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A COMPARISON OF THE USAGE OF DIFFERENT APPROACHES FOR THE MANAGEMENT OF PLANT ENGINEERING PROJECTS

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ABSTRACT

Customized planning, engineering and construction of one-of-a-kind products (like wind energy, biogas or power plants) are complex and contain a lot of risks and temporal uncertainties, e.g. of logistics and project schedules. Therefore the management of this kind of projects has to be supported by adequate methods for the estimation of project risks and uncertainties. Based on the results of the joint research project *simject* of the Universities of Paderborn and Kassel, which aims at the development of a demonstrator for simulation-based and logistic-integrated project planning and scheduling, this paper discusses the usage of different approaches for supporting project management of plant engineering projects. After a short introduction and description of the approaches to be compared a wind energy plant as evaluation model as well as the application of the different methods are presented. Additionally, the usage of the approaches is compared and the advantages and disadvantages are pointed out.

1 INTRODUCTION

As already argued in Wenzel und Laroque (2013) und Gutfeld et al. (2014) the customized plant engineering and construction is distinguished from the stationary series production. "The planning and implementation of these plants always depend on technical and structural boundary conditions. Further important points are organizational project specifications (e. g. production steps, construction phases or resource disposition) and logistic 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." Gutfeld et al. (2014: 3423). Today, planning and implementation of a plant - especially in SME (small and medium-sized enterprises) - are done with simple methods of project management, see also DIN 69901-3 (2009). These methods do not reflect temporal uncertainties of logistics and project schedules. Therefore critical points of the project cannot be detected and the robustness of the project schedule cannot be evaluated. To answer these questions in industrial sectors like the construction engineering (see e. g. Chahrour 2007; Weber 2007; Günthner and Bormann 2011; Kugler 2012; Mefisto 2015) as well as the shipbuilding (see e. g. Steinhauer 2011; Beißert et al. 2010; SimCoMar 2015, SIMoFit 2015) the discrete event simulation (DES) is already applied. However, in plant engineering applications the use of project planning approaches combined with a simulation-based planning (e. g. of logistic aspects as optimization potential) are not customary.

Therefore, the University of Paderborn and the University of Kassel worked on the joint research project *simject* from April 2013 until March 2015. The aim of this project was to develop a demonstrator for simulation-based and logistic-integrated project management in plant engineering. Based on a presentation of this demonstrator and its application possibilities the involved industrial partners discussed different arguments using a deterministic planning approach, a Monte Carlo Simulation or a DES-based planning approach. To compare the adequateness of these three approaches we identify four evaluation criteria: modeling effort, practicability for SME, user acceptance and quality of results. In this paper, starting from a short description of the three approaches in Section 2 and a presentation of the evaluation model in Section 3, a comparison of different approaches for the management of plant engineering projects will be pointed out. Therefore, in Section 4 we discuss the application of a deterministic planning approach, a Monte Carlo Simulation and a DES-based planning approach in detail. Section 5 deals with the results of this comparison. The paper closes with a short conclusion and outlines further research fields in this context.

2 APPROACH DESCRIPTIONS

This paper evaluates three different approaches in project management based on a realistic evaluation model. In this section, these approaches are presented in short.

2.1 Deterministic Planning

Today, within the plant engineering process, we mostly find deterministic planning approaches, where a project is sub-divided into several planning tasks. Main focus of traditional planning approaches is to create and define a valid project plan by recognizing dependencies in the planning steps and the consideration of project resources in a given time span, e. g. workers, tool, etc. Today, this planning process is typically supported by specific project tools, e. g. Microsoft Project, which also provides some reports on utilization, project costs and the safeguarding of a given project deadline (PMI 2015).
However, in the planning of a concrete project task, the project planner estimates its duration by a deterministic value, which is set either by experience or “best-guess”. Implicit risks of a tasks regarding its duration are considered by adding buffer times for each task or by adding buffers between tasks. By this approach, the implicit risk during the execution of a project plan are considered in a very limited way and, in some case, overestimate the execution duration of the project.

