Intelligent Performance and Cost Analysis of Construction Machines' Data

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ABSTRACT: *The European construction industry faces a challenging environment with very tight time scales and budgets. At the same time, a lack of (real time) information makes it impossible to control projects effectively. The research project EPOS (Efficient process design by satellite supported software in the earth moving and road construction industry) which is described in this paper aims to alleviate this. It is pointed out how this could be achieved by using intelligent performance and cost analysis of data from construction sites. At first the basic ideas of the EPOS project and the underlying corporate performance management approach are explained. Thereafter the system architecture and its data sources are briefly outlined. At a glance the main components, namely a machine guidance system, a production activity control (PAC) component, an enterprise resources planning (ERP) system, and a business intelligence (BI) software are introduced. An explanation of the performance and cost analysis components follows. Examples for data analysis are given. The final sections outline possibilities for further developments and summarize the paper.*

Keywords: Controlling, project supervision, Earth moving and road construction industry, Business intelligence, Corporate performance management

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1. Construction Industry's Challenges

For many years the European construction industry has been in a process of change due to different influences, for example globalization, legal changes and technical progress. In such an environment, companies can only survive if they are able to complete their projects on time and to budget. This requires a smart analysis of project opportunities. For current projects smooth construction sequences and real time information about progress are crucial. In case of incidents or developing delays during a project it is important to counteract as fast as possible to avoid a loss of profit. Unfortunately there is a lack of controlling systems which support the complete production process. However, technological progress has been made. For example, satellite-supported systems for controlling bulldozers have already been applied successfully (Gut 2007). Other authors report on experiences with GPS-based control of trucks (Günthner et al. 2007; Günthner et al. 2006). Schreiber et al. describe a digital terrain model (DTM)-based machine guidance system for excavators using GPS positioning (Schreiber et al. 2008). The next important step is to collect all the generated data and to analyze it. The idea is to set up an intelligent performance and cost analysis system for projects in the construction industry. Managers and construction supervisors should be supported by reports which provide key figures and information. The research project EPOS (Efficient PrOcess design by Satellite-supported software in the earth moving and road construction industry) tries to fill this gap.

The following sections will show the details. First of all, the basic idea of the EPOS project and the corporate performance management approach are described. The system architecture and its data sources will be outlined in the following section. In subsequent sections, the performance and cost analysis components are explained in detail. The last sections summarize the paper including a future outlook.

Figure 1. Closed-loop approach (White 2010)

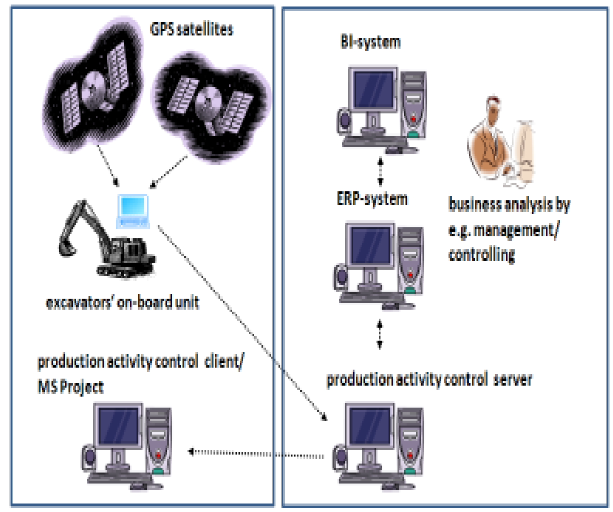

Figure 2. EPOS architecture

2. Research Project EPOS - Overview

The research project EPOS started in July 2009. Its main goal is to enable a fully automated transfer of locally collected cost and performance data of excavators to an information system and to prepare the data for several stakeholders for example construction supervisors, controllers or managers. For this purpose a multi-layer closed loop system for project controlling was developed. The system design, which will be outlined later, considers the possibility extending the approach to other machine types. EPOS is an extension of the research results which were published by Rausch et al. (2008) and Schreiber/ Diegelmann (2007). In the first step an excavator was equipped with a Digital Terrain Model (DTM) software and a 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. The next step was to transfer locally collected cost and performance data of excavators to an ERP-System to support business analysis. EPOS intends to expand the scope of the controlling approach to a fully automated multi-layer closed-loop system for project controlling in the earth moving and road construction industry. Therefore a central production activity control (PAC) component and business intelligence (BI) were introduced.

