Closed loop controlling approaches for projects in the earth moving and road construction industry

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Abstract
The research project EPOS (Efficient process design by satellite supported software in the earth moving and road construction industry) started in July 2009. The basic idea of the project is to build up a basis for a multi-layer closed loop approach for project controlling in the earth moving and road construction industry. Therefore standard software for enterprise resources planning (ERP) and business intelligence (BI) is used. At the top level a BI system is used to support the management level of a company. An ERP system also provides a more detailed view of the data. The bottom level is represented by the production activity control (PAC) which supports project managers and construction supervisors in the controlling and planning activities. The controlling functions can also deliver interesting information for managers or controllers of construction companies:

1. A daily schedule which visualizes the status of excavators and other equipment.
2. A comparison between the planned and actual quantity of excavated material in a period of work.
3. A path-time diagram which shows the project progress.

The PAC is a Web-based application and accessible at all construction sites via a wireless network-connection. In order to provide the EPOS software with real data on the performance of an excavator, the authors developed a complete system for machine guidance: The DTM Navigator. This system records data sets consisting of: GPS-time, coordinates of the excavator’s bucket, heading, fuel consumption, and so on. Using this data the supervisor of a construction site can calculate the daily performance of the excavator. That is the main basis for the EPOS control system.

Keywords
Controlling, project supervision, GPS, earth moving and road construction industry, production activity control (PAC), business intelligence

1 RESEARCH PROJECT EPOS

The construction industry has to cope with many challenges. Since many years permanent cost pressure, increasing expenses, shortened schedules for the completion of projects and a highly complex system of official laws and standards have to be mastered. Profitable projects are based on a smooth construction sequence and current information about progress. In case of incidents during the project it is important to counteract as fast as possible to avoid a loss of profit. Unfortunately planning and controlling systems which support the complete production process are not available up to now (Nebe 2003). However during the last years some progress has been made. In the field of coal mining satellite supported systems for bucket wheel excavators are already applied successfully. They deliver mining data and data for material planning (Heck et al. 2004; Bulowski/Körber 2004; Weber/ Cerfontaine 2006). Apart from that GPS-based control of bulldozers is another important field of application (Gut 2007). Günthner et al. report on experiences with GPS-based control of trucks (Günthner et al. 2007; Günthner et al. 2006). Another interesting application is a DTM-based machine guidance system for excavators using GPS positioning which is described in Schreiber et al. (2008).

Currently the next steps are going to be made. The research cooperation "Virtual construction site" (ForBAU) aims to adapt concepts and practices of modern industrial organizations, their production
technologies and logistics systems to those of the construction process (TUM 2009). The idea is to
collect data from different phases of a construction project. The data is transferred to virtual
landscapes. This 4D-information system of the construction site shall be used and constantly
developed over all phases of the project (TUM 2009). The integration approach is based on process
simulations and digital tools. In comparison with the construction plan variations of data can be
immediately discovered and counteractive measures can be induced at an early-stage. Further
information about ForBAU can be found in (TUM 2009).

As an important part of a complete information chain satellite supported software for excavators can
be used. This is the focus of the research project EPOS (Efficient process design by satellite supported
software in the earth moving and road construction industry). Locally collected cost and performance
data of an excavator can be transferred in short periods to an information system. Afterwards it can be
prepared for several stakeholders, for e. g. construction supervisors, controllers or managers. This
process is fully automated. The results of the EPOS project can be combined with the findings of the
ForBAU project in future. EPOS was initiated by the authors and started in July 2009. As an extension
of the research results which were presented at the MCG 2008 the basic idea of the project is to
expand the scope the controlling approach to a multi layer closed loop system for project controlling in
the earth moving and road construction industry. Therefore standard software for ERP and business
intelligence is applied. Apart from that a production activity control component is developed. The
following sections illustrate the idea of performance and cost control based on powerful software
tools.

Before we go into details the data basis of the EPOS project is described in section 2. The closed-loop
approach is explained in section 3. Afterwards the basic architecture and the EPOS components are
outlined. The last section summarizes the paper and includes a future outlook.

2 DATA SOURCES/ DEVELOPMENT OF THE DATA LOGGING
EQUIPMENT

In order to provide the EPOS software with real time data the authors developed a complete system for
machine guidance: The DTM Navigator for heavy equipment such as excavators and bulldozers. This
system records data sets consisting of GPS-time, coordinates of an excavator's bucket, heading and
angles.

2.1 The DTM Navigator: Basic Ideas

In the beginning of the development of the DTM and GPS-based machine guidance system, it was
intended to improve the productivity of construction machines, such as excavators. The excavator was
chosen, because it is the geometrically most complicated machine for machine control applications.
GPS-based electronic receivers are able to determine their location within a few meters. The position’s
accuracy of highly sophisticated differential GPS-equipment (based on the RTK-receiver TRIMBLE
5700 datasheet) is stated:
- horizontal: +/- 10 mm + 1 ppm
- vertical:    +/- 20 mm + 1ppm.
Recent terrestrial surveying systems such as tachymeters have comparable accuracies. Only these
accuracies fulfill the standards and the building regulations for surveying. Machine guidance is a
specific type of surveying construction sites. Due to this reason the accuracies which were mentioned
above are a demand for machine guidance.
An accuracy test determining the position of a bucket-tooth of an excavator at our test area led to an
accuracy of 15 to 25 mm. Stempfhuber / Ingensand (2008) report on an accuracy range from 20 to 30
mm (height) and 20 to 50 mm (3D-position).