2.2 Monte Carlo Simulation

In order to improve the risk management in the planning process of a project, Monte Carlo Simulation can be used as a method to describe the duration of the project task by a probability distribution. The Monte Carlo Simulation is a stochastic approach on the basis of often performed random experiments, numerical statements can be made. The simulation is an alternative approach to mathematical analysis with random distributions (Mooney 1997). Doing this for each task in a project, the entire project schedule afterwards can be simulated multiple times. Here, the given dependencies in the project plan are to be considered. By this approach, the implicit risks for a given tasks are considered more precisely and by the simulation, and improved judgment of the project plan, e. g. according to its given deadline, can be derived. The execution of a large number of independent simulation runs considering the stochastic deviations for each project task to become leads to a better assessment of project risks and leads to quantified results like: "we have found 93% opportunity to finish our project in time". During the execution of the project, the plant tasks can be refined by their real duration and the rest of the project can be simulated again. By this approach, the project leader is able to judge the deviations and its impact on the project's deadline (cp. e. g. Kurihara and Nishiuchi 2002, Kwak and Ingall 2007).

2.3 Discrete Event Simulation

Discrete Event Simulation (DES) has been used as a well-established method for analyzing dynamical interdependencies and stochastic processes in production and logistics systems since more than twenty-five years (Wenzel et al. 2010). Automotive, aircraft, shipbuilding and semiconductor industry as well as supply chain management and healthcare logistics or call centres are typical industrial application domains. A variety of saleable high-quality DES tools for production and logistics applications differ in the scope of application, the modelling concept, the software functionality, and the performance. Additionally, today tools like the Afinion Project Simulator (Afinion 2015) and the Project Simulator 2010, a scenario planning, simulation and reporting add-in for Microsoft Project (ProModel 2015), are offered at the market. These tools can be used for modeling, simulation and visualization project plans based on a constructed plant or product.

The advantages of DES as a experimental method are the modeling and analyzing of dynamic stochastic processes and the developing of processes over time. Therefore, DES could help to evaluate malfunctions and interdependencies in processes. In order to support the risk management in the project planning process we are able to use DES-based models for evaluating uncertainties, e. g. in logistics processes, and achieving improved and at least more robust plans during project management.

3 EVALUATION MODEL

In order to compare the three presented approaches in the application field of plant engineering a suitable sample model is needed. This model should satisfy all properties of a large system and be described in the literature adequately. However, it should also have a limited complexity, so that it is easily comprehensible for the reader. The model of a wind energy plant meets all these requirements. To build up a wind energy plant, only a limited number of tasks is executed. The wind energy plant consists only of a few prefabricated parts that are transported to the building site and assembled on site. In the following the single tasks of the construction of a wind energy plant are described accordingly to Hau (2008).

Foundation: To build up the tower of the wind energy plant a stable foundation is necessary. For this purpose, a recess must be excavated, that is filled with concrete. Previously, the recess must be prepared by further measures, e. g. formwork and introduction of reinforcing steel. The concrete requires a certain time for hardening, before the assembly of the tower can be started. The concrete is transported by several trucks on a great number of tours to the building site. Here, traffic jams before delivering the concrete are possible.

Tower: After the anchoring of the base element on the foundation, the other parts of the tower are placed to each other and screwed together. As the last part the generator pulpit is placed and fixed on top of the tower. All parts are transported by trucks to the building site just-in-time. Delays in part delivery, e. g. by congestions, inevitably lead to a delay in construction activities.