3. Corporate Performance Management (CPM)

Before the corporate performance management approach is introduced it is useful to understand the performance management concept in general. In literature a huge variety of definitions can be found, for example (Krause 2005), (Bourne et al. 2003), (Becker et al. 1999), (Hoffmann 1999), (Klingebiel 1999) or (Lebas 1995). In this paper Geishecker's and Rayner's interpretation should be used. They define performance management as "methodologies, metrics, processes and systems used to monitor and manage the business performance" (Geishecker / Rayner 2001). Corporate Performance Management (CPM) is a subset of this term. It focuses on performance management in context of enterprises. The basic idea, which is illustrated in fig. 1, is the closed-loop approach.

Key data from the operational layer (in our case the construction sites) is monitored and analyzed on a regular basis. The analysis makes the actual performance transparent. It is intended to recognize problems as early as possible and to improve the business processes. Improvements may be achieved by taking certain actions or changing the processes. The positive or negative effects of those changes are measured in the next iteration and so on (White 2010). This general principle is used on the different levels of the EPOS architecture which is described in the following section.

4. Architecture

As fig. 2 shows EPOS is based on a multi-layer architecture.

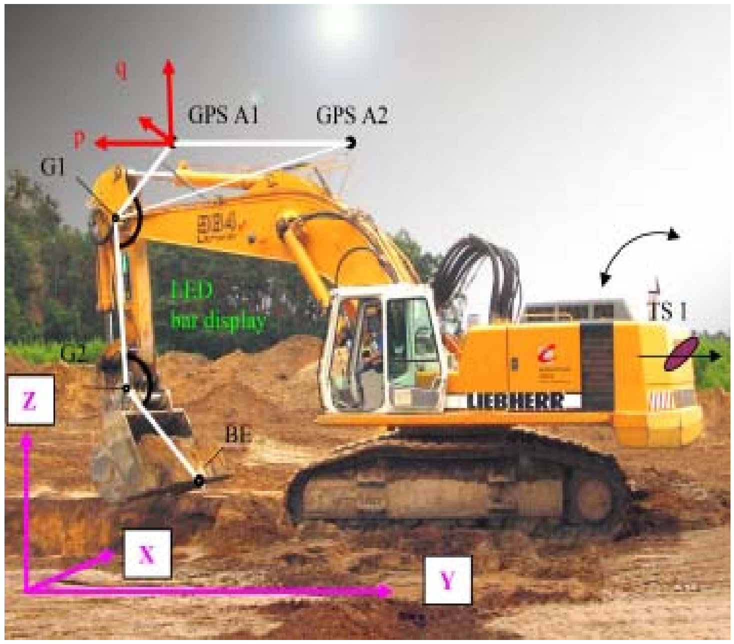

Figure 3. Set-up of an excavator (Schreiber/ Diegelmann 2007)

As already mentioned, the machines' data is collected at the construction sites. Via a wireless network connection it is transferred to a central production activity control server. The PAC receives the data and offers support for the controlling and planning activities of project managers. Some examples will be provided later. Construction supervisors can access the

analysis by their mobile devices. Additional parameters, for example cost parameters, can be provided by an ERP system. So users can get a more detailed view of the data from a business perspective. At the top level a BI-system is used for further analysis of project data. It can support several stakeholders, for example managers and controllers. The PAC, the BI component and the associated data flows were the focus of the EPOS project. Before the closed-loop approach and the analysis components are explained in detail the collection of data is briefly described.

