Design and implementation of automated, mobile construction projects monitoring system (MEVMS) based on Earned Value Management as an element of BIM in the execution stage

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Abstract

Polish construction market received huge amount of European Union funds during years 2007-2013 and will receive even more during new budget perspective 2014-2020. Case studies of the most important and valuable Polish construction projects especially in the Design and Build formula (e.g. highways, Warsaw Metro) show that it is very difficult to finish projects on time and within planned cost. New high-efficiency mobile tools for cost and schedule monitoring are needed in order to increase profitability of construction projects. As a response to this requirements the Mobile Earned Value Monitoring System (MEVMS) was developed and implemented in one of the office construction projects in Poland. New tool is an element of BIM and uses mobile computing technologies. Project manager can use mobile devices (smartphones, tablets etc.) to enter cost, schedule and progress data to the EVM monitoring system. The core of the system receives input data and calculates EVM progress indicators e.g. Budget Cost of Work Performed (Earned Value), Actual Cost of Work Performed, Cost Performance Index, Schedule Performance Index, Estimated Cost at Completion and Estimated Time at Completion. Different users have authenticated access to the MEVMS system and can observe project performance reports “online” using mobile devices. The summary of the paper presents effects of the system implementation, other application possibilities (e.i. keeping record for claim management) and further possibilities of system upgrading (Augmented Reality).

Keywords: Building Information Modeling (BIM), claims, Earned Value Management (EVM), mobile computing, project monitoring.

1. Introduction

The dynamic development of the construction industry in the beginning of the twenty-first century, manifesting construction of higher, bigger and more complicated structures in connection with the necessity to minimize cost, time and fulfill the conditions of sustainability require the use of new, more efficient tools in construction project management. A high level of complexity of the project, wide scope of works, high level of specialization, frequent and significant changes in the design documentation and technology make it very difficult to efficiently manage construction projects without modern tools for the design, execution and information exchange. Building Information Modeling seems to be a response to the needs of present and future construction projects. Case studies of the largest construction projects carried out in Poland in recent years show that often construction costs and realization time are exceeded. Due to the reasons listed above there is a need to implement efficient monitoring system of the construction works progress and cost in the execution phase of construction projects. In this paper the Mobile Earned Value Monitoring System (MEVMS) of construction works was introduced which can be an element of Building Information Modeling. Case study with the system implementation was conducted on the office construction site in Poland.

2. Earned Value Management description

The aim of Earned Value Management is the effective monitoring of the project performance and progress with regard to time, cost and scope. This method is a tool that analyses the project performance factors and forecast project future performance. This method can also be applied to the already finished project in order to show analytical and graphical characteristics of its time and cost performance.

Essential features of EVM are listed below:

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• PV (Planned Value) – planned cost according to the financial schedule;
• EV (Earned Value) – project progress measured as a planned cost of work performed until the date of inspection;
• AC (Actual Cost) – real, actual cost of work performed;
• BAC (Budget At Completion) – total planned cost of the project.

PV, AC, and EV are function of time and can be presented in the form of figures on a graph. PV figure is created in the planning phase of the project, while the AC and EV figures are determined on the basis of data collected during the monitoring of the project.

Data from graph figures AC, PV and EV is the basis for the calculation of further indicators. They can be divided into two groups: indicators that are used to monitor project actual progress and indicators that are used to forecast further costs and progress basing on results already achieved.

2.1. EVM monitoring indicators:

Cost Variance

\[ CV = EV - AC \]  \hspace{1cm} (1)

Schedule Variance

\[ SV = EV - PV \]  \hspace{1cm} (2)

Cost Performance Index

\[ CPI = \frac{EV}{AC} \]  \hspace{1cm} (3)

Schedule Performance Index

\[ SPI = \frac{EV}{PV} \]  \hspace{1cm} (4)

2.2. EVM forecast indicators:

Estimated Cost at Completion

There are optimistic and pessimistic indicators, which depending on the assumed relationship between planned and actual costs have different forms.

If the project cost is lower than planned (CPI > 1):

\[ EAC_{OPT} = \frac{BAC}{CPI} \]  \hspace{1cm} (5)

\[ EAC_{PES} = AC + BAC - EV \]  \hspace{1cm} (6)

If the project cost is higher than planned (CPI < 1):

\[ EAC_{PES} = \frac{BAC}{CPI} \]  \hspace{1cm} (7)

\[ EAC_{OPT} = AC + BAC - EV \]  \hspace{1cm} (8)
Estimated Time at Completion

\[ ETTC = ATE + \frac{OD - (ATE \cdot SPI)}{SPI} \]  

(9)

where:

ATE – time from the beginning of the project until date of inspection
OD – project planned time of realization

3. Mobile EVM monitoring system description

According to the actual Code of Construction Law in Poland there are 4 participants of construction process: Client, Client’s Inspector, Design Team and Site Supervisor. For the Client it is very important to receive accurate and reliable information concerning work schedule and cost as quickly as possible. From the Contractor point of view it is not so important and sometimes even undesirable when these information are unfavorable. In conclusion the mobile EVM monitoring system was designed that could be used by Client’s Inspector to increase quality and speed of monitoring schedule and cost on a construction site.