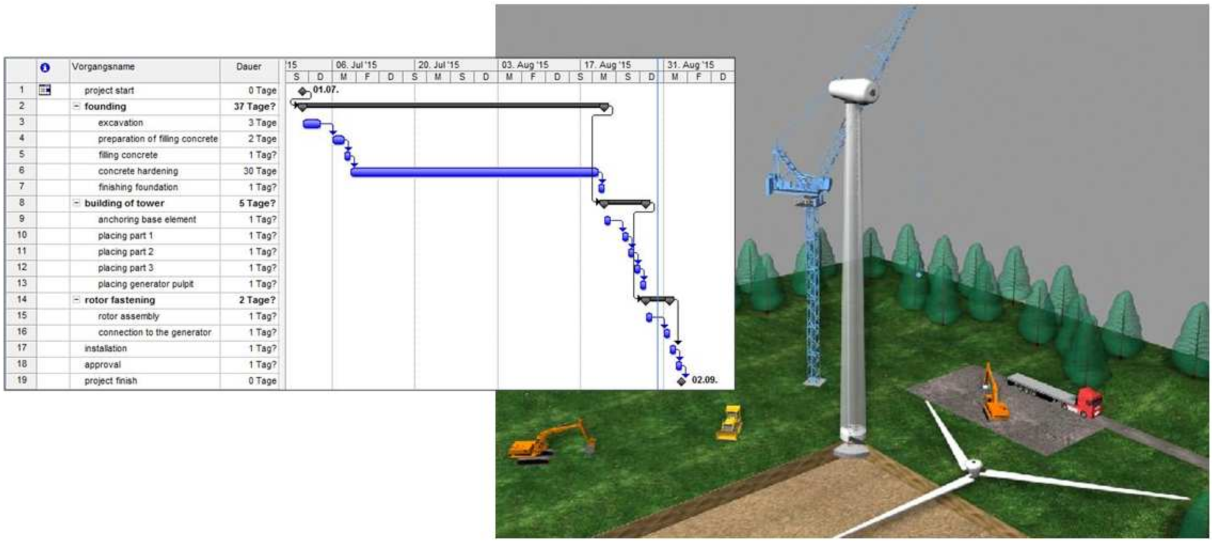

Figure 1: Schedule and building site of a wind energy plant.

Rotor: The wings are already bolted on the ground with the rotor hub. As a whole, the rotor is then connected to the rotor shaft of the generator. The rotor parts are also delivered just-in-time to the site. The assembly of the rotor can be performed only if a specific wind speed is not exceeded. Thus, also the weather influences the building activities.

Installation: Last-but-not-least several installation tasks must be done in and at the tower. This especially includes the electric installation, i. e. establishing an electrical connection from the generator to the power network.

The project is finished with a orderly approval of the plant.

4 METHOD APPLICATION

To compare the approaches for the management of plant engineering projects, they are applied to the presented evaluation model. The evaluation considers the utilization of the methods, the needed data and the results, which can be expected. Regarding the utilization, the field of application is outlined. Additionally the data sources are identified and the planning respectively the simulation process are described. Regarding the results, examples for their presentations, e. g. line or Gantt charts, are shown.

4.1 Deterministic Planning

The result of an efficient planning process is a project plan, which takes into consideration all needed resources, working steps and their corresponding start and end dates. Its importance is located in two tasks that can be fulfilled by using the plan. First, after a plan made, utilization and time planning of all required resources can be derived and resource conflicts can be located and resolved (Aytug et al. 2005). Second, it is easier to fulfil external contracts, such as shipping orders to suppliers. Today, this planning is mostly supported by software. It provides the ability to define processes and set their attributes. Attributes could be a name, a fix duration, allocated resources and their dependencies to other processes in the current plan. In interviews with SMEs, we noted that Microsoft Project 2010/2013 is very common, and the usefulness of such tools is undisputed in practice (see Figure 2).

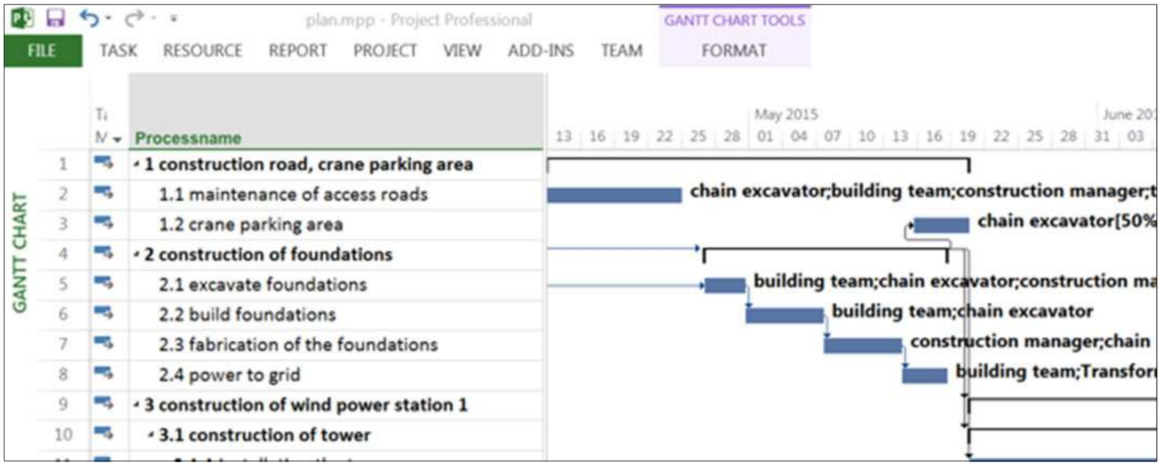

Figure 2: Deterministic planning with Microsoft Project 2013.

