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ESTIMATING PROCESS DURATION AND SAFEGUARD PROJECT PLANNING IN A ONE-OF-A-KIND PRODUCTION ENVIRONMENT BY THE USE OF SIMULATION TECHNIQUES

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ABSTRACT

Customized engineering and the build-up of unique products are complex tasks, where project management contains lots of uncertainties. Simulation techniques could help to evaluate and achieve improved and more robust plans during project management, but are typically not applied in industry, especially at SMEs (small and medium-sized enterprises). This paper covers some ideas of the joint research project SimCast of the Universities of Kassel and the University of Applied Sciences Zwickau. It aims at the development of a method for duration estimation of a project task during project planning. Based on the researched state-of-the-art, requirements and a planning process are described as well as a draft of the current technical infrastructure of the intended modular prototype. First plug-ins are implemented and already show possible benefits for the project management process. The paper describes possible scenarios for the use of simulation techniques in this setting, based on gained experience.

1 MOTIVATION

Today, on-time completion and delivery of a product are important competitive factors for manufacturing companies (Emmanouilidis et al. 2012). This applies in particular to companies producing one-of-a-kind-products or small series, which are typically SMEs. An important objective of modern manufacturing companies is to increase the added-value in and around manufacturing by consistently eliminating all non-productive workloads and buffer times. The company's success is determined by the efficient design of its value-adding processes, the reliable and precise scheduling and thus also by a valid planning process. As already argued in Gutfeld et al. (2014) and Gutfeld et al. (2015) the customized engineering and construction from plants, machinery or one-of-a-kind products in general differs significantly from stationary series production. Besides technical and structural boundaries, relevant aspects are organizational project specifications (e. g. production steps, construction phases or resource disposition) and logistical constraints. Temporal feasibility of the design, construction and production, the robustness of project plans together with the customized constraints have crucial importance for the competitiveness of each participating company. Specifically in an one-of-a-kind production, due to the project-specific customer orders and components, only a limited amount of assumptions can be derived to determine process times from previous projects and transferred 1:1 to new projects. For this reason, additional time buffers are often added during the planning process in order to be able to react to uncertainties and possible disruptions. They are usually cost-intensive and may represent a competitive disadvantage for SMEs in particular; A weak planning process leads to a weaker market position.

Today's project management tools do not yet offer a methodology to support a planner for reliable forecasting of processes in these environments. Planning and implementation - especially in SME - are today still done mostly with simple methods of project management. Approaches, that consider the use of simulation, exist and have been discussed in the past, but mainly from an academic perspective. By using simulation, temporal uncertainties of logistics and project schedules could be considered more adequate. However, especially in an one-of-a-kind-production, the generation of specific simulation models for the logistical processes might not be applicable in every case, since a high amount of the given restrictions on the project are specific to this unique use-case. Nevertheless, simulation might play an useful role. Some possible approaches are discussed in this contribution, after a general overview over the existing state-of-the-art and the approach of the underlying research project SimCast is given in the first sections. A technical framework is discussed after the simulation application ideas, where these approaches can be integrated and used in a pragmatic way. An outlook on future work within the research topic and especially within the research project concludes the paper.

2 RELATED WORK

2.1 Project Planning and Control in One-of-a-Kind Production

The timely completion and delivery of a product as well as the individualization of products required in the context of fourth industrial revolution are today important competitive factors for manufacturing companies. This is especially true for customer-specific constructions, usually implemented by an one-of-a-kind production. The order processing is afflicted with a high customer specificity and complexity, which does not permit the transfer of standardization in the product business. The customized product is usually manufactured in a fixed-site production; small batches depending on the component types are also pre-configured in fixed-site production. The planning and execution of these production orders can be understood as a project management task. Pmbok (2013) defines project management as an application of knowledge, skills, tools and techniques to project activities to meet project requirements. In serial production, the logistical processes in particular are understood as a part of factory planning; in order-specific manufacturing (one-of-a-kind and small batch production), these processes are only set up during the project planning phase after the order has been placed. Depending on the type of specifically submodules (amount, size, distance to the customer), for example, heavy shipments for the production of a large equipment have to be planned. Likewise, the in-house transports of cranes and forklifts with special outfit must be individually planned and scheduled.