5. System Components

5.1 Collecting Data from Construction Machines

The EPOS project is based on a complete system for machine guidance which was developed by Schreiber/ Diegelmann (2007). They developed a system for heavy equipment such as excavators and bulldozers called the DTM Navigator. In addition to navigating the excavator, the machine guidance system provides users with valuable real time information. It

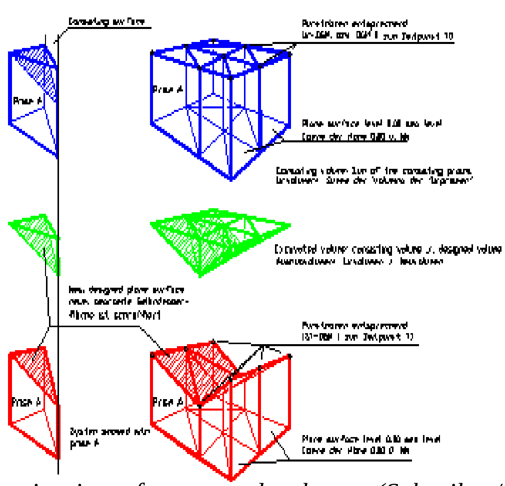

Figure 4. Determination of excavated volumes (Schreiber/ Diegelmann

records data sets consisting of GPS-time, coordinates of an excavator's bucket, heading and angles. In order to generate the data, a number of sensors are required on the excavator (see fig. 3): two GPS antennas for the GPS Receivers (GPS A1/2), two angle sensors (G1/2), and a tilt sensor (TS1) (Schreiber/ Diegelmann 2007). Standard GPS-based electronic receivers are able to determine their location within a few meters, which is not sufficiently accurate for our purposes. Therefore, we use a reference based GPS-system. An accuracy test using such a system to determine the position of an excavator's bucket-tooth at a test area proved accurate to within 15 to 25 mm.

The DTM Navigator software is installed on an excavator's on-board unit. It logs the performance data of the construction machine. A more detailed description of the technical set-up can be found in (Schreiber/ Diegelmann 2007). To compute the excavator's performance, the software compares two digital terrain models (see fig. 4). A basic DTM (fig. 4, top), namely DTM_0 at time T_0 before the excavation work begins, and a temporary DTM (fig. 4, bottom), namely DTM_1, at the moment T_1 of performance assessment.

DTM_0 represents the construction site coordinates at time T_0 when work starts. At the first volume assessment (time T_1) the actual coordinates of characteristic points are recorded by the excavator's operator, while the working movements of the construction machine are recorded and automatically stored. The coordinates represent a temporary base area model (fig. 4, bottom). It is created by the machine guidance system's CAD program and stored for subsequent use. When the excavation work is completed, the temporary DTM_1 becomes the target DTM. By comparison of DTM_0 and DTM_1 the volume $V_{0,1}$ excavated during time T_1 - T_0 can be calculated (fig. 4, middle). The volumes $V_{1,2}$, $V_{2,3}$ etc. at measuring times T_2, T_3 etc. can be determined analogously (Rausch et al. 2008).

The volumes are stored and processed for further analysis. Performance assessment is important to indicate whether the actual excavator's performance is according to plan, and is also crucial in terms of operational planning and invoicing. The performance data can also be used to derive revised cost calculations from comparable machine operations. The volumes and the time stamps are transferred to the central production activity control server.

5.2 Production Activity Control (PAC)

The PAC is designed for excavators at construction sites in the field of civil engineering. Nevertheless, it can be seen as a basis for the integration of other construction machines in future. Using a wireless network connection the excavators'