2.2 Technical set-up for collecting data

Important components of the DTM-based machine guidance system are (Schreiber/ Diegelmann
2007): two GPS antennas for the GPS Receivers (GPS A1/2), two encoders (G1/2), an LED bar and a tilt sensor (TS1). Fig. 1 illustrates the technical set-up.

To avoid over-excavation the operator's main information is the difference between the planned depth and the actual depth at the center of the bucket’s cutting edge (BE). It is zero when the planned depth is reached.

A more detailed description of the technical set-up can be found in (Schreiber/ Diegelmann 2007).

### 2.3 Calculation of the planned depth

In order to obtain the planned depth of the grade, the database of the site DTM, downloaded onto the on-board computer, is permanently queried. The queries yield the height $Z_{\text{DTM}}$ for the current position (coordinates $X_{\text{BE}}$ and $Y_{\text{BE}}$). The difference between the current height of bucket’s cutting edge $Z_{\text{BE}}$ and the planned height $Z_{\text{DTM}}$ provided by the site DTM is the height deviation. This is visualized in several ways: on the computer screen and on a stick mounted LED bar display. For the operator’s convenience an LED bar (fig. 2) provides an analog display of the vertical and lateral deviation. At a glance the operator can ergonomically see the moving bucket and its deviation from the planned depth.
2.4 Determining the excavator’s productivity

Apart from navigating the excavator, the machine guidance system provides users with valuable real-time information based on safe estimations in order to avoid guesswork. Performance assessment serves to indicate whether the actual excavator’s performance is according to plan. The determination of the actual performance at run time has advantages for construction companies in terms of operational planning, invoicing and deriving revised cost calculations from comparable machine operations. Determining the productivity is an essential step towards a modern controlling system for construction sites. Hence software is needed to monitor production and to control the solvency and the profit of a construction site (Wirth 2003).

The excavator’s performance can be calculated from volume and surface data. The machine guidance system’s volume and surface determination software uses the following working principle. Two digital terrain models are determined (Rausch et al. 2008):

1. A basic DTM (blue), namely DTM₀ at time T₀ before the excavation work begins, and
2. a temporary DTM (red), namely DTM₁, at the moment T₁ of performance assessment, after the excavating job is finished.

At time T₀ when work starts, all surface points have the original site coordinates, which means that all DTM₀ data are valid. At time T₁ of the first volume assessment, the actual coordinates of characteristic points on the site are recorded by the excavator operator as a temporary base area, while the working
movements of the construction machine are recorded and automatically stored.

The machine guidance system’s CAD program creates the temporary DTM₁ from the actual coordinates just measured; this data is stored for subsequent use. As soon as excavation work is completed, the temporary DTM₁ becomes the target DTM. By comparison of the two DTM values (DTM₀ and DTM₁), the volume V₀,₁ excavated during time T₁ - T₀ can be determined (DTM-green, fig. 3).

In the same way as for excavated volume V₀,₁, the subsequent excavated volumes V₁,₂, V₂,₃, etc. at measuring times T₂, T₃, etc. can be determined.

They can be computed, processed, stored and evaluated. It is also possible to send them to an ERP-system which can analyze the data with powerful tools (Nebe 2003). The data is very useful for planning and preparing construction work. It provides a basis for post-calculation of important service components on the construction site and is useful for calculating subsequent bids for similar construction projects.

2.5 Use of the calculated excavated volume to determine operating data

Based on the calculated excavation volume or the covered surface and additional machine operating data, the operating data for the “excavator cost estimation” can be determined. Additional data can be saved and processed by the PAC and the ERP system: details of machine operators’ wages, cost of fuel and related operating materials, cost of the machine itself (depreciation A, interest charges V, and average repair charge rate R), costs of wear and tear, and miscellaneous costs.

Provided with all these parameters the excavator’s hourly costs can be divided into separate cost components.

2.6 ERP Interface

As we have already mentioned ERP systems offer powerful tools to analyze the collected data. For this reason the developer team has implemented an mySAP ERP interface. The interface is based on so called Business Application Programming Interfaces (BAPIs). BAPIs allow access to SAP business objects, which makes it possible to add data to the ERP database. To provide the ERP interface with data the SAP tool “Legacy Systems Migration Workbench” (LSMW) was used. Alternatively other powerful SAP technologies called „Exchange Infrastructure“ (XI), Java Connector or Business Connector could be used. The advantages and disadvantages of the tools are discussed in (Willinger/Gradel 2003, Stumpe/Orb 2005, Nicolescu et al. 2006). Because LSMW was readily availability and due to the fact that other technologies would have entailed additional license costs we decided to use the LSMW. With the implemented interfaces, data collected by the machine guidance system respectively the PAC can be transferred to the ERP system. It can be analyzed by the project system, the controlling and the finance component. It is also conceivable to use business intelligence tools for further analysis.

