Automated Project Performance Control (APPC) of construction resources

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ABSRACT: Real-time control of on-site construction is a growing field still in its infancy. A model for automated control was developed, implemented and validated in the field, to verify if Project Performance Indicators (PPI) can be automatically measured and controlled. The concept behind this development is that indirect data – locations measured automatically at regular time intervals – can be collected automatically and converted into PPI using computerized algorithms. The model was implemented in a concept-proving prototype for productivity measurement. The prototype was tested in four construction projects – three buildings, and one road – to validate the concept and test the feasibility of developing a full-scale prototype. The encouraging results of the field experiments confirmed that it is possible to convert the locations, automatically measured at regular time intervals, into productivity, and thus automatically control them. The expected accuracy of such a system is ±10-20% for building construction and ± 4-5% in road construction.

KEYWORDS: Automated Data Collection; Control; Manpower; Monitoring; Performance Measurement

1. INTRODUCTION

Real-time control of on-site construction, based on high quality data, is essential to identify discrepancies between *desired* and *actual* performances. Such control enables timely *corrective measures* to be taken when needed and, consequently, a reduction in damages caused by the discrepancies. The longer it takes to identify discrepancies, the more serious the potential damage is and the more complex and costly the corrective measures will be.

The performance is measured in terms of project performance indicators (PPI), such as cost, schedule, quality, labor productivity, materials consumption or waste, etc. The role of the control system is to identify the discrepancies – the construction manager then identifies the causes for the deviations and, accordingly, decides about appropriate corrective measures. Accurate data is needed not only to control current projects, but also to update the historic database. Such updates enable better planning of future projects in terms of costs, schedules, labor allocation, etc.

Project engineers and managers, involved in construction, spend a disproportionate amount of time collecting and processing construction data, typically causing the construction manager to be distracted from the more important task of supervising and controlling the project [McCullouch]. Because current data collection methods are expensive and time consuming, many construction companies do not collect detailed data and even less in real-time. Consequently current methods do not enable corrective measures to be taken in time to mitigate the damage to the ongoing project. Corrective measures can be effective in the ongoing project if they are taken in real time, or shortly after the deviation occurs. Sometimes project managers and/or foremen do perform some control on-site, but this is normally not done in a systematic way and may be done at long time intervals. Consequently, decision-making may sometimes be based on intuition.

The construction industry is changing – projects are becoming more complex and sophisticated. Consequently, controlling them is becoming more difficult, but at the same time, more needed. Data collection technologies, enabling faster and more accurate data acquisition, are beginning to be used by the industry. Many efforts and achievements have been made to model construction projects, enabling the integration of computerized design and construction functions. Additionally, automated data collection techniques have emerged, which can be used for real-time data collection [Ciesielski]. The declining cost of hardware allows the use of automated data collection (ADC) technologies in real-time control systems.

2. PROJECT PERFORMANCE CONTROL

Project performance control can be defined as the identification of deviations between the desired and the actual performance of a project. The problem with this definition is that it is difficult to determine the desired values for project performance indicators. This is due to the diverse nature of construction projects where even 'identical' projects are normally built under different conditions.

A comparison between the desired and the actual performances is the beginning of the control procedure. When a deviation is detected, the construction management analyzes the reasons for it – the deviation can be schematically divided into two groups: (a) unrealistic target setting (i.e. planning), or (b) causes originating from the actual construction. (In many cases the causes for deviation originate from both sources.) If the deviation is caused by the actual construction, the construction manager analyzes the reasons for it and takes corrective measures that will bring the actual performance as close as possible to the desired one. Consequently, the definition of the desired performance is very important. Normally the tendency is to equate the desired performance with the planned one because it increases predictability and reduces uncertainty.

When the deviation is caused by unrealistic target setting (plans), the latter and the historical database have to be updated. This approach, where initially the desired performance is the planned one but as the project progresses, after analyzing the actual performance, the desired performance changes accordingly is called *Adaptive Control*.

Effective control needs two types of information in real-time: (a) a list of the activities to be performed on the given day, broken down in terms of PPI. (b) Measurement of the actual performance in the same terms. The first type of information is automatically extracted from the Project Model – PM [Sacks et al.], which has up-to-date project planning and design data. The best way to measure the actual performance in real-time economically is by automating it.

3. AUTOMATED PROJECT PERFORMANCE CONTROL

The main challenge today in automating the control process is the automated measurement of the performance indicators. There are many examples of measuring devices, which evaluate a given parameter indirectly, e.g. analogue thermometers, which actually measure changes in volume and translate them to temperatures; scales, which measure displacements and transform them into weights; Global Positioning Systems (GPS), which measure time-of-flight of a signal from known reference stations and calculate positions. The same approach is used here for automated PPI measurement – the values of some indirect parameters are measured automatically and converted into the sought value of the PPI by special algorithms.

