A COMPUTER BASED SYSTEM FOR DOCUMENTATION AND MONITORING OF CONSTRUCTION LABOUR PRODUCTIVITY

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ABSTRACT: Improving labour productivity is one of the most significant areas that may result in competitive advantage for construction companies. This requires continuous monitoring, documentation and measurement of factors like quantity of work, site conditions, work conditions and crew characteristics. Time study is a systematic approach that can be applied by the site management to achieve these goals. However, various numbers of tasks to be undertaken are time/cost consuming and may seem to be a burden to the site management. Thus, a computer based system is a requisite for the long term success of the applications.

Literature discusses the advantages and disadvantages of three widely used systems for documentation and monitoring of labour productivity on site. This article introduces a novel computer based system for documentation and monitoring of construction labour productivity. The system not only provides a user friendly environment for documentation and monitoring of construction labour productivity but also undertakes various statistical analyses. The future work includes development of a neural network module.

KEYWORDS: construction labour productivity, time study, programming, documentation, monitoring.

1 INTRODUCTION

Continuous process improvement is an essential factor of competitive advantage for the contemporary organisations. For construction works, one of the most significant areas that continuous improvement can be achieved is the minimisation of waste in terms of labour productivity. In order to succeed, a structured and systematic approach to collect and analyse labour (crew) productivity data is essential. 'What to measure' and 'how to measure' are the key questions to be answered. Use of computer based systems that assist the site management in answering these questions and collecting and analysing the related data is thus a perquisite for time and cost effectiveness of these implementations.

After Egan report in 1998, British construction companies focused on implementing monitoring systems. The companies utilised either their own systems or standard monitoring systems like Calibre, Activity Based Planning and ImPACT (Cook, 1999). While literature shows no further studies related with the development of standard monitoring systems, the pros and cons of these three systems are summarised as follows.

1. Calibre, developed by BRE, requires the use of Psion palmtop computers and consultants' observers to identify the work plans and how long different tasks take (Cook, 1999). The observers monitor the work done by each labour by categorising the work into four main categories; value adding, statutory, support and non value added work. Courtney (1999) states that it costs 100 pounds per observer per day and two observers for every 100 operatives are recommended on site. Thus, although the developers of CALIBRE claim to save up to 12% of costs, the operating costs are expensive and CALIBRE is defined to be 'bureaucratic' and to be using 'excessive amount of information'.
2. Activity Based Planning, developed by Mace, is based on proformas filled by subcontractors at the beginning of each week and reported to be lacking detail. Meanwhile, it is reported to be much cheaper and simpler to operate than CALIBRE, i.e. costs about 100 pounds per month.
3. ImPACT is based on a traditional clipboard and stopwatch time-and-motion study. It uses a large amount of data during analysis and provides feed back for the next project. It is reported to save 5% costs. However, consultant costs are 500 pounds per day which is the most important con of the system.

A concluding remark can be made from the above discussion that it is not practical to spread the use of these monitoring systems to other countries like Turkey, mainly due to high costs of consultants for operating the systems. Literature supports this fact as there are no articles related with the applications of these systems in any other countries. Thus, the aim of this research has been to develop a user friendly computer based system which will not require any specialist expertise for documentation and monitoring of construction labour productivity.

2 A SYSTEMATIC APPROACH TO MONITORING LABOUR PRODUCTIVITY ON SITE

Construction productivity can be calculated in a number of different ways like the ratio between output and work hours or the ratio between work hours and output where; the first one is more commonly used as called ‘production rate’ (Sönmez and Rowings (1998)). When the site management decides to monitor labour productivity on site there are a number of activities that have to be organised as a ‘time study’. Time study includes:

1. Defining the work: The first step for undertaking a systemised time study is to define the work. Definition of the work should guide the site management on when the labour will be observed and what will be measured.
1. Identifying the duration of the observations: In manufacturing industry duration of the time study observations may even be in minutes. However, for construction works, as time and cost schedules or overruns are mainly calculated on daily basis, a daily basis observation would quite be satisfactory. (Thomas and Daily (1983))
2. Identifying required number of observations through a pilot study: After defining the work and the duration of the observations, it is time to observe the productivity of the crew. At this point, an important question about the required number of observations arises. A pilot study of between 5 to 10 observations then have to be carried out in order to determine the statistically valid number of observations required (Equation 1).

$$N' = \left(\frac{40 \cdot \left(N \cdot \sum X_i^2 - \left(\sum X_i \right)^2 \right)^5}{\sum X_i} \right)^2 \quad \text{(Kobu (1999))} \qquad (1)$$

N’: Required number of observations within 95% confidence interval.

N: Number of observations during the pilot study.

X_i: Unit output of the related labour (crew) during the i.th observation.

3. Observing the labour crew and measuring the quantity of the work: Once the work is defined clearly and broken down into components it is straightforward for the site management to collect data about the amount of time spent by the labour crew on the related work and the quantity of work completed. However, additional information on factors affecting the labour productivity during the observation time should also be recorded in order to arrive at realistic results.
4. Observing the factors affecting the labour productivity: Various authors like Sönmez and Rowings (1998), Assem (2000), Moselhi et al. (2005), Thomas and Napolitan (1995), Akindele (2003), Jonsson (1996), Winch and Carr (2001) discuss the factors influencing construction labour productivity. These can be grouped as labour related, work related and site management related factors. Labour related factors are age, education, experience, working hours, payment method, absenteeism and crew size. Work related factors are location of the site, location of the work on site, the type and the size of the material used and the weather conditions. Site management factors are site congestion, transport distances, and, availability of the; crew, machinery, materials, equipments and site management.