Despite these tools are mature and common, there is still missing a possibility to integrate uncertainties, like fluctuations of durations in a working step. Project software like Microsoft Project 2010/2013 only pursues a deterministic approach for planning. This means that time and cost of a working step are set deterministic, which will not usually corresponds with practical experience. This is why deterministic planning is criticized in literature (Goldratt 1997). Delivery problems, adverse conditions, changes in the law or simply human error may cause a delay in a working step or increase costs, which should be depicted in a realistic plan. In this paper, we propose a method for integrating uncertainties within a project plan.

4.2 Monte Carlo Simulation

By the import of the deterministic project plan as a basis for the simulation, the plan is transferred from deterministic form into a stochastic project plan. This means that the duration of the processes in the plan don't have a fixed value anymore, because now they can generated from a distribution function. The method allows to set a minimum duration, a maximum duration and an expected duration.

Currently, the *simject* demonstrator only provides two different distribution functions. The uniform distribution and the normal distribution. The uniform distribution provides the parameters upper limit and lower limit of the deviation, the normal distribution provides the parameters expected value and the standard deviation of the individual deviation of each process. The parameters are set in percent, and the underlying value is the value of the deterministic project plan. Additionally, the number of iterations of the Monte Carlo method can be set by the user, which defines how many project plans will be created. If a distribution is selected, its parameters are set and the desired number of simulation runs is defined, the simulation can start.

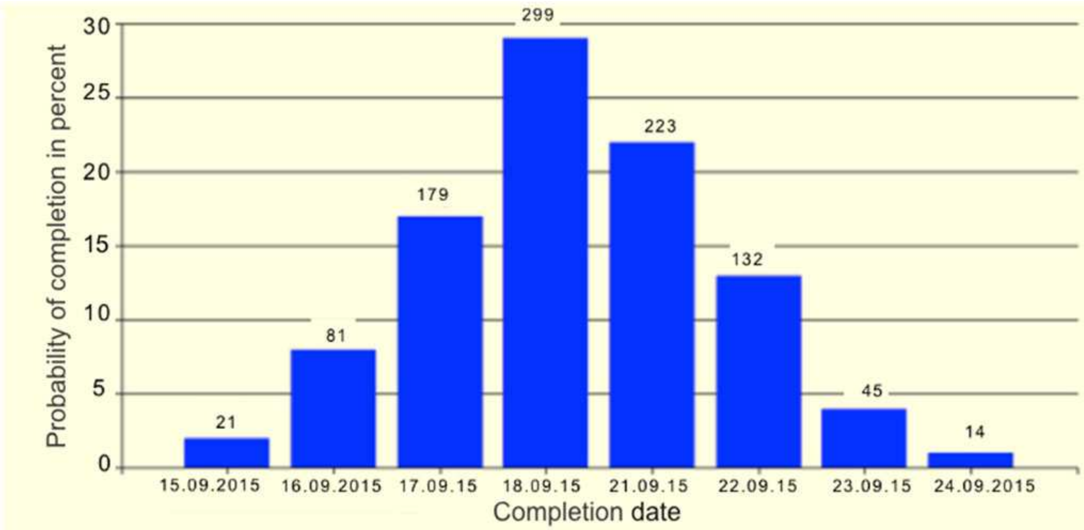

Figure 3: Result of Monte Carlo Simulation as bar chart within the *simject* demonstrator.

After the simulation is completed, the results are displayed in a bar chart. The X-axis indicates the possible completion dates, the Y-axis shows the probability of the completion dates. The simulation yields the result that the date 21.09.15 of the deterministic project plan will be achieved with a probability of 81 percent. In addition to display the probabilities of completion dates, it is also possible to display the probabilities of all individual processes. For this purpose, another plug-in to visualize all processes with their probabilities in a Gantt chart (see Figure 4) was developed and evaluated.