Project management tools are widely used to support project planning and play a crucial role in successful project execution. In contrast to series production, experiential knowledge gained from past projects cannot be transferred to a new project on an one-to-one basis due to the customer-specific components. The historical data of successful project plans can only be used to a limited extent. Therefore, experts roughly estimate the process times manually and add the logistics process times in particular to the total project time. Although interactions between unique products and their logistical processes can be depicted (see e.g. Heidmann 2015; Voigtmann 2014; Szczesny and König 2015), these processes are associated with strong uncertainties due to customer order or component specificity due to disruptive factors. Since secure time management is important in global competition, the project planner adds additional buffers in order to determine a consistent framework of personnel, technical and financial conditions. Especially scheduling a specific time period for each (sub-)process of a project must be estimated. Akhavian and Behzadan (2013) as well as Xie et al. (2011) propose different approaches for improving the estimation of project durations via knowledge extraction or the collection of real-time data for concrete individual cases, but do not refer to logistical process times in one-of-a-kind or small batch production.

2.2 Simulation in Project Planning

Specific software tools exist in various application fields, which simulate simple 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. These simulation tools consider the precedence of a combination of location and schedule plans for the visualization of portable processes measured over time without handling or viewing logistical processes. Other simulation tools offer distance-time planning capabilities and show construction processes in respective distance-time-diagrams (TILOS 2018). This kind of simulation software will often be used in road, rail and pipeline or tunnel construction. A process-oriented approach is offered by the tool *OTD-PM* (Fraunhofer 2018). This is a process chain model, which enables the simulation and visualization of the project steps and it is possible to take into account the logistical supplier process.

Within the German shipbuilding industry, the *simulation tool STS* (Simulation Toolkit Shipbuilding) is used and since the 1990s this tool has been adjusted constantly for customized shipbuilding (Steinhauer 2008). The toolkit is integrated within the *Siemens Plant Simulation* and contains parameterized and reusable blocks for modeling different aspects of manufacturing and logistics. In addition, the influence of weather data was mapped and developed for discrete event simulation. Since 2006 the research foundation between shipbuilding and civil engineering called “Simulation of Outfitting in Shipbuilding and Civil Engineering“ (SIMoFIT 2018; Steinhauer 2011) has developed a constraint-based simulation approach (Steinhauer et al. 2007). The aim of the project is a simulation based planning tool, which considers the individual project participants, suppliers, different execution variants, order dependencies and the dynamic production environment. In the described approach, a “ConstraintManager” is integrated into STS, 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 (see e.g. Beißert 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.

2.3 The Research Project S*imject* (2013-2015)

Between 2013 and 2015, the University of Paderborn and the University of Kassel worked on the joint research project *simject* (Gutfeld et al. 2014; Gutfeld et al. 2015;). The aim was 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 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. Interviews were conducted for analyzing project management restrictions in this field. The results reflect in particular that simulation-based logistic-integrated project management tools should have an interface to project planning tools like Microsoft Project or at least to the relevant enterprise resource planning (ERP) system. In addition, weather information and the influence of weather on the logistics processes should be included within the simulation model to derive the consequences on a specific project plan. Geographical information system data (GIS data) should be represented in the simulation model of such a tool. With regard to the simulation tools used, there were no simulation analysis of any project processes taken place within project planning and no simulation-based analyzing of project plans. A simulation-based project management with integrated logistics was developed, that supports the process of utilization shown in Figure 1 (see below). Starting with a deterministic scheduling, this process describes the different steps of probabilistic planning, the subsequent project schedule simulation updated during the realization of the project as well as, finally, the plan analysis (Gutfeld et al. 2014).

