ON-SITE LOGISTICS SIMULATION IN EARLY PLANNING PHASES

Markus König
Ruhr-University Bochum
koenig@inf.bi.rub.de

Ilka Habenicht
SimPlan AG
ilka.habenicht@simplan.de

Sven Spieckermann
SimPlan AG
sven.spieckermann@simplan.de

ABSTRACT: *Logistic processes have a large impact on the planning and execution of large-scale or inner-city construction projects. A common way to analyze different logistic scenarios is the application of discrete-event simulation in order to proof the feasibility of time schedules and identify bottlenecks. The data preparation is one of the main challenges during the simulation of construction logistic processes because of the unique characteristics. Especially, in early planning phases only elemental information about activities, deliveries, and resources are available. In this paper an innovative concept to extract and prepare input data for logistics simulation in early planning phases is presented. The so-called Mefisto container is used to integrate essential project data. In the next step, the project data is analyzed and prepared by an additional software tool, the so-called SiteSimEditor. Based on the extracted and prepared data a simulation model can be generated by using configurable simulation components. The resulting simulation model contains information about the construction site layout and logistic processes. The concept was validated by case study, which comprises the shell construction of an airport terminal.*

KEYWORDS: logistics simulation, simulation input data preparation, construction management, discrete-event simulation, early planning phases.

1. INTRODUCTION

Logistic processes often play an important role during the planning of construction projects, especially in large-scale or inner-city project. In these cases construction clients often define certain demands concerning delivery or on-site logistic, for example, restricted delivery and working times or arriving limits of trucks per day. Especially, in early planning phases one of the main challenges is the consideration of the given logistic restrictions in an appropriate way. Usually, in these phases only general project data exist with low details regarding building elements, construction processes and required resources. In consequence, the integration and specification of reliable logistic information is not trivial. Logistic restrictions have significant effect on construction process and cost estimation. Delays often occur due to insufficient analyses of logistics processes and their restrictions. The analysis of the influences of logistic aspects on the construction processes in early planning phases allows to discover limitations in terms of the project schedule. In the last decades discrete-event simulation became an important method of analyzing production and logistic processes and their dynamical interdependencies (Wenzel et al. 2010). Thereby, a simulation model can be used to specify a different number of logistic and construction scenarios. Typical functions of logistic simulation in early planning are (Spieckermann et al. 2010):

- Generation of time schedules based on material flow specifications, milestones and framework dates, and available resources. All these restrictions must be integrated and satisfied in an optimal manner.
- Evaluation of different logistic concepts and identification of possible bottlenecks. This compromises alternative storing and transportation strategies.
- Analysis of reliability and robustness of time schedules by considering possible disturbances and uncertainties regarding the available project data.

Today, logistic simulation plays only a minor role in the context of construction management. In general, the main reasons are unique building designs, varying construction site locations and individual construction processes. Furthermore, construction logistic processes are more dynamic due to varying construction site conditions. For these reasons the simulation of construction and logistic processes requires a large effort for modeling and data preparation (Kugler et al. 2009). The collection and preparation of reliable and reasonable input data for logistic simulation is very time-consuming and requires special knowledge. Bill of quantities, first drafts of the construction site layout and general information about the construction processes are often the only available project.

In order to support the project planners during the specification of appropriate logistic simulation models, the *Mefisto* project was funded by German Federal Ministry of Education and Research. *Mefisto* stands for data integration, simulation, controlling and prediction in construction management. The main objective is the development of an integrated multi-level data container concept to handle different data models during all planning phases. Thereby, the so-called *Mefisto* container links all data models in a consistent and adaptable way (Scherer et al. 2010). Within the sub-project "knowledge-based simulation modules" certain project data are extracted and used for the preparation of input data to simulate construction and logistic processes. However, in most cases the project data are not sufficient to generate significant simulation models. In addition, material dimensions, packing units, means of transportations and logistic chains must be added. In the next step these logistic data can be used to produce a specific simulation model and to define the input data for the simulation scenarios.

In this paper a concept for extracting, defining and preparing data to create significant logistic simulation models is presented. Configurable software modules are used to define the simulation model for a unique construction project. Furthermore, input data for simulation experiments are prepared and generated by an external tool. Using this concept, realistic logistics scenarios can be set up more time-efficient to support the construction planning.