3.1 Conceptual Framework

The basic concept behind the selection of the indirect parameter is the fact that to construct a building, a road, or any other facility, the 'construction agent' – worker or equipment – has to be close to the constructed elements. Therefore, knowing the construction agent's location at a given time, together with additional information (automatically extracted from the PM), the activity, in which the construction agent is engaged, can be determined. Consequently, it is possible to determine what the construction agent is doing at all times by automatically measuring its locations at regular time intervals. A variety of technologies can measure locations (e.g. GPS), and others can be developed on the strength of off-the-shelf technologies (e.g. Radio-Frequency based measuring techniques).

3.2 Principles

A control model determines what a construction agent is engaged in at the time the location is measured. The model associates the measured locations to a construction activity, or activities, on the strength of their vicinity to the construction elements correlated to the activity. This process will be explained for a case study of wall painting (Fig. 1).

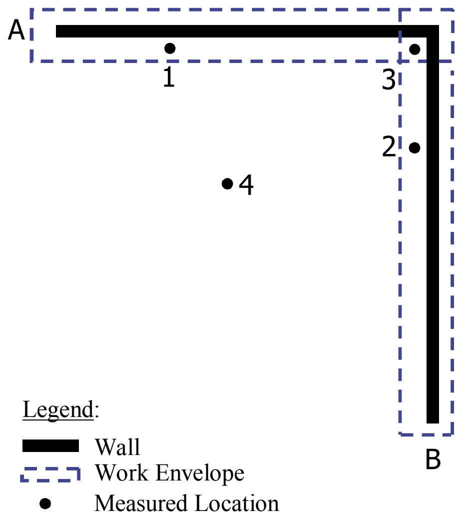

Figure 1: Geometrical Association

A work envelope (WE) is defined to assist with the association of locations to construction elements: it is a *volume in space where a construction agent, working on an element, could be located*. The shape and type of a WE depends on the nature of the activity, the type of element and the construction technology. For example, the WE of the wall painting, depicted in Fig. 1, is a prism of approximately the wall's planar measurements with a width, which is determined by the technology. Thus, if a measured location is enclosed within the WE, it is associated with the appropriate activity. In the present example, location 1 is associated with painting wall 'A', and 2 with wall 'B'. This process is called Geometrical Association (GA).

Locations number 3 and 4 are more difficult to associate, because location 3 is enclosed within two WE and location 4 is not enclosed within any. Such locations are associated, at a second stage, by an algorithm called Logical Association. The latter uses decision rules, which are based on work continuity, on crew affiliation, or on statistical considerations.

3.3 Concept Proving

The idea was examined in two stages: (a) checking the basic concept – i.e. that the activity a construction agent is performing can be determined knowing its location. (b) Applying this concept to control earthmoving equipment in road construction.

Simulated field experiments carried out for the first stage, in three building construction sites, verified the concept. In each of these experiments c. 10 activities were checked by simulating location measurement at regular time intervals. The measured locations were fed into a computerized algorithm that determined which activity the workers were engaged in, for each measuring cycle. A comparison with what the workers actually did (determined by parallel manual measurement) confirmed the concept. The accuracy level of the simulated measurement was ± 10-20% – a detailed report is given in [Navon 2003a].

The model was realized in a prototype system, to control earthmoving equipment in road construction, and tested for three weeks in a road construction site. The productivity of four activities was measured with the system and, at the same time, it was recorded manually so that the accuracy of the model could be assessed. A GPS was mounted on each of the pieces of equipment performing the controlled activities. At the end of a working day, the data recorded by the location measurement system was post processed and transferred to the prototype system for productivity calculations. The latter was compared to the calculations based on the data collected manually.

The comparison between the output of the prototype and what was actually performed indicates that an accuracy level of ± 4-5% can be expected in automated control of earthmoving operations – a detailed report is given in [Navon 2003b].

4. CONCLUSION

Traditional project performance control is usually generic (e. g. cost control techniques). It depends on manual data collection, which means that it is done at low frequency (normally once a month) and quite some time after the controlled event occurred (i.e. not in real-time). Moreover, manual data collection normally gives low quality data and is error prone.

Automated Project Performance Control is a novel approach, still in its infancy. It shows real potential to provide effective control of construction projects, thus solving an acute problem in construction management.

5. REFERENCES

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