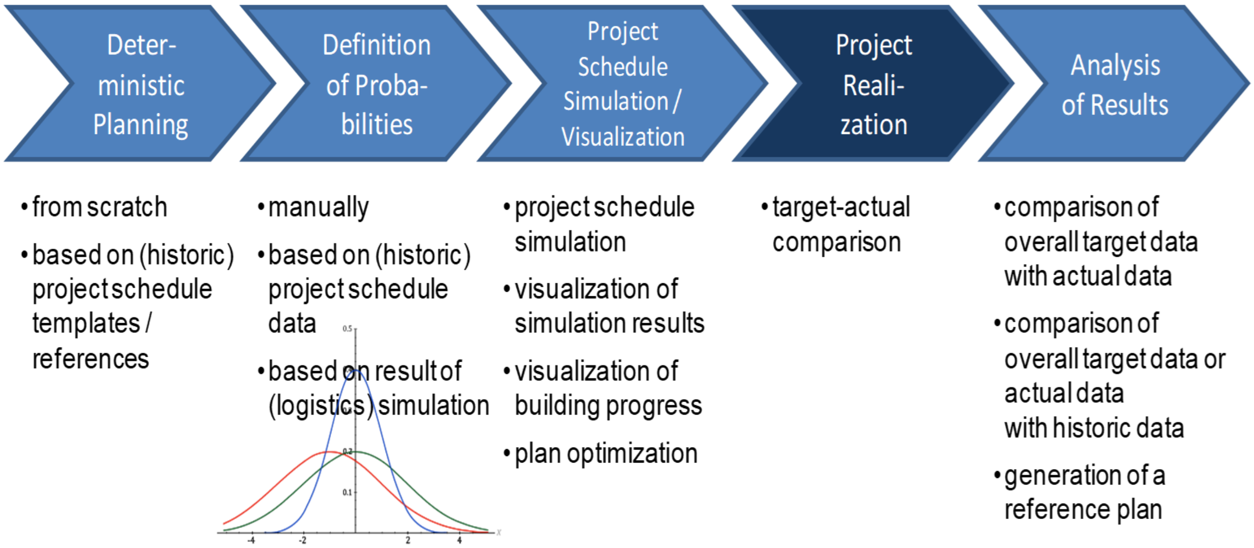

Figure 1: Utilization process of *simject* (Gutfeld et al. 2014).

During the next steps of the project, a demonstrator was developed, that integrated and compared three approaches for the management of plant engineering projects: deterministic planning, Monte-Carlo-Simulation and Discrete Event Simulation (DES), cf. Jessen et al. (2015). The comparison showed that for each approach a corresponding user scenario can be found. In practice, deterministic planning will be mostly used because many tools are available, where users need only a short training. A deterministic plan is the basis of further planning. Simulation has its advantages, if more accurate information about project deadlines is necessary and information about the included uncertainty is relevant. Monte-Carlo-Simulation may add probabilities for each project task and for the project as a whole. Most of the *simject* project's application partners have had no experience with this method before. Thus, the appropriate tool must be designed very user-friendly, so that the user put trust in this approach. DES is well known as a method for logistic planning as well as for schedule planning. The large modeling effort can be reduced by specific model components, that represent units of the application field. Within the scope of the *simject* project, it could be demonstrated, that simulation can improve project planning (Gutfeld et al. 2015). However, from the project have arisen some issues, that in part are to be addressed by a new research project called SimCast, which is described briefly in the next section.

3 THE RESEARCH PROJECT SIMCAST (2017-2018)

Most manufacturing SMEs today still lack a practicable methodology to schedule realistic process times for made-to-order manufacturing processes and its logistics with a view to achieve high planning quality. Due to the fact that experiences from past projects cannot be included in estimations, some of the developed approaches from the *simject* project cannot be applied in an adequate way, especially, since the methods shall be applied by manufacturing SMEs. As part of the research project SimCast an approach is developed, that may reliably forecast the duration of logistical processes in one-of-a-kind or small batch production by using existing historical project data. Project planning, by this, shall be minimized. The scientific aim is to conceptualize a methodology for the correct derivation and valid quantification of process parameter values from past projects. The basic idea is to classify the logistical processes in one-of-a-kind or small batch production and to describe them universally via parameters to be specified within a project and put them in a distinct, quantifiable context to the process duration. The process duration can be predicted by the value of parameters. Subsequently the quality of estimation based on these project data can be determined for a given significance level. Over time the estimated parameters can be continuously improved.

The main objective of the methodology is to provide a functionality to forecast the duration of the process as decision support for the involved planners. The methodology shall later be implemented as an add-on for existing project management tools used by SMEs. A practicable utilization of existing methods combined with externalized expertise makes an improved decision support for SMEs possible. Overall, the planning process becomes higher quality.