2. LOGISTICS SIMULATION

Logistics simulation can be used to analyze specific aspects during the construction of a building. In general, the focus lies on simulating the material flow. That means that certain material elements are delivered, handled and stored on construction sites. It is also possible to combine production and logistic simulation. Thus, production processes of buildings are also taken into account. In the paper only the simulation of logistics processes is considered. Nearly for every logistics simulation similar data must be prepared. This data compromise transport ways, transport equipments, storage areas, delivery dates, packing units, and transport chains. Normally, in the context of logistics simulation static transport ways and storage areas are used. Due to the building itself and other external site effects it is also possible that transport ways and storage areas can change during construction. In the presented concept only static ways, storage areas and transport chains are considered.

In order to implement logistics simulation models abstracted, predefined, and configurable simulations components can be used. Nearly, every commercial material flow simulation tool provides elements to support the user during the implementation process. However, in general these components are highly abstract and hard to use in particular for construction simulation. Therefore, additional components and frameworks are often developed for special purposes to overcome these drawbacks. The *Simulation Toolkit Shipbuilding* (*STS*) is a holistic component-based simulation framework, which has also some special components for the construction industry. The *Simulation Toolkit Shipbuilding* was developed by Flensburgers, a German ship building company (Steinhauer 2006), based on the commercial simulation engine *Tecnomatix Plant Simulation* by Siemens PLM Software. This toolkit comprises several components to model construction and logistic processes at shipyards. The classes were adapted for construction processes in cooperation with the Ruhr-University Bochum, the SimPlan AG, and the Bauhaus University Weimar. The *STS* provides also a so-called constraint-based modeling approach. That means that restrictions for executing processes are formulated based on certain constraints (König et al. 2007). Thereby, so-called hard and soft constraints can be considered. Hard constraints are used to model necessary restrictions which must be satisfied, for example, technological restrictions. Soft constraints can be used to implement different scenarios or strategies, how the construction process should be executed. This concept offers a generic way to generate models of logistic and construction processes on different levels of detail. In Fig. 1 some typical simulation components to simulate logistic processes are highlighted.

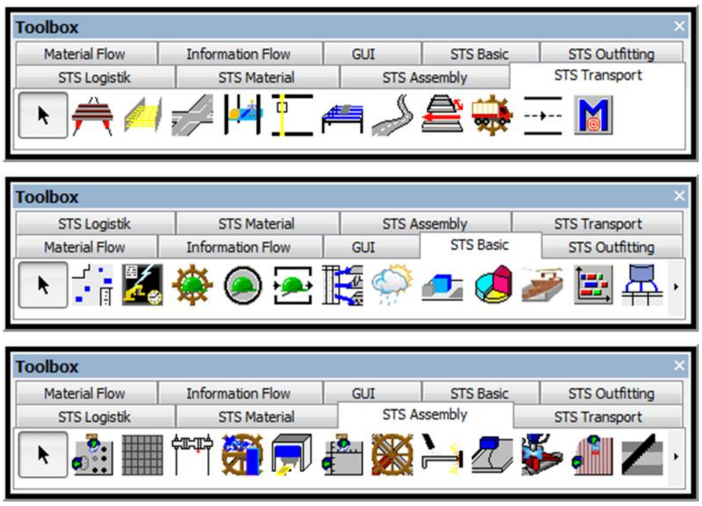

Fig. 1: Components of the Simulation Toolkit Shipbuilding for simulating logistic processes

The *STS* components are used to implement logistic simulation models for early planning phases. In addition to the components values for the configuration are need. For example, dimensions, locations, and rules of the transport ways must be specified as well as operation values and machine data. Furthermore, transport and logistics chains need to be modeled, for example, which storage areas can be handled by which cranes or where are unloading positions for certain material elements.

3. INTEGRATED DATA PREPARATION

Generally, the data preparation is the main challenge within the realization of simulation models and scenarios. Thereby, some of this data are used to generate the simulation model layout. Other data can be used as input data for experiments regarding desired objectives. Normally, data collection and preparation is done in different successive steps. In the first step the available information must be analyzed and prepared in terms of the defined goals. Levels of detail and data quality play an important role. In some cases the simulation objectives cannot be reached due to the available data. In the next step additional information has often to be defined manually. For example, if material dimensions and packing units are not known to analyze storage bottlenecks, then the only possibility is to generate realistic data using some reasonable assumptions. In the last step the enriched data can be used to prepare simulation models and simulation scenarios for certain simulation frameworks. The three data steps, shown in Fig. 2, are supported by the so-called *SiteSimEditor* (Marx et al. 2011).