3 THE CLOSED-LOOP APPROACH

Before the functional components are explained in detail it is helpful to understand the closed-loop approach in general. Fig. 4 illustrates the basic idea.
Data from the operational layer is monitored and analyzed on a regular base. The data provides insight about the actual performance of the construction site processes. Among others business intelligence applications can be used for this purpose. The results produced by the BI applications can be shared and evaluated by the users. The idea is to recognize problems in time and to improve the business processes. Later on, the positive or negative effects of those changes are measured by the closed-loop applications and so on (Eve 2009). It is important to notice that the closed loop is not a single iteration. The data is collected and analyzed again and again to determine if the concluded action and the analysis were correct and addressed the business issue. This general principal is used on several levels of a controlling system which is explained in the following section.

4 ARCHITECTURE AND FUNCTIONAL COMPONENTS

Fig. 5 illustrates the architecture and the components of the EPOS system.

At the top level a BI-system is used to support the management of an enterprise. An ERP system provides a more detailed view of the data. The bottom level is represented by the production activity control (PAC) which allows project managers to support the controlling and planning activities. The EPOS project focuses on the PAC, – the construction supervisor’s workplace –, its’ data sources and the associated data flows. To get a better understanding of the closed loop approach the different levels are explained in detail.
4.1 PAC-level

As already mentioned the PAC mainly supports the construction supervisor. It is a web-based application and accessible for all construction sites by a wireless network-connection. Apart from that the controlling functions can also deliver interesting information for managers or controllers of construction companies. The PAC supports the collection of data which is manually entered by the construction supervisor. Fig. 6 illustrates the user interface.

Data which is logged by the on-board system of an excavator or other equipment is automatically transferred to the PAC server. Furthermore fine planning is supported. The PAC is designed for excavators at construction sites in the field of civil engineering. Nevertheless, the PAC can be seen as a basis for further enhancements, allowing the integration of other construction machines in the future.

The PAC component includes three basic functions:
1. A daily schedule which visualizes the status of the excavators.
2. The graphical representation visualizes the operating and down times of an excavator.

Figure 6: PAC prototype: GUI to collect construction site data

Figure 7: PAC prototype: comparison between planned cost parameters and actual values
2. A comparison between the planned and actual cost/performance parameters. The supervised time period can be freely chosen. Deviations violating a certain threshold are highlighted. Fig. 7 shows a comparison between the planned cost parameters and the actual values as an example.

3. A path-time-diagram which shows the project progress.

4.2 ERP-level

Further analysis of the collected project data is done by the analysis and reporting components of the ERP system. Current cost and activity data of the construction sites is provided to the construction management accountancy, which is focused on calculating the cost of projects and single items of work. Apart from that comparison of actual figures, for e.g. of two following periods, can be generated by the ERP-System. These reports can be used for comparisons of expenses types of cost centers (Rausch et al. 2008). Moreover, it is possible to distribute the analysis results to mobile clients, such as notebooks or mobile phones, for persons needing such information. Until the end of September 2010 the ERP interface will be improved and the possibilities of ERP reporting will be extended.

4.3 BI-level

The BI level mainly addresses management and the controlling department of construction companies. The collected data is processed for decision-makers and controllers (Gómez et al. 2009). It can be accessed and analyzed by business intelligence tools. For example, the analysis of expense and performance data is possible using online analytical processing (OLAP). Expenses such as those caused by vehicles, construction sites or departments can be analyzed in terms of the criterion “time”. The EPOS BI demo system offers also other valuable reports. Uptime information of excavators or excavator types can be used to determine the level of utilization or the excavators’ productivity (fig. 8). This information can be very interesting for controllers.

![Figure 8: BI demo system: key figure “productivity”](image)

5 CONCLUSIONS AND FURTHER DEVELOPMENTS

The information age has definitely arrived and in fact it has just begun to affect the business processes of the construction industry. In this paper a new generation of a controlling system for the earth moving and road construction industry was presented. The multi layer closed loop approach provides different stakeholders like construction supervisors, managers or controllers of construction companies with valuable information like comparisons between planned and actual key figures in a period of work. In case of deviations action can be taken in time. Its main data source is a machine guidance system which delivers real time operating data of construction sites. Based on this data more accurate schedules and estimates are possible. Additionally it is possible to analyze operating data to get information about the performance of the used equipment.
Quite certainly the project will be finished on time in September 2010 providing all the features which were on the project’s schedule and described in this paper. So far we have established a complete information chain to deliver a detailed view of production processes in the earth moving and road construction industry. There are however many starting points for extending the scope of the closed loop approach. Up until now we have focused our attention on excavators. The next big step would be the integration of other equipment such as bulldozers etc. Apart from that additional reports on different levels (BI, ERP, PAC) could be useful.

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