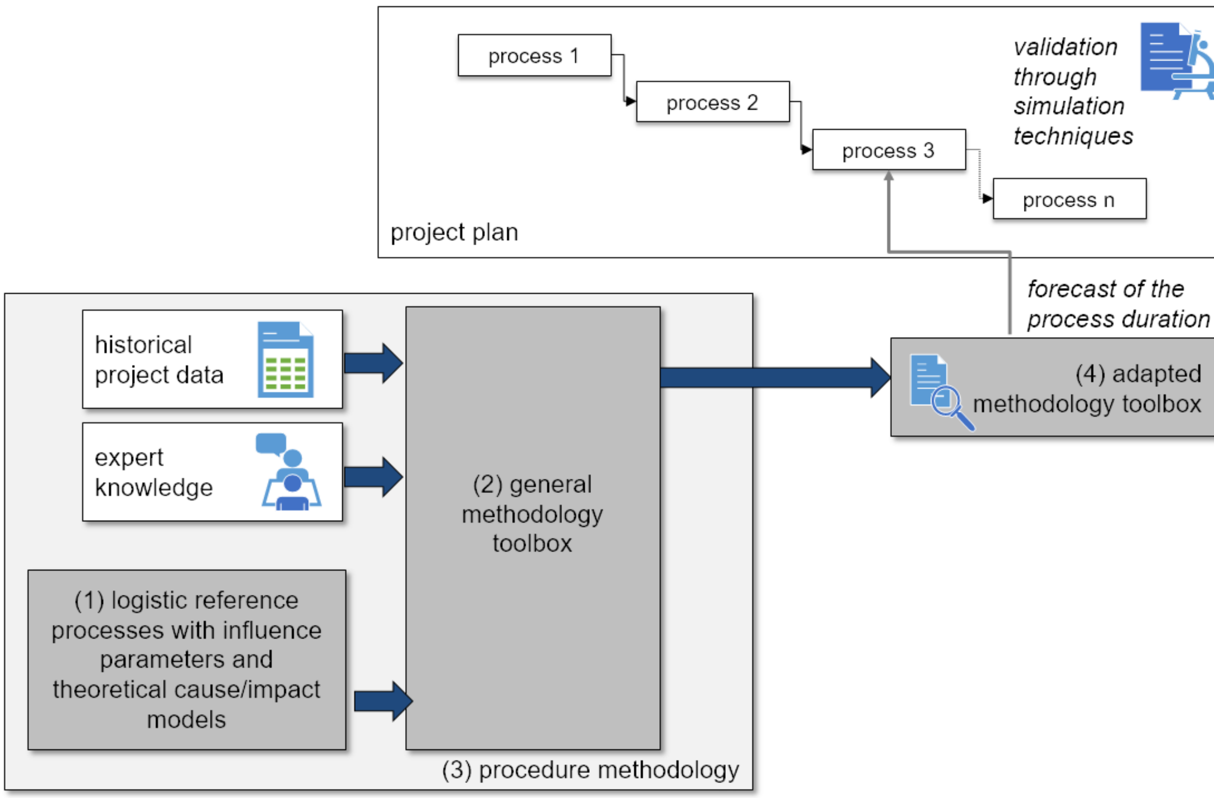

Figure 2: Draft of the procedural model in SimCast.

Figure 2 shows the interaction between the logistical reference processes (1), the general methodology toolbox (2), the procedure methodology (3), and the adapted methodology toolbox (4). **Logistical reference processes** for one-of-a-kind or small batch production are already developed following the Supply-Chain-Operations-Reference-(SCOR)-model and determine influencing parameters (e.g. length, weight or material of components or capacity of technical or human resources) including required expert knowledge. Based on the results of a Delphi study, parameters particularly influencing the duration of logistical processes are set on roles with cause-and-effect relationships to quantify the duration of logistical processes. The **general methodology toolbox** includes management methods for externalization and systemization of expert knowledge as well as methods of data analysis and business intelligence in order to be able to estimate the process time for the logistical reference processes on the basis of historical data. Thus, the methodology provides an assessable estimation of logistical process times for project planning. The **procedure methodology** can be used for an enterprise-specific adaptation using the general methodology toolbox, so the general methodology toolbox becomes a company-specific, **adapted methodology toolbox**. In contrast to the generic methods, the procedure methodology supports the SME to externalize and systemize the SME-specific expertise. Moreover, the adoption of the reference processes as well as the enterprise-specific process parameters and causal relationships in terms of process duration are derived. A high quality forecast works for the specific application context by using selected, combined and configured data analytics. Process duration within a project plan then can be forecasted by using those rules of the adapted methodology toolbox. The validation of the forecast rules may be done by simulation.