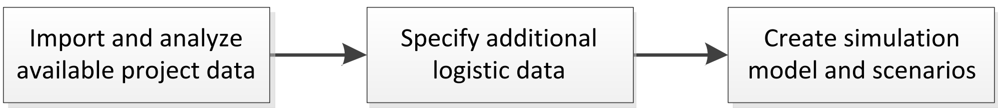

Fig. 2: Integrated data preparation for logistics simulation

During the first step all available project information are imported. The project information must be stored digitally to support reusing. Nowadays, standardized building information models comprise many required information for logistics simulations. However, essential data is often missing. In the following available data, which is normally necessary to set up logistics simulations, is highlighted:

- Material quantities can be taken from building information models. For example, in-situ concrete, reinforcement steel, formwork, and pre-cast elements for shell construction activities can be calculated. Today, the material quantities and building elements are associated, that delivery and storage locations can be derived.

- Milestone schedules and framework dates are often corporately specified by the client and contractors based on building information models. These general data or rather general activities can be linked with their corresponding building elements by using modern project management tools.

- Layout information about construction sites and the nearby environments (i.e., transport ways, storage areas, equipment, or existing buildings) are normally modeled digitally and are often basis of general contract.
- Sometimes special logistic restrictions are defined a priori. Logistic restrictions can cover, for example, time windows for delivery, number of simultaneous tucks on the site, gateway checks, or storage of hazardous materials. This information is sometimes provided by the client.

Generally, the described data is not exclusively defined for logistics simulation. It can be used for different purposes during planning, construction and operation. In the last years consistent coupling and integration of project data models was in the focus of several research projects. In the *Mefisto* project an innovative concept for coupling different models on different levels of detail has been developed. Different models can be linked by using unique identifiers. Links are stored using XML in an external link model. Project data, link models and additional Meta information can be integrated into an archived ZIP-file, and forms the so-called *Mefisto* container. Each project can contain several *Mefisto* containers for different purposes. One special container was implemented to support the data collection und preparation for logistics simulation. This Mefisto container covers amongst others data *IFC*-based building information models (*IFC* STEP format), bill of quantity (BoQ) files using the German *GAEB* standard (*GAEB* XML format), model-based quantity takeoffs (QTO), construction site layouts including construction equipments (*Mefisto* XML format), and general activities and milestones (*Mefisto* XML format). Further information about the *Mefisto* container and different used data formats can be found in Scherer et al. (2010).

These essential data models are linked to provide the required information for the logistics simulation. Starting with the general construction activities, for each activity the required material quantities can be extracted. For example, if a reinforcement activity of a building section is processed, the calculated steel in kilogram can be determined. Furthermore, the general location of an activity on the construction site can be calculated using the building information model, and consequently to find an appropriate storage area. Some typical model links for logistics simulation are shown in Fig. 3.

