs. In this way, the project schedule is improved through an iterative process. In addition, to address other target groups with the utilization of a realistic representation instead of the abstract visualization as Gantt chart, the 3D-visualization would be applicable which allows the visualization of individual stages of the construction progress based on the degree of completion of the work packages.

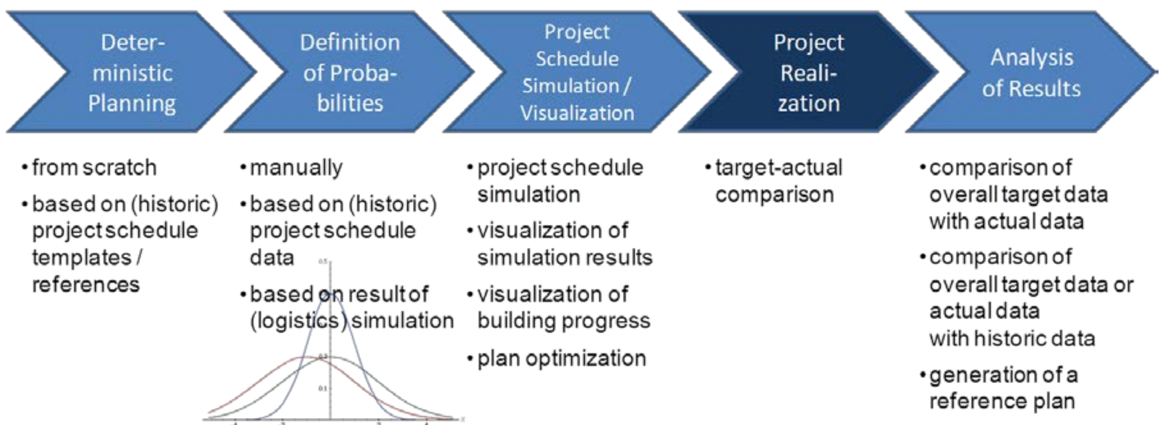

Figure 2: Utilization process

- *Project Realization:* During the project implementation, the simulation is used to update the optimized target plan continuously with the current data. In this way, the delays of the start of the work packages and their durations will be documented and compared with the spectrum of results determined by simulation.
- *Analysis of Results:* After the end of the project, a detailed analysis of the target plan based on the process data that were logged during the project implementation phase will be carried out. For this purpose, total target data will be compared with the total actual data. This comparison may include deviations between target and actual start times or planned and actual duration of work packages. In addition, historical total target data and total actual data from similar or comparable projects can be included in the analysis. The goal of this process step is to build a knowledge base consisting of analyzed and documented project schedules. With the support of the knowledge base, it will be possible to generate suitable reference schedules or a project template for specific projects. This feature could improve the planning of projects during the *Deterministic Planning*. The project final analysis and the subsequent use of the knowledge in planning new projects, completes an iteration cycle that suggests that the quality of planning will continuously be improved. In addition, comparison between process steps is not excluded, so that even during the usage process, improvements will be made by integrating findings from the current realized project into the simulation of the project plan, thus making further adjustments of the target plan possible. In addition, not all listed tasks need to be performed in a more detailed way. That is why

a suitable tool is demanded which supports the process of usage in a flexible way. It will be outlined in the following section.

4 TECHNICAL STRUCTURE

4.1 Information technical (IT) architecture

For IT-support of the previously defined usage-process a wide variety of tools are needed to cope with the individual tasks and sub-tasks. These tools include the following main functions:

- Interface to external data sources (schedules, data from ERP systems, GIS and weather data).
- Project editing (editor to manage and modify project schedules)
- Logistics simulation (discrete event simulator for logistic models)
- Project simulation (simulation for project schedules)
- Project optimization (optimization tools for project schedules)
- Visualization (plan visualization, 2D-/3D-construction progress visualization)

The used functions will vary depending on the identified planning task, so that a fixed planning process cannot be supposed. Thus, the functions and the used tools will be suitably orchestrated for each planning task. Figure 3 illustrates an example usage process.