A **demonstrator** embeds the results from (1) and (2) as an example in a project planning process. In the research project the general methodology toolbox and the procedure methodology will be evaluated by the demonstrator. With regard to the integration of the methodology, the project management tools used by SMEs shall be given priority consideration. The possibility of extending other project management tools is basically given after the project has been finished end of 2018.

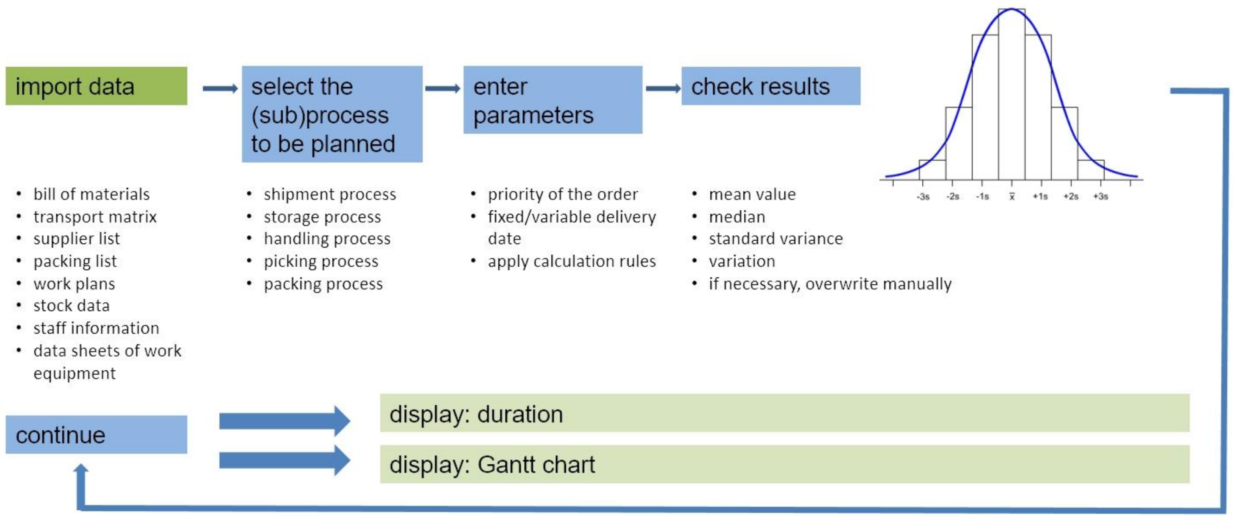

Figure 3: Exemplary estimation process in SimCast.

Externalized knowledge as well as historical data of past projects provide the basis for the quantification of logistical process times. Using the enterprise-specific configuration of the general methodology toolbox, the realistic time required for a particular logistical process is predicted. An exemplary estimation process is given in Figure 3.

The tool user will get an understandable measurement of the safety of that estimation or the uncertainty contained in the estimation. The result of the estimation is included as a process parameter in the actual project plan and the entire project planning can be secured against fixed delivery or start-of-production dates.

4 SIMULATION ASPECTS IN SIMCAST

Different simulation methods play a role within the SimCast project, in order to validate the forecast rules on the one hand and to improve the risk management in general on the other hand. In this section, possible scenarios are discussed, where simulation approaches are to be integrated within the further development of the research project.

4.1 Validation of the Forecast Rules through Simulation Techniques

The forecast rules within the adapted methodology toolbox have to have high quality. Therefore it is necessary to test the adapted methodology toolbox (based on the developed demonstrator) as well as the validity of the rules by using enterprise-specific application scenarios. For these scenarios, simulation models are set up to check the estimated parameter values and to determine the limits of the rules analytically. The models should take into account the order specifics of the one-of-a-kind products and small batches. Possible knowledge from the simulation are in turn incorporated into the parameter estimation. The simulation checks the logistical process times and validates the developed rules of the demonstrator. As a result, the estimation of the demonstrator are checked on one page, but the rules for the estimation parameters are also improved. The simulation models could later also be implemented as an extension of existing project management tools to change or improve the rules of the demonstrator.