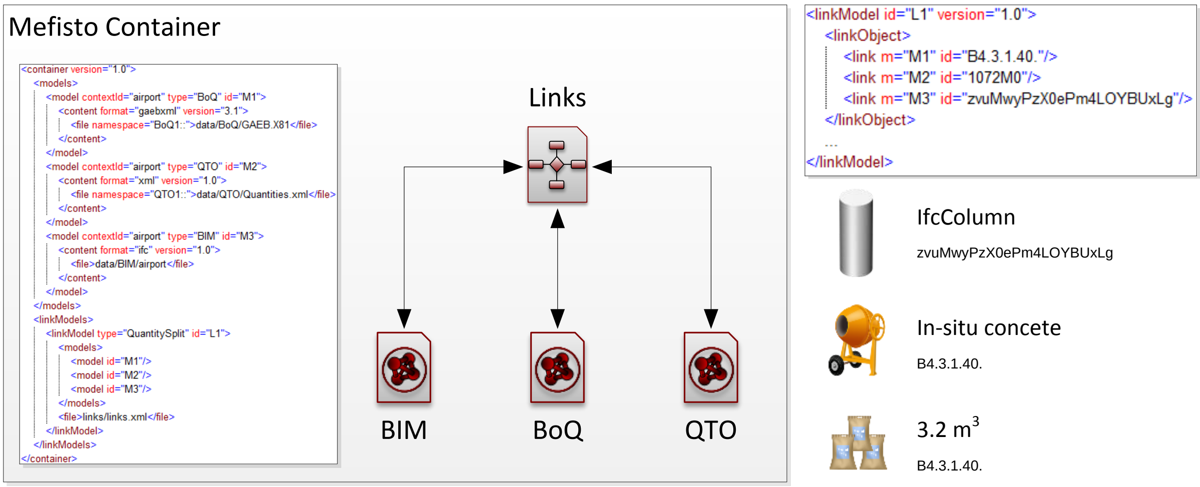

Fig. 3: Mefisto container to support the collection and preparation of logistics simulation

Using information about construction site layouts, general transport ways, storage areas, gates, and equipments including their positions can be extracted to set up a simulation layout. The described *Mefisto* container for logistics simulation is also used to define additional input data. Very important are the specifications of delivery dates, means of transportations, material quantities, and packaging units. Normally, this logistic data is not needed for any purpose other than logistics simulation. Therefore, it must be defined manually by planers. However, in early planning phase detailed information about the delivering is often unknown. Consequently, the planers use their experiences and reasonable assumptions for their definitions.

In the *Mefisto* project the *SiteSimEditor* has be implemented to support data preparation and definition processes. Necessary input data can be filtered from the *Mefisto* container and can be visualized clearly. The *SiteSimEditor* provides an intuitive and flexible user interface for definition of the additional logistic data. For each general activity the material quantities can be listed. Next typical packing units are specified. Information about common packing units for certain material can be select form an internal knowledge database. This database can be extended by the user. Based on the packing units the means of transportations can be typed in. For example, formwork and reinforcement steel meshes can be normally transported by different truck and cast-in-place concrete by concrete mixers. The SiteSimEditor uses the quantities and the packing units to calculate the required number of transports for the selected vehicles. Normally, the material is not delivered at the same time. In fact it is distributed over time considering the underlying activity. Therefore, the *SiteSimEditor* provides interfaces so that the user can define certain distribution functions and reasonable handling times. If additional restrictions like time windows or arriving limits of trucks per day have to be taken into account, these conditions can be also specified beforehand and considered during the generation process. As a result the daily amounts of vehicles, which must be handled on the construction site, are available for logistics simulations (cf. Fig. 4).