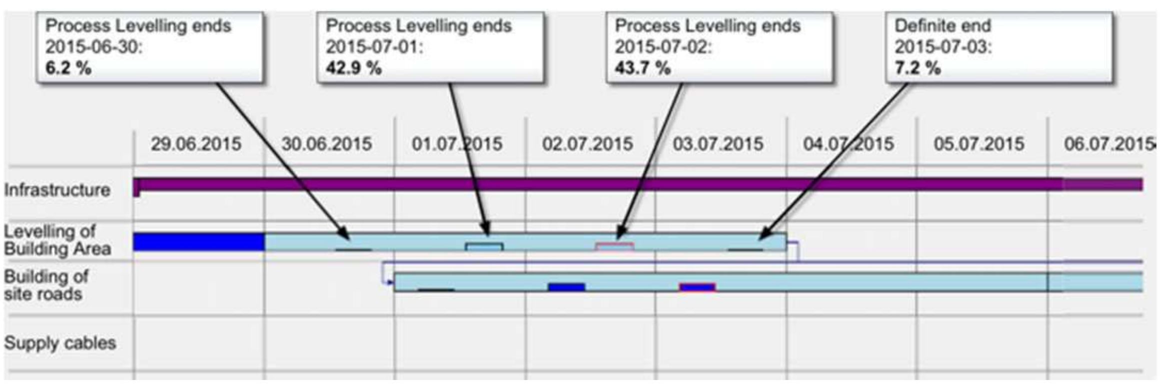

Figure 4: Result of Monte Carlo Simulation as Gantt chart within the *simject* demonstrator.

In this Gantt chart, each row represents a separate process. The columns represent days in this example, so that the temporal extension runs like a X-axis. A process consists of two parts. A deterministic part and a stochastic part. The deterministic part is displayed in dark blue, this part is as the name says fixed and there are not expected fluctuations. The stochastic part is shown in light blue, this part represents the discussed uncertainties. After the Monte Carlo Simulation has been completed, the stochastic part of the process indicates the probability when each process starts and ends. For this purpose dark blue bars are drawn in the light blue sections. The higher the dark blue bar, the greater the probability that the process starts on this day or ends on this day. Thus, the planner can see in great detail what processes represents the largest uncertainty in the project.

4.3 Discrete Event Simulation

For further evaluation of project plans DES has been used in the context of the research project. Therefore, an exemplary simulation model has been developed in Plant Simulation by Tecnomatix. This model reproduces the construction of a wind energy plant. Basically, it consists of two parts: one which reflects the project plan and another one which includes the logistic processes. Both have been established in separate networks of the overall model.

In the first part, buffer modules represent the project plan. Each buffer is named according to a task respectively work package in the original project plan and the modules are arranged on different levels to show their position in the project plan. Moving objects in the project plan reflect the project progress. The second part represents all the logistic and construction processes associated with the setup of a wind energy plant. On the one hand, this includes transportation processes from the suppliers to the construction site, on the other hand, the processes to build up the plant on site are displayed. However, the logistic model does not contain the procedures at the suppliers factory or in-house of a company to manufacture parts of the wind energy plant. Further, the influence of disturbances for example from traffic jam, delays in delivery or weather can be used to include disruptions or delays of these processes. All those processes (e. g. process times and disturbances) are displayed with the help of statistical distributions functions which allow to include randomness into the simulation and thereby helps to improve the analysis of the observed system. It has been discovered that input data that are used to generate those distribution function describe an important aspect in this context. The reason for this is that only appropriate distribution functions help to model a system in an adequate way. Incongruous function may lead to wrong conclusions later on. Analyzing historical data about the affected processes (e. g. historical traffic information about the affected roads, weather history on the construction site, experience with similar construction processes from other projects) is seen as one of the best way to improve the quality of those distribution function and therefore the quality of the simulation results.

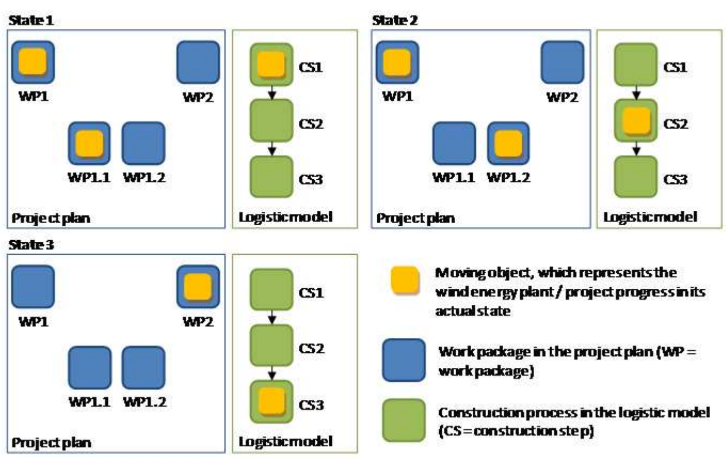

Figure 5: Illustration of link between project plan and logistic model.

