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Review

Simulating quality assurance and efficiency analysis between construction management and engineering geodesy

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ABSTRACT

High-rise building construction is highly complex and involves many different disciplines. Such projects can only be accomplished efficiently and with appropriate quality by means of an overall optimized construction process. However, the understanding of the term “quality” among involved participants is not always equivalent. E.g. providing required tolerances of elevator shaft walls constantly throughout the concrete works is often a challenging task during the execution of in-situ concrete works.

This paper is based on the scientific research project “Efficiency optimization and quality control of engineering geodesy processes in civil engineering” (Effizienzoptimierung und Qualitätssicherung ingenieurgeodätischer Prozesse im Bauwesen - EQuiP), which aimed at developing a method for instant quality assurance in construction based on geodetic surveying techniques, and at the same time optimizing the efficiency of the process, e.g. with respect to time. This paper shows how hierarchical and modular modeling of construction and geodetic processes using high-level Petri nets delivers a base for a real time quality evaluation and re-planning on construction site.

As an example, this modeling approach is simulated for the construction of concrete stairs and elevators core of a characteristic high-rise structure. The concrete works were considered to be carried out using climbing formwork. Three different scenarios are shown in this paper. The first scenario is simulated with deterministic durations and validates the developed Petri net. The second scenario uses stochastic process durations to show the robustness of the construction process. Finally, disturbances and delays are integrated and an automated rescheduling based on prioritized alternative paths is used.

Contents

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1. Introduction

An increasing overall acceleration and an optimization of processes can be observed in many construction projects. This includes especially the construction of high-rise buildings. The stairs and elevator cores are often erected using climbing formwork, which functions in constantly repeating working cycles. Within one cycle, which takes a week or even less, the concrete structure of a single story can be produced.

Compliance with the quality requirements and documentation of the achieved quality of the individual components of the building are essential and imply an intense use of geodetic surveying methods on construction sites [2,18]. An optimized integration of geodetic processes into the construction process facilitates and accelerates the work of the subsequent tasks, such as facade or elevators.

The project "EQuiP" funded by the German Research Foundation (DFG) was carried out within the topic described above. The main goals were:

- to identify the interfaces between the construction and surveying processes,
- to achieve sufficient integration of construction and surveying processes for a smooth project execution,
- to increase efficiency of the overall construction process and
- to develop a quality assurance method focusing on proactive and instant failure prevention.

For these purposes the activities of a high-rise building construction were thoroughly reviewed and a process model was established. The high level of detail adopted in this model was defined by the interfaces between construction and surveying activities. The simulation of the construction and surveying activities of the process model was carried out using Petri nets. Different input values, such as the number of workers or the sequence of activities, can be changed within the simulation, enabling a bottleneck analysis for determining the robustness of the planned processes.

Firstly, the developed process model is used to plan an efficient integration of measurement processes into the construction processes of building construction. By simulating the processes, the duration of the whole construction process can be estimated. In addition, bottlenecks in the process model can be identified.

Secondly, the process model should be used on site during the construction phase to provide the required quality parameters during, or immediately after the measurement. Through process model, which continuously compares the planning with reality, a decision support for further procedures should also be provided if the processes do not proceed as planned. Therefore, the implementation of disturbances and delays is included into the process model as well as appropriate reactions.

In the future, the best possible schedule should be created by continuously updating the most optimally efficient processes directly on the site. Methods to carry out such an efficiency optimization have been developed herein.

The paper is organized as follows. First the authors describe the theoretical background of Petri Nets and their extensions as well as quality assurance and efficiency optimization basics. Then, the example project, a self-climbing formwork for high-rise buildings, is presented. This includes the construction process as well as the relevant geodetic processes and their interactions that lead to possible disturbances and delays. Finally, the process simulation covering different scenarios is explained and the results with respect to the process model are presented. The paper finishes with a conclusion and future outlook.

2. Process modeling

Both quality assurance and efficiency optimization define high requirements on the process model. To satisfy process-oriented quality parameters (e.g. error-proneness) a detailed level of modeling is required (see [23,25]). The high level of detail leads to a high complexity. The process model should reproduce this and be able to simulate the whole process in a sufficient time to find a construction process, which meets all the quality restrictions and is efficient in terms of time and costs.

The process model has to provide alternative processes automatically or rerun the process if, e.g., quality parameters are not met (see Section 2.2). It should be noted that a redesign of the whole process model without handling versions and dependencies between processes and resources is not possible on site, as this would be too complex and time consuming [12]. Therefore, the structure of the process model has to facilitate the replacement or changing of complex processes without affecting the overall process (see Section 3.2 & [21]).

2.1. Petri nets

Based on the above requirements Petri nets were chosen for process modeling and simulation. The graph-based structure of Petri nets makes it easy to include a hierarchy and modularization, so that coherent and/or repetitive processes can be replaced or modified [9]. A Petri net is a bipartite graph, described by a 6-tupel (P, T, F, C, W, M_0), where

- P is a finite set of places. A place represent a condition or a state in a workflow,
- T is a finite set of transitions. A transition represents an activity in a workflow,
- F is a set of relations $F \subseteq (P \times T) \cup (T \times P)$, which connect places with transitions and vice versa,
- C is a map C: $P \rightarrow \mathrm{N}^+$, which indicates the capacity of every place,
- W is a map W: $F \rightarrow \mathrm{N}^+$, which assigns a weight to every edge.