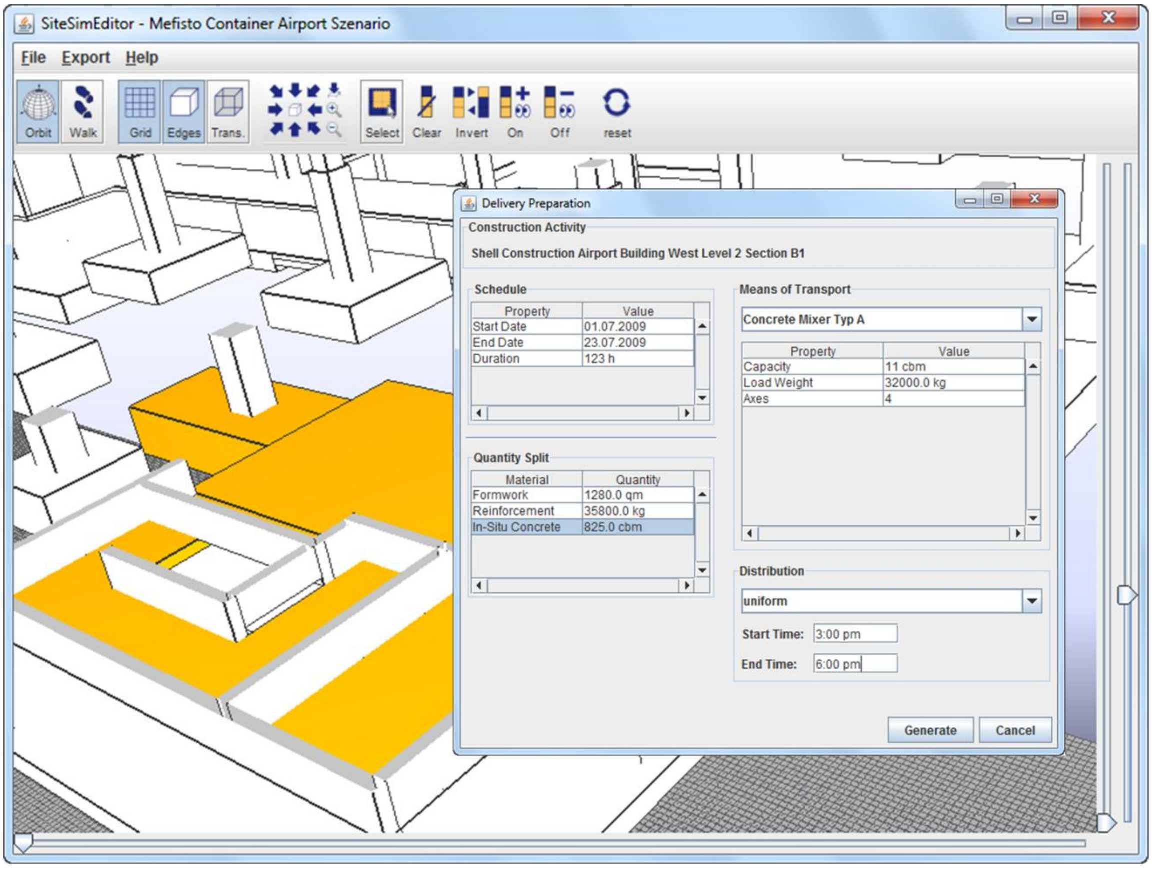

Fig. 4: Specification und generation of delivery data for logistics simulations

Further information must be defined to model transports on the construction site. Usually, arriving vehicles are unloaded at certain positions. Subsequently, the delivered material is stored on default storage areas or is processed directly like cast-in-place concrete or pre-cast elements. On construction site cranes are often used to unload the material. The integrated consideration of vehicles, unloading positions, storage areas, production locations, and cranes is called logistic chain. For each delivery a logistic chain must be defined. During the logistics simulation for each arriving vehicle the optimal transport way to its destination is calculated automatically. The logistic chains are specified based on the imported construction site layout. For each generated vehicle or a group of vehicles the associated logistic chain can be interactively defined by selecting unloading positions, storage areas, and cranes for unloading. If the delivered material should be processed directly, the unloading positions can be calculated by analyzing the corresponding building elements of the building information model.

Usually, several scenarios are modeled compromising varying transport processes and logistic chains. Each scenario must be simulated and analyzed separately. Therefore, the *SiteSimEditor* provides functionalities to manage and store different data sets. For this reason a simulation input database was implemented, which also serves as interface for the connected simulation framework. However, the simulation framework must also be extended to process the input data for model generation and running the experiments. In our case Tecnomatix Plant Simulation from Siemens PLM is used as simulation tool in combination with components of the Simulation Toolkit Shipbuilding. Currently, the model generation must be done in an explicit way by establishing a connection to the database and executing a special import method. The simulation model must be created each time, when general modifications of construction layout were carried out. Following, a simulation scenario can be selected and executed. The result like waiting times on construction site of the vehicles, utilizations of cranes, or start and end times of the construction activities, are stored back into the simulation database and can be used for further analysis.

4. CASE STUDY

The described concept was validated by a practical case study. The case study deals with logistic processes for shell construction activities of an airport terminal during full operation. The new airport terminal consists of six levels and has a total area of 185,000 square meters. The given framework time schedule includes 60 construction activities. The total shell construction time was estimated to be around 12 month.

The client defined several logistic restrictions. Essential restrictions are crane positions and storage areas due to existing buildings and on-going operation, fixed entry gates for trucks, maximal deliveries per day, and limited access and construction times. Construction site layout data were extracted and prepared using the *SiteSimEditor* based on an integrated *Mefisto* container for logistics simulation. The result of simulation model generation is shown in Fig. 6. The simulation models includes 16 cranes, 11 storage areas, 12 construction areas, 148 transport way elements, and one entry gate.