The most important part of the overall model is the connection between the two separate parts. This is realized with the help of a method. Therefore, a table was included in the project plan part of the model which contains information about events in the logistic model that lead to changes (i.e. the beginning or ending of a work package) in the project plan. For example, the start of a particular construction step during the setup of the wind energy plant leads to the start of the associated work package, whereas the ending of this construction step also causes the ending of the associated work package. Further, the table includes information about preceding and following work packages as well as about the level of a work package in the project plan. This allows to include a method into the model that controls the processes in the project plan based on the behavior of the logistic model. Therefore, this method has to be connected with the relevant modules in the logistic model. Only then the entrance or exit of a moving object can work as a trigger for the method. The little schema in Figure 5 shows how the linkage between project plan and logistic model in an exemplary simulation model works.

The first state in Figure 5 shows that while in the logistic model the first construction step is executed, in the project plan the work package WP1.1 is marked by an moving object as the actual project progress. Because work package WP1.1 is part of work package WP1 the latter is also marked by an moving object. When construction step one ends, work package WP1.1 ends, as well. This is the start of the next construction step (CS2) and the next work package (WP1.2). In this context the end of construction step one triggers the method which investigates in a specific table which work package in the project plan is now ended and which one is the next one to start. Then the method moves the moving objects in the project plan and the logistic model accordingly so that state two is reached. When construction step two ends both work packages WP1 and WP1.2 in the project plan are also ended. Next, the work package WP2 starts with the beginning of construction step three (State 3). Overall, always the events in the logistic model, i.e. the beginning or ending of a construction step, trigger the method that moves the moving objects in the project plan.

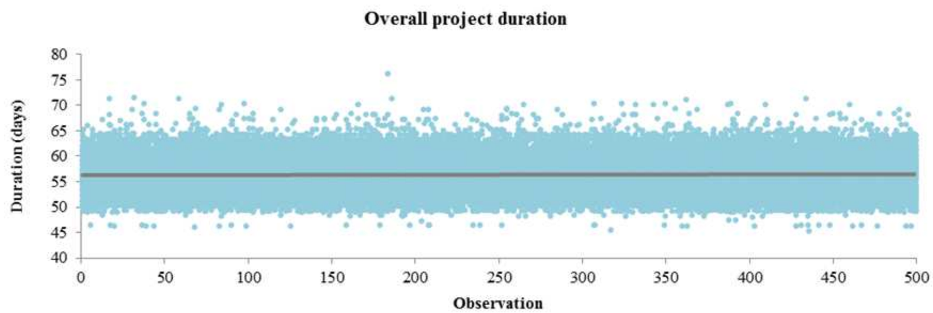

Figure 6: Distribution of overall project duration.

Further, in the simulation model result tables have been established, that collect the duration of all work packages. In this way, big simulation based data samples can be generated that allow for statistical analysis and consequent statements about the estimated duration of work packages and the overall project. Figure 6 shows the overall duration of the project which was measured during a simulation with replication over 500 observations. Each dot represents one finished project and its duration which varies around an average of 56.35 days.

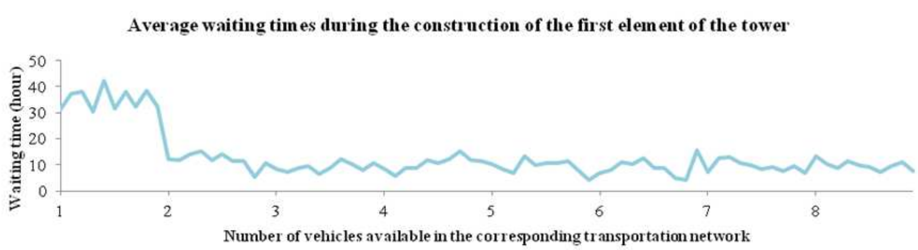

Figure 7: Average waiting times.