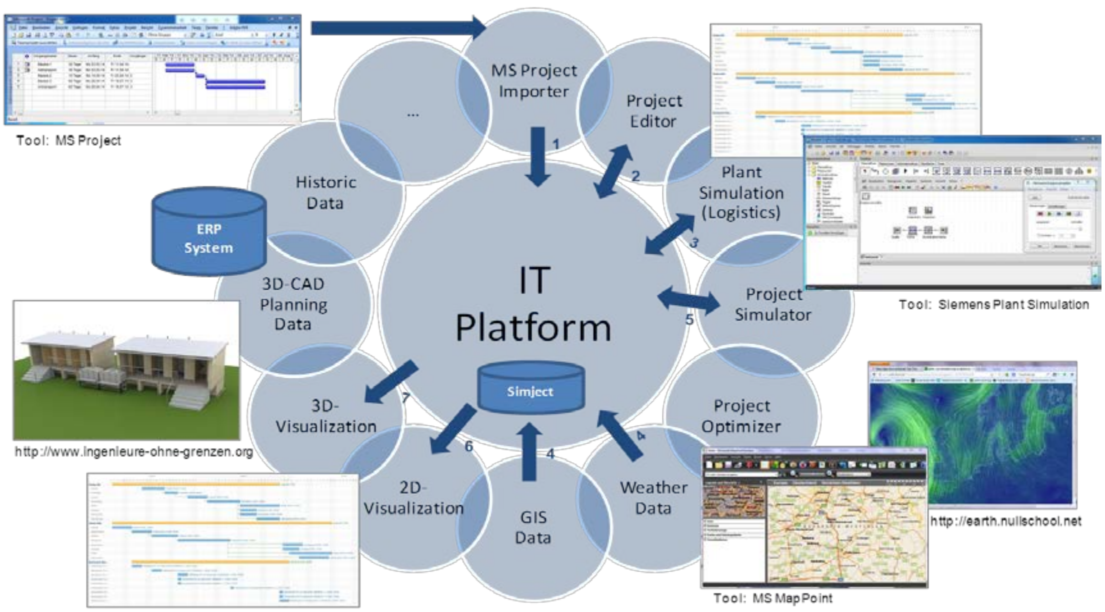

Figure 3: IT-architecture of the *simject*-demonstrator

In the shown example in Figure 3, the initial plan is first transferred through an interface from the MS Project tool (1) to the platform and the data are loaded into the tool's internal *simject*-database. Now the plan is available for editing in the project editor (2). In the Project Editor various adjustments can be made, including the definition of uncertainties for probability functions (in the beginning, this is done manually by the planner by selecting from different distributions). Suppose the project has a high proportion of logistics, a logistics model is established for individual work packages and the simulation results produce further adjustments for the project schedule (3). In logistics simulations, further information can be considered, such as weather data or an available road network in the form of corresponding data (4). All previously determined and calculated information can be entered into the simulation and optimization of the project plan (5).The results are ultimately visualized. The spectrum of options ranges from a pure plan visualization via Gantt chart (6) up to the complex 3D-visualisation of construction progress based on the defined plan (7). All tools and interfaces exchange information among themselves with the support of a common platform, in which the current state of the planning project will also be saved into a database. In this database, the realized As-Is-information of running projects is also stored and can be used for a systematic approach for the parameter estimation in future projects.

To enable this process, a software development platform is required that allows the development and integration of new tools into the platform. Furthermore, existing tools will be connected under the usage of interfaces to the platform and the utilization of the interfaces for managing external data sources and project data are possible. It is important that under project-specific requirements, tools and interfaces are able to connect to the platform. In addition, to connect additional tools and to realize additional interfaces, the platform has to be designed open and extensible.

4.2 Using SimAssist as Software Platform

A software development platform, called SimAssist from the company SimPlan AG, satisfies the requirements formulated in section 4.1 with regard to the interfaces and extensibility of the software as well as the satisfaction of flexibility and utilization.

A significant percentage of the requirements are met by SimAssist's modular structure, which allows the development of functionalities as closed plug-ins that communicate with each other via standard interfaces to a common platform. SimAssist consists of a platform in which various functions for data management as well as the communication between the connected plug-ins are implemented. Additionally, a library for standardized plug-ins is provided. The number of plug-ins can vary. As the plug-ins are linked dynamically only at running time with the platform, it is easy to connect, integrate, delete and replace existing plug-ins under standardized settings. The graphical user interface (GUI) shows the user the modular structure of a tool developed by SimAssist (see Figure 4).