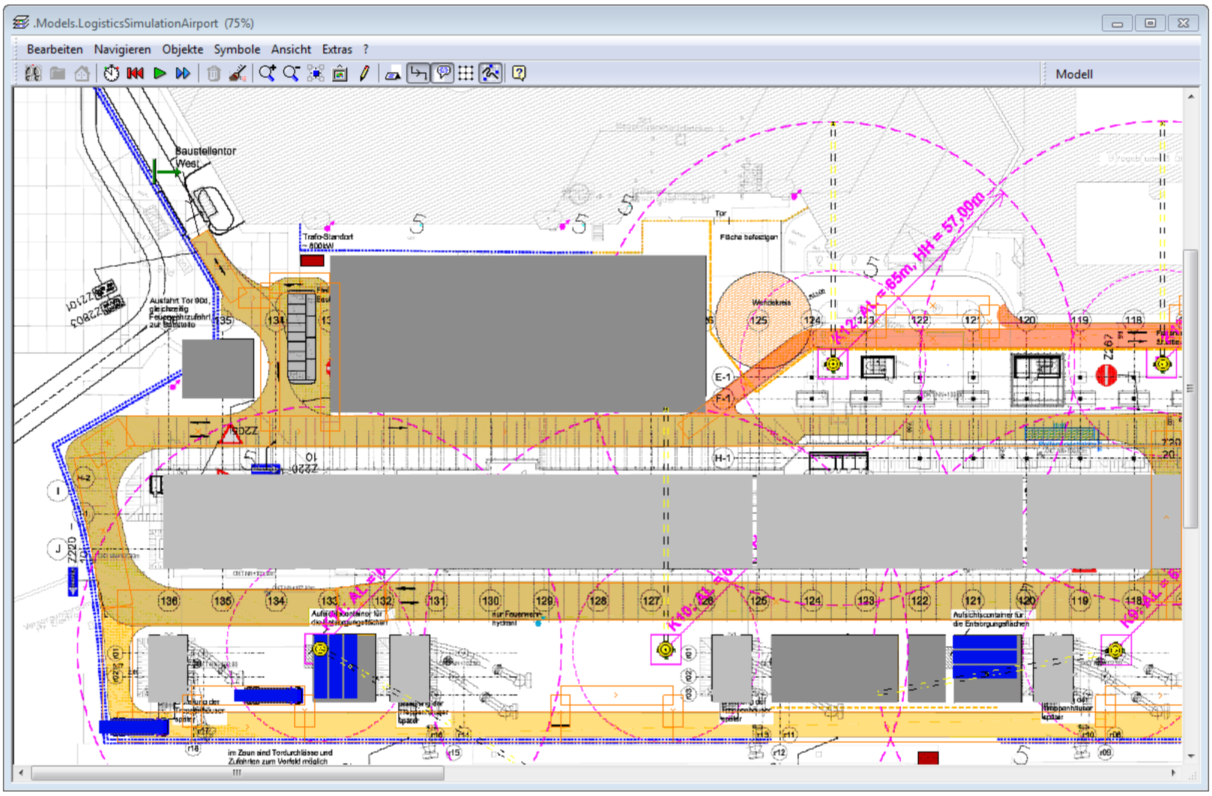

Fig. 6: Logistic simulation components of the airport construction site

In the next step the main deliveries were specified. Primary, in-situ concrete, pre-cast elements and reinforcement steel were modeled und transported by different trucks through the entry gate to the cranes for unloading. Therefore, capacity information of the trucks was needed. For example, seven precast floor slabs can be carried by one truck or 8 cubic meter in-situ concrete by standard concrete mixer. The *Mefisto* container provides the estimated material quantities and elements for each construction activity by analyzing the links between building elements, construction activities, bill of quantities, and quantity take-off. More than 6500 deliveries were generated, that means about 25 deliveries per working day. Next, the deliveries were distributed over the activity durations taking limited access and construction times into account. In this case study a uniform distribution was used. Due to practical experiences the delivery of pre-cast building elements should be scheduled between 8 am and 11 am. Furthermore, priorities for certain deliveries were defined. If several trucks are arriving or waiting at the entry gate, then deliveries with higher priorities will be preferred dispatched. Typical priority deliveries are, for example, material for Just-In-Time (JIT) construction like in-situ concrete or large-size pre-cast building elements. Each delivery is related to an activity and the location where this activity takes place. However, the daily amount of deliveries often varies significantly. In Fig. 7 the daily delivery amount of reinforcement, in-situ concrete and pre-cast building elements highlighted.