4.2 Simulation as Estimator for Project Tasks

As already discussed during the *simject* project, the specific duration of a single project process might be estimated by the use of simulation. As shown, this can be solved by Monte-Carlo-Simulation, when a certain distribution for a specific process is given. Even more complex estimations might be derived by solving a more complex process model via DES (logistical or manufacturing sub-steps) or System Dynamics (in case of more complex Supply-Chain processes). However, due to the procedural model within the SimCast project, these applications might be further enriched by three additional scenarios:

1. **The use of historical values as an empirical distribution function**: Due to improvements according to the engineering efforts in the past, even one-of-a-kind-products are today typically manufactured by a significant amount of 'standard' product modules, that are enriched by customized elements and customer-specific parts. The job of the affected engineers is to maximize the amount of standardized modules vs. the individual construction process. If any data according to manufacturing and process times in logistics is available on the module level, then historical data from former project might be used for an estimation of specific durations for manufacturing or assembling these modules in specific environments. Based on data analytics and distribution fitting, the corresponding estimation rule for such a process might rely on a Monte-Carlo-based estimation on these historical values.
2. **The product-specific parameterization of a sub-step simulation model**: Diagnostic analytics on these data sets might include specific Cause-And-Effect-Analysis, so that based on the product specification influence factors can be derived, that explain a significant amount of the measured time for construction, manufacturing, transport and/or assembly. Here, automatic rules might be applied, that conclude a mathematical function for this estimation, of course based on a given uncertainty. This might again be used as an input function on the Monte-Carlo-estimation of the process duration within an estimation rule.
   Relevant product-specific factors might also be used as an input parameterization for more complex simulation models of manufacturing or transport simulation models, e.g. using the discrete, event-based simulation approach. If product specification, e.g. height or weight, might be a significant influence on transport (forklift vs. crane), the given specification data from the SimCast procedural model might be used for a specific configuration of a simulation experiment. Simulation results may then be applied as an estimator for a given process.
3. **The simulation-based optimization of sub-processes or sub-projects**: As a future outlook, these simulation-based approaches for the estimation of a given project process might be enriched by coupling heuristics or optimization approaches to these sub-steps or sub-models of a project plan. Thereby, not only a risk assessment due to the integration of the given uncertainty can be considered, but sub-processes can be optimized and by that, improve the quality of the given project plan further.

4.3 Simulation for Sensitivity Analysis of Data-driven Rules

As current research results in the SimCast project show, data availability and data quality are still a major issue for the SMEs, that are considered in this research project. The ideas mentioned above might lead to better process estimations, but only if a certain level of data quality is secured. Since this is not the case in most real-world use-cases, that are integrated in the research project, simulation might also be used for a sensitivity analysis of given data sets. Here, the consequences from bad estimation rules or good estimation rules, that are calculated with 'bad' data, might be exactly derived within the given project plan. If, by this, it can be observed, that a specific data-based estimation rule has a major influence on the overall project process, an additional safeguarding process might be installed. Figure 4 (see below) shows an example of an estimation of a project duration based on stochastic estimators (here the estimation rule is a Monte-Carlo Simulation). The corresponding total project costs are derived. If a given project budget (see red button) is given, uncertainties and bad data quality might lead to significant deviations, that are to be clarified during the planning of the project.

The sensitivity analysis approach might also be applied on the entire project plan itself. By a systematic deviation of process durations, a sensitivity analysis might derive new knowledge, which processes easily lead to a significant change of the entire duration in the project. These processes, especially when estimated with a high variation, should be in the awareness of the responsible project manager, though they do not necessarily are part of the critical path of the project (even critical path method (CPM) is not used frequently at SMEs as results of the *simject* project have shown).