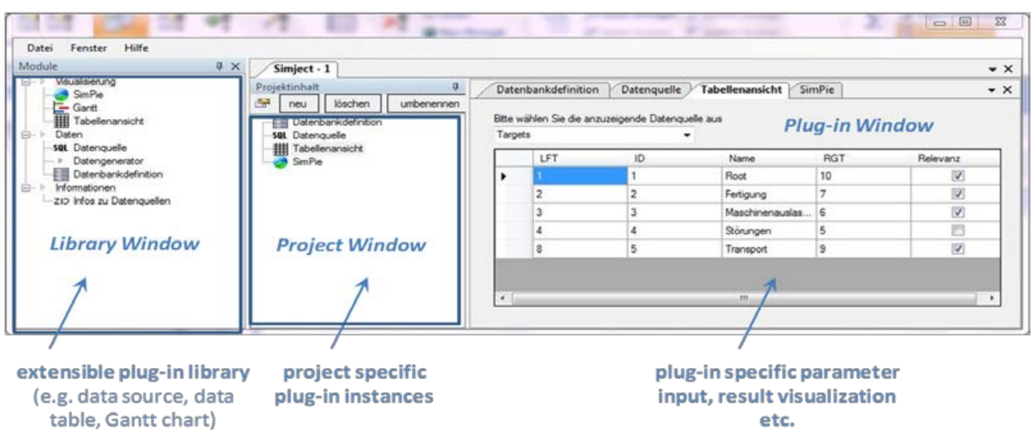

Figure 4: GUI – Plug-in concept of SimAssist (SimPlan AG)

The GUI shows the user three windows, the *Library Window*, the *Project Window* as well as the *Plug-in Window*. The *Library Window* shows all plug-ins that are included in the library, connected to the platform, and therefore essentially ready for usage. The *Project Window* represents the project structure, including plug-ins that are assigned to the respective instance of a specific project. The *Plug-in Window* represents the front-end of each plug-in, which has been selected in the *Project Window*.

The platform SimAssist provides the following sequence of operations: The user can choose the specific plug-ins needed out of a selection of all plug-ins. To do so, after creating or opening a project, one has to choose the necessary plug-ins in the *Library Window* and paste the individual selection into the specific project structure via Drag-and-Drop. After the selection of a specific plug-in in the *Project Window*, the chosen front-end appears as index card within the *Plug-in Window*. The user is able to set, configure and parameterize the function of the plug-in or is able to visualize the content of the plug-in. The entire project configuration is managed by the SimAssist database. The GUI example in Figure 4 shows a table view in the *Plug-in Window* as a front-end of a corresponding plug-in. This plug-in gets its data from the plug-in *Datenquelle* (English *data source*) in which a specific database access is formulated which uses the plug-in *Datenbankdefinition* (English *database-definition*). It represents a specific database in the project. All plug-ins have been taken out of the plug-in library, where the plug-ins are classified by the themes *data*, *information* and *visualization* as well as stored in a structural order.

5 A FIRST USE CASE

Some of the intended plug-ins has already been realized in a prototypical manner, e.g. those for project simulation and multi-project optimization. In the selected use case, the parallel building process of two houses was taken into consideration and optimized. For this purpose, the corresponding project plans have been designed and resources have been aligned to each of the process steps. Furthermore, in the basic data, corresponding transfer times have been generated, where concrete transfer times for resources from the locations of both projects have been documented. For each resource (machine, workers, e.g.), the maximum work time has been limited. For each of the building projects, the project plan has been simulated by using Monte-Carlo methods and its robustness has been evaluated by different diagrams. Since the underlying project plans have not covered detailed logistical processes in this case, the uncertainties according the duration of the process steps has been considered by using the Monte-Carlo simulation. Figure shows an example for one of the analysis diagrams (here the comparison of the projects length and its costs based on the project simulation). A project planner now can evaluate how the included uncertainty in his project plan might result in longer project times or higher project costs.

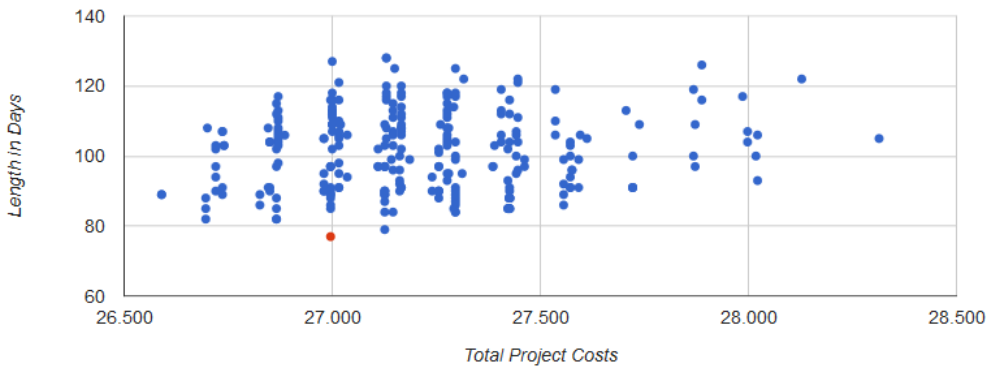

Figure 5: Length in days in dependence of the total project costs as one result of a project plan simulation