Mobile EVM monitoring system framework is presented on figure 1. All the system modules can be divided to 3 key groups:

- system input (green color) – data collection, initial analysis and transfer to the system core;
- system core (red color) – a platform receiving and processing data from the system input;
- system output (yellow color) – data transfer to the Client.

The participants of this structure are: Client, General Contractor (including subcontractors), Design Team and Client’s Inspector. Client commissions execution of works that are conducted by General Contractor and the Design Team. In order to supervise the works in terms of schedule, cost and quality Client employs Inspector. EVM mobile monitoring system can be a valuable tool for Client’s Inspector.

First part of the system implementation is developing the system core – a platform where the data can be stored, processed and accessed remotely (using mobile cloud computing). The decision should be made which parts of the construction process will be monitored by the system. Design documentation including time schedules, cost plans and drawings should be carefully analyzed and entered to the calculation sheets of the core. It is more convenient to perform this stage with the use of desktop computers or notebooks rather than small mobile devices. Complete system core should have all planned data entered – Budget Cost of Work Scheduled for the whole time of realization. Also cells, formulas and charts of EVM factors for future data entry should be prepared at this stage.

When the construction starts system input is used for real-time data collection from a construction site. Each time the inspection is made Budget Cost of Work Performed data should be entered with the use of mobile devices (smartphones, tablets, notebooks etc.). Mobile devices must have access to the system core via internet. Data entry can be done daily, weekly or monthly depending on the type and scope of monitored works. Data concerning Actual Cost of Work Performed can be put rather after billing period is finished – then regular and additional cost can be assigned to particular works. System core should have built-in error detection that signals obvious data errors for example entering finish time earlier than start time. The system core engine automatically processes data that is entered during inspection. As an effect EVM indicators are calculated and EVM graphs are created in the system core.
System output allows Client to have a real-time access to the mobile EVM monitoring system. Access to the cloud platform with system core is granted through personal login and password. With the use of mobile devices with internet connection Client can see an up-to-date schedule and cost monitoring of the ongoing project. Client could also receive electronic reports of monitoring and alerts when EVM indicators have critical values or significant changes. In that way Client can quickly react to schedule disruptions and cost overruns.

4. Case study

Mobile EVM monitoring system was implemented on a construction of an office building in Warsaw. The building will have 2 underground and 5 overground levels, dimensions in plan 73x33m and the height 20m. Main construction elements will be reinforced concrete and the foundation on diaphragm walls with foundation slab. The monitoring included structural elements (slabs, walls, columns, beams) and has been started on 1st January 2014. The system core was placed on 2 different cloud platforms – Google Drive for smartphone Samsung S3 Mini and Microsoft OneDrive for Nokia Lumia 625. The results of the first 4 months were presented in this paper. Main indicators of EVM was presented in figure 2. MEVMS mobile data entry on a construction site was presented on figure 3.

Figure 1. EVM mobile monitoring system framework.

Figure 2. Mobile EVM monitoring system core table with indicators.
MEVMS analysis showed that EV was higher than PV during almost whole time of the monitoring only without the period from 16th March to 3rd April 2014. It showed that during most time the project was ahead of schedule (max. SPI=1.33). AC was equal to EV because there were no cost overruns (CV=0; CPI=1.00; EAC=const.). Unfortunately there were signs of rush observed during inspections and their negative influence to the quality of the elements: concrete cracks, not proper concrete cover and reinforcement arrangement.

5. Summary

The paper presents innovative way of Earned Value Management application to the construction project. Mobile Earned Value Monitoring System (MEVMS) seems to be a valuable tool for Clients to execute real-time control of time and cost performance. However in the next step the system should be upgraded. Data entry using standard smartphone spreadsheets can be sometimes inconvenient on a construction site. In conclusion the professional mobile application with voice commands should be developed that imports time and cost data from BIM model. The system core communication with the Client could be more effective by sending reports and alerts automatically when EVM indicators values are extreme. Also photos and voice commands from the inspections could be added and Augmented Reality application could be considered. Further works on upgrading MEVMS will be performed on Civil Engineering Faculty at Warsaw University of Technology.

References

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