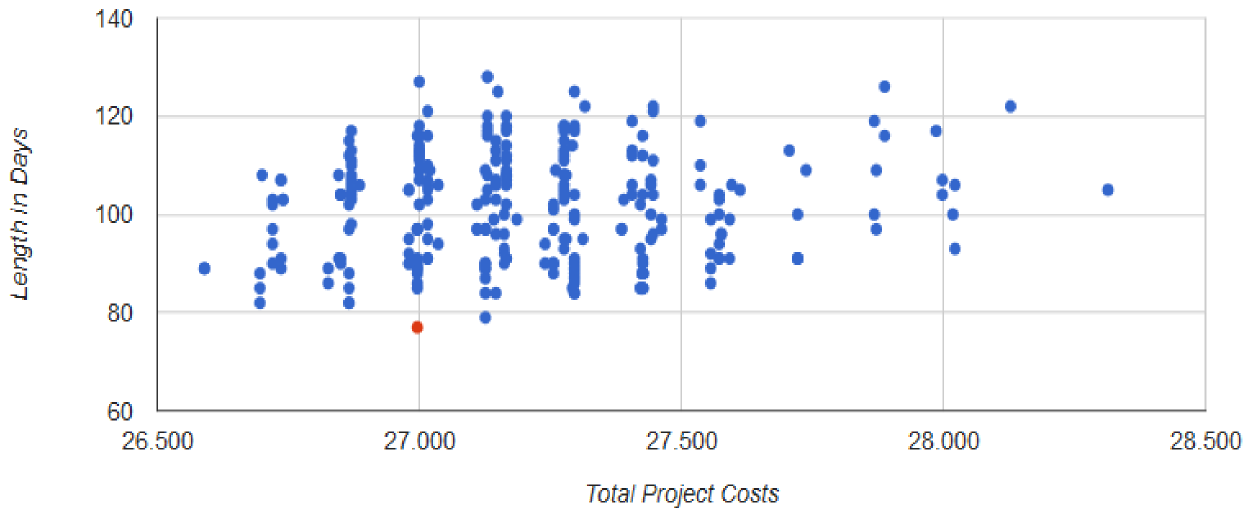

Figure 4: Deviation from project length and project costs by simulation approach.

4.4 Simulation for Validation of the Project Plan

In the end, the corresponding project plan is enriched with additional information about the uncertainties included in the single process steps. So, as generally shown within the *simject* project, the project plan for the one-of-a-kind-product in sum might also be simulated or improved during the planning phase by simulation-based optimization approaches. By this assessment, the overall risk management of the project might be significantly improved and changes during project control might be accessed according to their probable consequences on the entire project. Here, in the nearer future, further work has to be done to include these expert methods within the used project management tools in order to give the responsible project manager a better decision-support during planning and safeguarding a project. Figure 5 (see below) shows an example of a possible visualization of the cumulated certainty to finish the project at a specific deadline (cumulated over timeline).

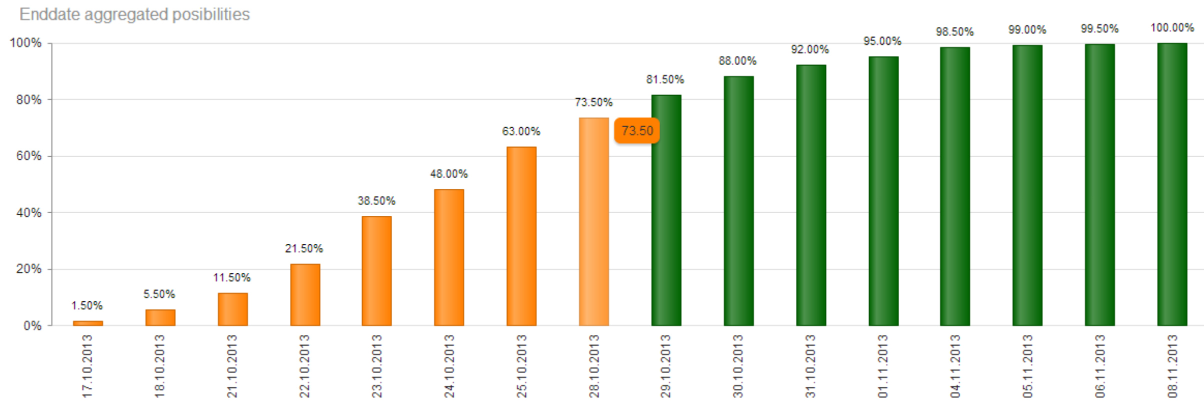

Figure 5: Cummulated certainty to finish project in time (example).

5 DRAFT OF THE TECHNICAL APPROACH

The given ideas of the previous section are to be integrated in a consistent technical implementation. During the SimCast project, first results of the resulting demonstrator are fixed and shall be discussed briefly in this section (for an overview see Figure 6 below).Within the general methodology toolbox, some basic instruments have been developed, that shall support the manufacturing SMEs in the implementation of the SimCast-process. One of these instruments is an ontology, that links and organizes the relevant terms and definitions within the given domain and their relationships. Moreover, concrete estimation rules can be attached to these terms and relations, that have been derived generally from the project and can be adapted to the companies specific needs. The ontology can be stored as an independent data structure and builds the foundation of the estimation plug-in, that is planned to be integrated within standard project management tools (in a first step, an implementation for MS Project Professional is implemented). During the SimCast procedure, this basic data structure is customized to a specific enterprise.