In a next step both project plans, which use common resources, have been optimized in another plug-in for project optimization. Including the referenced transfer times between the locations, by the use of an ant-colony heuristic (ACO), the project plans can be optimized according to different optimization criteria, e.g. the minimization of transfers, the minimum of total costs or the earliest-deadline. ACO was selected, since it could be applied successfully to this kind of problems in similar applications in the past (cp. Merkle et al. 2002). The user can compare the generated scenario solutions and a specific optimization result can be selected. Figure 6 shows one of the possible comparison graphs for the user`s decision support. As can be seen, the green optimization solution leads to lower costs for the execution of the project plan at equal risk points for missing the project deadline. Alternatively, regarded from another point of view, for a specific limit of costs for both of the optimized project plans, the risk of missing a specific deadline is lower.

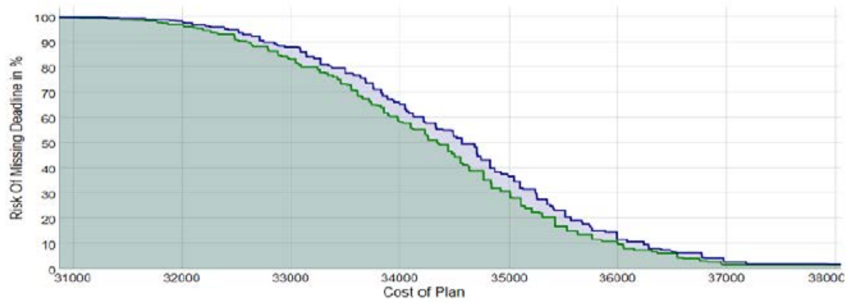

Figure 6: Cost-/Risk-graph of two project optimization results

6 CONCLUSION AND OUTLOOK

This paper describes some major results of the current joint research project between the Universities of Paderborn and Kassel. The project goal is a demonstrator for a simulation-based and logistic-integrated project planning for SMEs in the single-part construction and engineering domain. Based on an analysis of the state-of-the-art, requirements and a concept for a modular software structure were derived. Its realization bases on the existing plug-in framework SimAssist and follows a guided process for process planning, re-planning and re-use of the gained data and, thereby, knowledge as it is described above. First plug-ins for project simulation and multi-project optimization based on ant-colony heuristics have been implemented and already show possible benefits for the project management in the build-up process of these complex products. During the next steps, the framework is to be validated by some practical use-cases of the project's application partners in order to evaluate the benefits in comparison to the planning process today. By this, a measurement of the tool's benefits may be rolled out.

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AUTHOR BIOGRAPHIES

THOMAS GUTFELD studied civil engineering at the Technical University of Leipzig and project management at the Bauhaus-University of Weimar. He can be contacted via gutfeld@uni-kassel.de.

ULRICH JESSEN studied computer science at the University of Dortmund (Diploma in 1990). Since 2007 he has been working at the University of Kassel as manager of research and consultancy projects as well as manager of the master degree program Industrial Production Management. His email address is jessen@uni-kassel.de.

SIGRID WENZEL is Professor and Deputy Managing Director of the Institute for Production Engineering and Logistics, University of Kassel, and head of the Department of Production Organization and Factory Planning. In addition to this, she is a board director of the *Arbeitsgemeinschaft Simulation* (ASIM), spokesperson for the ASIM working group Simulation in Production and Logistics, member of the advisory board of the Association of German Engineers Society of Production and Logistics (VDI-GPL), and head of the Committee Modeling and Simulation of the VDI-GPL. Her email address is s.wenzel@uni-kassel.de.

CHRISTOPH LAROQUE studied business computing at the University of Paderborn, Germany. Since 2013 he is Professor of Business Computing at the University of Applied Sciences Zwickau, Germany. He is mainly interested in the application of simulation-based decision support techniques for operational production and project management. His email address is Christoph.laroque@fh-zwickau.de.

JENS WEBER is a research associate and PhD student at the department of Business Computing, especially CIM of the University of Paderborn. He studied industrial engineering with focus on mechanical engineering, process engineering and material science and finished in May 2013. His email address is Jens.Weber@hni.uni-paderborn.de.