Moreover, during simulation data can be collected about particular logistic aspects like transportation times, waiting times at the construction site for missing building material or storage content. Further, the DES gives the possibility to conduct experiments with different settings, e. g. vehicle quantity for transportation, storage capacity or varying delivery dates. For example, an experiment can be conducted during the number of vehicles in a transportation network is varied. On the one hand, the simulation allows to measure how this influences the duration of the corresponding work package or the overall project duration. On the other hand, logistic aspects like the waiting times of the depending construction step can be analyzed. The latter is shown in Figure 7. It becomes clear that waiting times can be reduced by half when more than one vehicle is available in the particular transportation network.

In sum, DES helps to analyze various aspects of a system and to integrate logistic aspects into the planning of a project. A connection between an IT environment and the simulation model can be generated with the help of Microsoft Excel that allows for import of input data and export of simulation results.

5 COMPARISON AND RESUMEE

To compare the adequateness of the presented three approaches we have identified four evaluation criteria: modeling effort, practicability for SME, user acceptance and quality of results. Modeling effort specifies the effort that is needed to build up a model for plan evaluation. Practicability describes the skills of the user and the functionality of available tools to build up a model. User acceptance relates to the availability of tools on the market, modeling know-how and the acceptance of the produced results. The quality of the results expresses the usefulness of the results.

Table 1: Comparison of the approaches for the management of plant engineering projects.

	Modeling effort	**Practicability**	**User acceptance**	**Quality of results**
Deterministic planning	***low*** • manual schedule planning • manual resource planning • manual definition of restrictions • static deterministic plan	***high*** • available tools provide a big variety of functions, e.g. resource balancing, network diagram • functions are easy to learn and use • results can be produced quickly • presentation of results are well known	***high*** • many tools available, e.g. MS Project • basic skills of project management include the utilization of these tools • deterministic plan is often sufficient • tools are suitable for project control	***low*** • manual planned schedule and resources • fixed start and end points • risk only considered by time buffers
Monte Carlo Simulation	***mid*** • based on the deterministic plan • uncertainties have to be included in the plan • simulation based on variation of uncertain task length	***mid*** • deterministic plan can be used as input • statistical know-how is needed to find the right distribution for plan uncertainties	***low*** • extended statistical know-how is needed • Monte Carlo Simulation is not well known • results need interpretation	***mid*** • probabilistic plan • start and end point provided with a probability • risks considered on low level as distributions
DES	***mid to high*** • based on the structure of the deterministic plan • complete logistic model is included • link between logistic model and project plan defines task starts and ends • behavior of simulated logistic model defines project task lengths	***mid*** • tools provide a graphical user interface that is easy to use • tools provide element libraries for specific application fields, e.g. logistics and production • extended simulation know-how is needed	***mid to high*** • many tools available, e.g. SIMIO, Plant Simulation, ED • presentation of plan and logistics is based on real objects • animation shows model behaviour • statistical know-how is needed • extended modeling know-how is needed	***high*** • plan related to simulated processes • start and end point provided with a probability • risks considered on high level as logistic model details

Table 1 shows that each approach has pros and cons. It depends on the specific project conditions. Very often a deterministic plan is sufficient. At the end the customer expects an exact deadline for his project from the planner. Monte Carlo Simulation gives the planner a better predictability. Logistic simulation in combination with planning gives the planner the highest flexibility and highest grade of predictability but needs also the highest effort for modeling.

6 CONCLUSION AND OUTLOOK

This paper describes results of the joint research project *simject* between the Universities of Paderborn and Kassel. The project goal was the development of a demonstrator for a simulation-based and logistic-integrated project planning for SMEs in the single-part construction and engineering domain. The demonstrator integrates three approaches for the management of plant engineering projects: deterministic planning, Monte Carlo Simulation and DES. For this paper these three approaches are compared.

The comparison shows that for each approach a corresponding user scenario can be found. Mostly, the deterministic planning will be used because many tools are available for which users need only a short training. A deterministic plan is the basis of further planning. Simulation then has its advantages, if more accurate information about project deadlines is necessary. Monte Carlo Simulation adds probabilities for each project task and for the project as a whole. For this, a tool has been developed within the Simject project. 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 will trust to this method. DES is well known as a method for logistic planning as well as for schedule planning. The great effort for modeling could be reduced by using specific model units which represent units of the application field, planning tasks and the link between logistic model and planned tasks within the same model or to a linked planning tool.

Within the scope of the Simject project it could be demonstrated that simulation can improve project planning, but is still a lot of work to do. This comprises in particular the improvement of user acceptance by better user interfaces and result visualization as well as the better integration of simulation methods in the digital method context of an organization of construction and engineering domain.

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