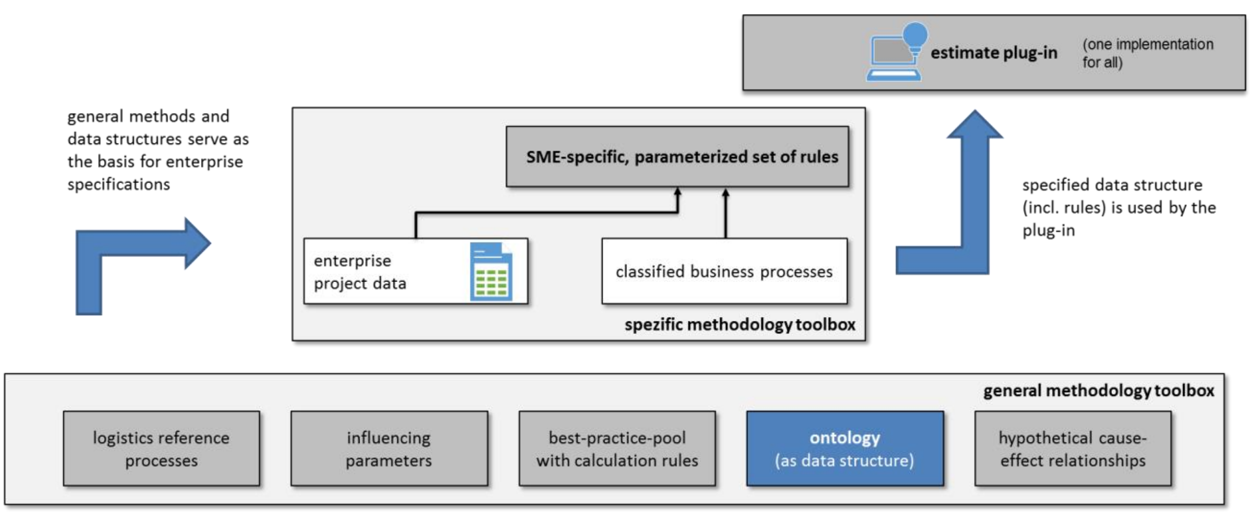

Figure 6: First draft of the technical implementation idea.

Not all kind of rules might be relevant and the estimation rules have to be parameterized according to the functions parameters and the data sources for historical values as well. In addition, the relevant business processes of the company are classified according to the structure of the ontology, so that a mapping is made possible and the general and specific estimation rules can be stored in an updated, company-specific data structure, still based on the ontology.

The estimation plug-in, that will be implemented in the project management tool, will use this data structure to dynamically create the relevant user-interfaces for parametrizing. They are designed as step-by-step-wizards, that allow the customized estimation of a process task of the given project plan by using the defined estimation rules and corresponding data. As explained in sections 3 and 4, these rules can be very simple and deterministic as well as more complex and use simulation functions. Finally, the user will get an estimation on the process duration for the selected task. He can accept or overwrite this estimation and apply the resulting duration to the task within the project management tool directly. With this approach, all relevant project tasks can be estimated with the SimCast toolbox. Finally, the entire project plan might be simulated and assured by the demonstration toolbox out-of the *simject* project.

6 CONCLUSION

Customized engineering and build-up of one-of-a-kind products are very complex tasks, where project management contains lots of uncertainties. Existing simulation techniques could help to evaluate and achieve improved and at least more robust plans during project management, but are typically not applied in industry, especially at SMEs. This paper deals with a joint research project SimCast of the University of Kassel and the University of Applied Sciences Zwickau, which aims at the development of a method for project duration estimation for project planning and scheduling. Based on pre-knowledge of other research projects like *simject*, a procedure for the estimation of process durations has been developed, that allows a better risk management for companies in one-of-a-kind production. One goal of the underlying research project SimCast is to improve these estimation rules by the application of simulation techniques in various stages of the overall planning process. The paper describes the ideas, where simulation application in this area might be meaningful. In order to implement these approaches a first draft of an technical implementation is explained.

As a next step, the project team will continue to implement the approaches and validate them in a real-world industrial environment. Moreover, a general evaluation of these ideas will take place within the research project. As a future outlook, the gained results already show, that data availability, accessibility and the use of the existing data for better decision taking are still open issues at the manufacturing SMEs. Here, future projects might contribute.

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