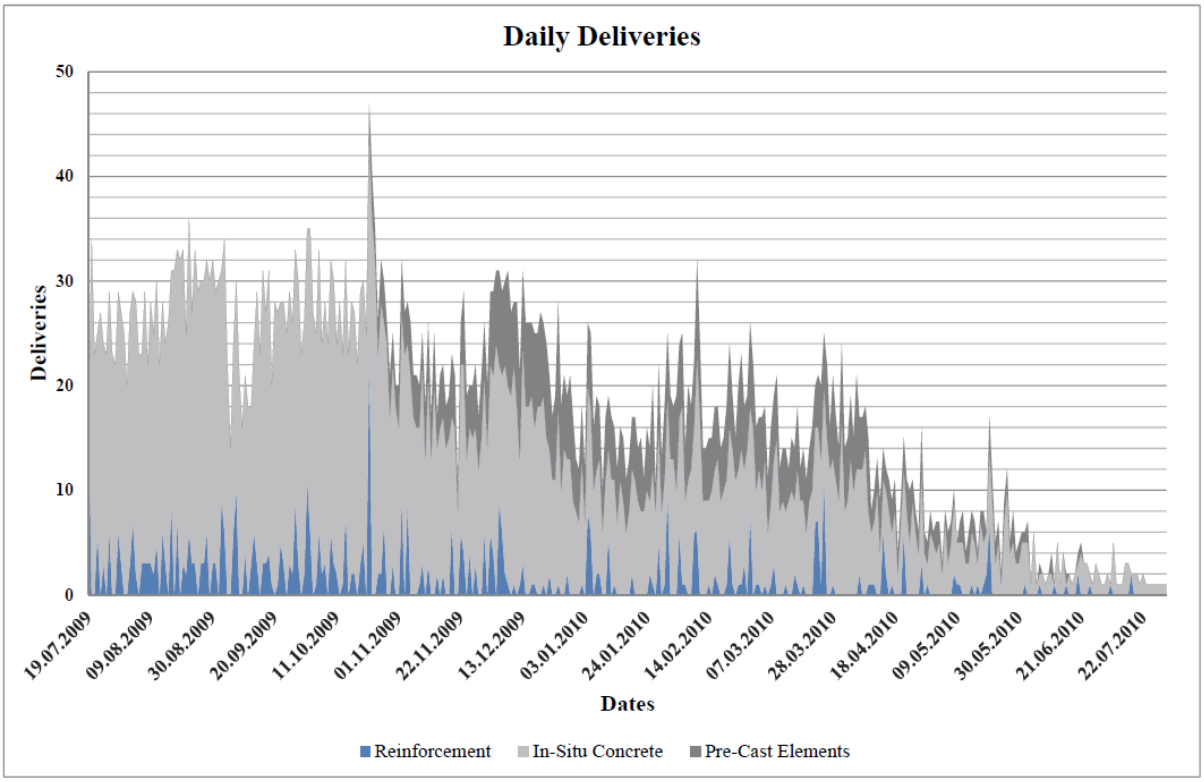

Fig. 7: Daily deliveries of reinforcement, in-situ concrete and pre-cast building elements

Different statistical data sets were collected during the simulation run in order to analyze the on-site logistics. The statistical data include the utilization of resources, allocation of storage areas, transport and waiting times on construction site and entry gate. Fig. 8 shows the number of waiting trucks at the entry gate for each working day. The waiting trucks oscillate significantly in some time intervals. Consequently, more parking spaces in front of the gate were provided.