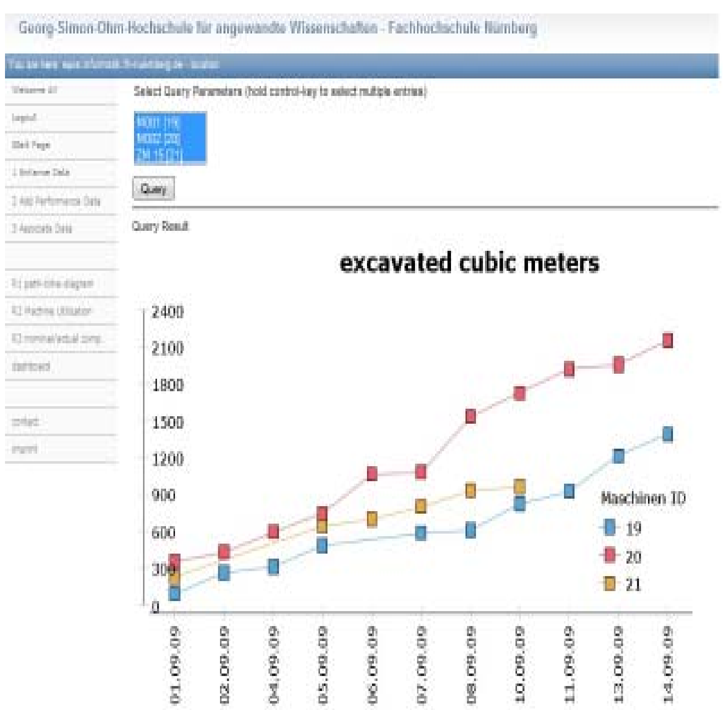

Figure 5. PAC: aggregate amount of excavation dependent on time

performance data and its time stamps are sent to the central production activity control server. The PAC mainly supports construction supervisors. It is a web-based application and remotely accessible from all construction sites. The server stores the data and makes it available to the PAC clients. Additionally, the PAC clients support the collection of data which is manually entered by the construction supervisors. This data, for example the lighting conditions or the soil class encountered during the operation of the excavator, can be used for analysis later on. In addition, the PAC component can deliver a graphical representation of the operating and down times of construction machines and a comparison between planned and actual performance parameters. Like fig. 5 illustrates, also a so-called path time diagram which shows the project progress can be supplied. In our example, the aggregate amount of excavation dependent on time is analyzed.

For further analysis, the data from the PAC can be transferred to a BI system by an extraction, transformation and loading (ETL) process. The BI level is described below. It is also possible to use an ERP interface. Thus the data from the PAC can be combined with the cost parameters of the ERP.

5.3 Enterprise Resources Planning (ERP)

ERP systems are widely used in the construction industry. Popular software products mostly offer powerful reporting tools. Additional data can be saved and processed by the ERP system: details of machine operators' wages, cost of fuel and related operating materials, cost of the machine itself (depreciation, interest charges and average repair charge rates), costs of wear and tear, and miscellaneous costs. It can be very useful to combine the collected performance data with these parameters and distribute the information by means of the ERP reporting components.

Additionally, the data can be analyzed by the project system, the controlling and the finance component. Actual cost figures which are based on the performance data for two following periods can be generated by the ERP-System (Rausch et al. 2008). Currently comparisons of expenses types of cost centers are implemented. As seen in fig. 6, negative deviations are highlighted.

Contract/Group	100240	Project 944474		
Period	1-12 2010			
Cost Type	ACTUAL	PLAN	Dev (abs)	Dev (%)
400000 Wages	33.256,00	31.278,00	1.978,00	6,324
400001 Social costs	32.873,00	30.435,00	2.438,00	8,011
400010 Building materials	48.877,00	46.856,00	2.021,00	4,313
400080 Operating supplies	42.212,00	43.255,00	-1.043,00	-2,411
400444 Machines	64.429,00	63.920,00	509,00	0,796
Sum Costs	221.647,00	215.744,00	5.903,00	2,736

Figure 6. Example for an ERP report

Moreover, it is possible to distribute the analysis results to mobile clients, such as notebooks or mobile phones, for persons needing such information. Additionally, BI tools can be supplied with data by the ERP system.

5.4 Business Intelligence (BI)

The BI level mainly addresses decision-makers and controllers. The collected data is stored in a data warehouse. So analysis can be reproduced. The EPOS BI system offers many valuable reports. Two selected examples are presented in this paper. The first uses uptime information of excavators or excavator types to calculate the level of utilization of the excavators (fig. 7).