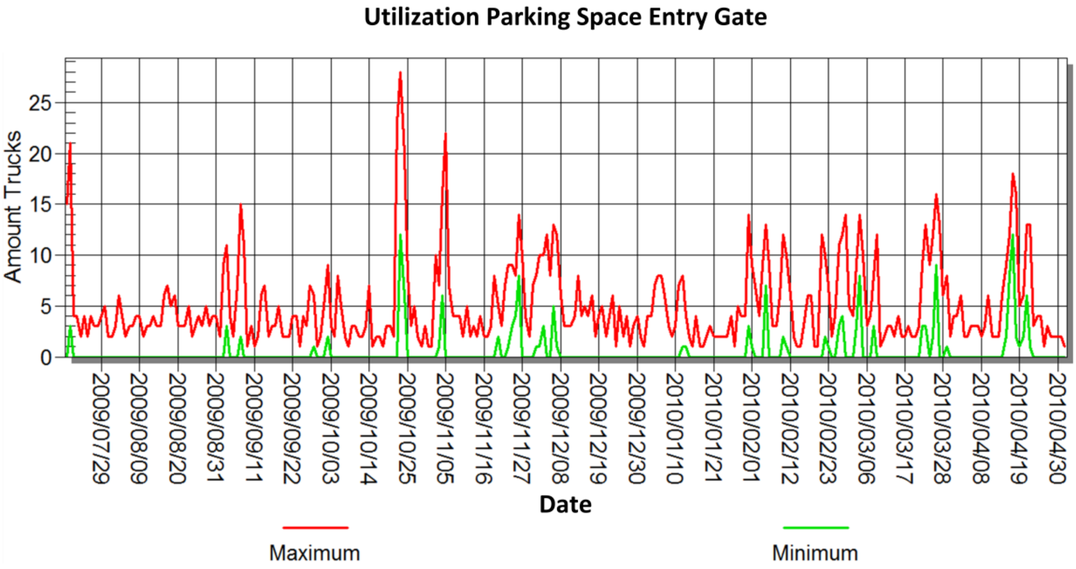

Fig. 8: Content of parking space of entry gate

In the next step the resource utilizations were analyzed in order to identify critical bottlenecks. For example, the weekly utilization of the concrete pump is illustrated in Fig. 9. The utilization correlates with the delivery amount of concrete. Critical bottlenecks were not identified.

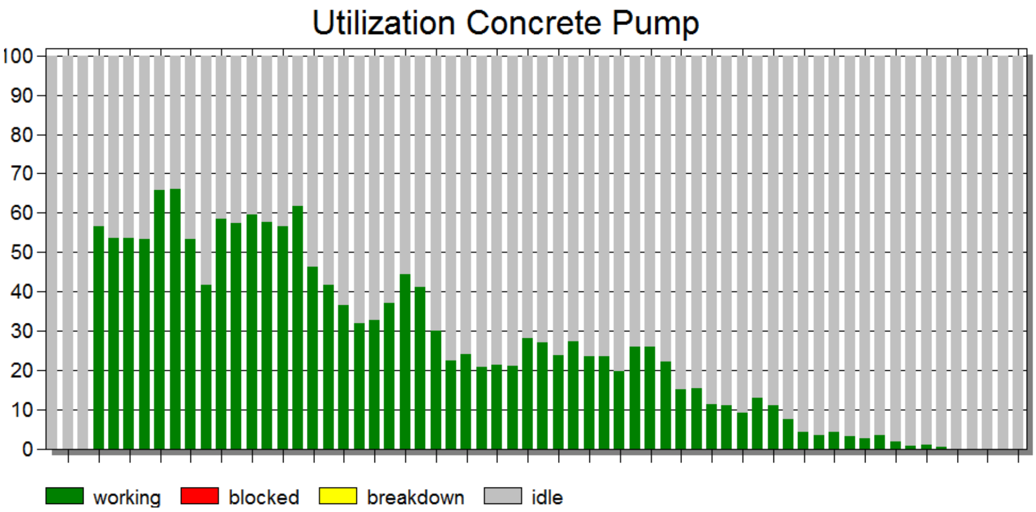

Fig. 9: Utilization diagram of the main concrete pump

5. CONCLUSIONS AND OUTLOOK

In this paper an innovative data preparation concept for logistics simulations in early planning phases is presented. Thereby, available project data is collected, integrated and linked to generate the necessary input data for logistics simulations. The basis of the data integration is the so-called *Mefisto* container, which enables links between different data models. The *SiteSimEditor* is used for data preparation and extension. Based on the prepared data the corresponding simulation model can be generated automatically using already implemented and configurable simulation components. Furthermore, the *SiteSimEditor* provides the input data for the simulation model like activities, deliveries and logistic chains. The presented data preparation and model generation approach allows the investigation of logistic processes of large-scaled construction project in an efficient way. The concept was validated by a case study considering the shell construction an airport terminal. In the next step the definition and reusing of logistic chains will be addressed. Furthermore, the Mefisto Container for logistics simulation will be extended by general packing units and further equipment data.

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