	EPOS_Betriebsdauer_B ⇕	EPOS_Ausfallzeit_Bag ⇕	Produktive Baggerzeit ⇕
EPOS_DIM_Fahrzeuge ⇕	HR	HR	
320BL	251,0	56,0	0,8176
325BLN	10,0	0,0	1,0000
325CLNVA	241,0	62,0	0,7954
350 BLII	224,0	75,0	0,7492
350LME	244,0	54,0	0,8188
A316 LITRONIC	255,0	67,0	0,7919
R904 STD LITRONIC	470,0	117,0	0,8007
R914 B HDSL LITRONIC	259,0	70,0	0,7872
R914 HDSL LITRONIC	207,0	55,0	0,7901
R932 HDSL LITRONIC	221,0	59,0	0,7893
Overall Result	2.382,0	615,0	0,7948

Figure 7. BI system: key figure "productivity"

The report contains the productive usage rate (PUR_i) of construction machines (right column). It is the result of the productive usage time pt_i (left column) divided by the total amount of available time which is the sum of pt_i and the idle time it_i (middle column):

$$PUR_i = pt_i / (pt_i + it_i) \quad (1)$$

When the PUR of a deployed construction machine under-runs a certain threshold for a long period, it could be a hint that a performance-based maintenance is necessary or that the machine should be replaced. Further analysis whether special machine types have more down times compared to others can be also helpful.

Another example for an interesting report which is also based on a multidimensional Online Analytical Processing (OLAP) analysis considers the key figure costs per cubic meter excavation material. It can be analyzed depending on the project specific environment, for example the soil conditions. As a possible finding it may be concluded that the costs of projects which have to cope with difficult soil conditions like rocky ground are generally much too high compared to other projects. Hence it should be analyzed whether the construction machine inventory is not ideal for this type of projects. It might be advisable to purchase specialized equipment.

So important information is generated automatically and distributed to all stakeholders. The information is also accessible by mobile devices. Managers and controllers are enabled to identify trends early so that they can take prompt action in terms of corporate performance management, and the variety of possible reports can increase the basis of information for decisions.

6. Further Developments

So far a complete information chain to deliver a detailed view of excavators' performances in the earth moving and road construction industry has been established. However, there are still many ideas to extend the scope of the intelligent performance and cost analysis. On the one hand additional reports on different levels (BI, ERP and PAC) could be developed. These reports could provide further performance or cost analysis. On the other hand the scope could be extended by additional data. More interesting data could be supplied by the "virtual construction site" system (VCS). VCS is the result of another research project which aims to adapt concepts and practices of modern industrial organizations, their production technologies and logistics systems to those of the construction process (TUM 2009). Its basic idea is to collect data from different phases of a construction project, which is transferred to virtual landscapes. Further information about VCS can be found in (TUM 2009). Apart from that the integration of other equipment such as bulldozers, trucks etc. would be desirable. The technical issues would be challenging but, as already mentioned in section 1, much progress has been made during the last decade. Based on that data the analyzing components can be extended.

7. Conclusions

The environment of the European construction industry is challenging. To be a successful player in the market, controlling costs and performance is crucial. This paper presents a new generation of controlling systems for the earth moving and road construction industry. It fills the gap between the strategic and the operational levels by offering intelligent performance and cost analysis. The corporate performance management approach provides different stakeholders, for example construction supervisors, managers, or controllers of construction companies with valuable information. The information is mainly based on data of a satellite supported machine guidance system which delivers real time operating data of construction sites. This data is combined with other data, for example data from ERP systems, to enable intelligent analysis. Hence measuring of performance and information supply is considerably improved. The data is very useful for planning and preparing of construction work. A permanent comparison of the actual and the planned performance can play a very important role in completing projects on time and avoiding contractual penalties. Additionally, construction supervisors and managers also benefit from cost transparency. Processed cost parameters can be very helpful for post-calculation of projects. They can also be important for calculating subsequent bids for similar construction projects. In section 5.4 it was shown how intelligent cost analysis helps to avoid future costs.

The project was finished on time in September 2010 providing all the features which were on the project's schedule and described in this paper. The results can help the construction industry to cope with the challenges mentioned and encourage further developments.

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