3 THE DEVELOPMENT OF THE COMPUTER BASED SYSTEM

3.1 *The content perspective*

Monitoring and documentation of the labour productivity on site, as discussed in Section 2, requires various tasks to be undertaken by the site management, which can be perceived as time and cost consuming and may not be effectively implemented unless a user friendly documentation system is applied.

Turkish construction industry, like most of construction industries in other developing countries, is dominated by reinforced concrete high rise building construction works. Thus, presenting the work items of reinforced concrete construction in a monitoring and documentation system would address the need of about 90% of construction companies (Paksoy, 2005). Therefore, the aim of the current study has been to develop a user friendly system that can easily be used by the site management in reinforced concrete building works . 45 time studies were carried out for concrete work, formwork, steelwork and masonry work on a reinforced concrete office building project constructed by a large scaled Turkish construction company between the years 2004-2006. During this period, details of both the monitoring and the documentation of labour productivity data/information have been revised continuously with the site engineers. It was first identified that definition of the work should be in the form of dividing the work items into sub activities (Table 1). Otherwise, different measurements were carried out by different or even the same observers. The definition of some of the work items included within the developed model is presented in Table 1. (Scaffolding, painting, plastering and slab covering are the other work items that have been included in the model.)

Table 1. Definition of the work items.

	Definition of the work item
Ready mixed concrete work	*Pump from the transmixer* *Vibrate the concrete* *Level the concrete* *Protect the concrete from hot/cold* *Water the concrete* *Take samples for the quality control of the concrete*
Timber Formwork	*Carry the scaffolding* *Erect the scaffolding* *Grease the formwork* *Dismantle the formwork* *Clean the formwork* *Dismantle the scaffolding*
Steelwork	*Unload the steel from the trucks* *Carry the steel within the site* *Cut the steel* *Bend the steel* *Lay down the steel*
Wall elements	*Carry the wall elements vertically/horizontally* *Prepare the mortar* *Build the wall* *Water the wall*

During the site studies, it has been observed that while some labour work for 8 hours, some labour work more / less due to the reasons like carrying the material before hand, leaving work earlier, watering the surface after the 8 hrs work and so on. From these findings, it has been concluded that, for the observations to be realistic, documentation should provide the working duration of each labour separately. 'Daily observation' sheets are thus designed in order to record the amount of material used, quantity of the work done and the amount of the time spent by each labour on each work item except formwork and steelwork items . A 'daily observation' sheet for masonry work is given in Figure 1 as an example.

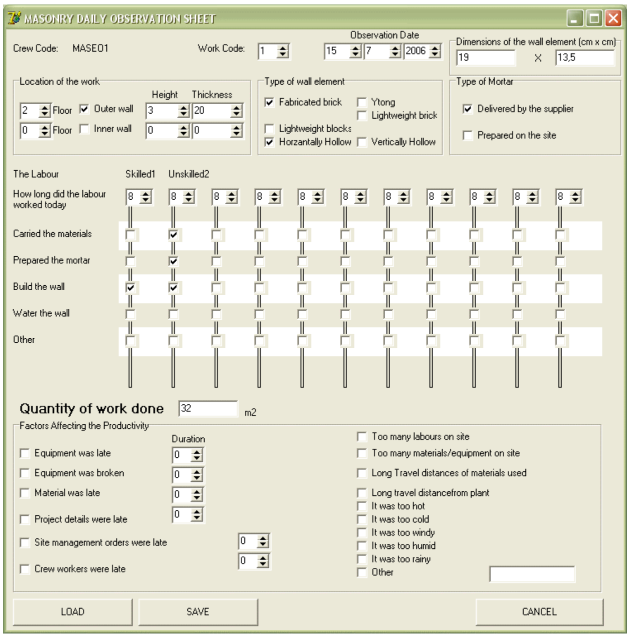

Figure 1. 'Daily observation' sheet for masonry work.

The site experience for formwork and steelwork has shown that it usually is not practically possible to measure the quantity of work done or quantity of materials used during 'one day' observations. Duration of an observation has to be calculated when the measured amount of material (i.e. formwork, steel) is completely used. These required two different sheets to be produced for documenting productivity data (see Figure 2 and Figure 3). 'Daily activities' sheet is used to document both the working hours and the work done by each crew member during each day of work for formwork and steelwork items. 'Observation' sheet is additionally presented for the input of total amount of material used, total quantity of the work done and total amount of the time spent on the work by the crew.

Work and site management related factors affecting the labour productivity are also presented on 'daily observation' and 'observation' sheets (see Figure 1, Figure 3 and Table 2).

Table 2. Work related productivity factors included in the model.

Work item	Work related productivity factors
Concrete pouring	The location of the work, weather conditions, the capacity and the number of the transmixers used, the transportation system of the ready mixed concrete(dry/wet), the power of the pump or the capacity of the crane buckets, the distance between the concrete plant and the construction site
Formwork	The location of the work, weather conditions ,the type of the foundation or the type of the slab, the slab area or the floor height, the type of the formwork (plywood/timber/steel), the type of the scaffolding (steel/timber)
Steel work	The location of the work, weather conditions, the type of the foundation or the type of the slab, the form of the steel when it arrived to the site (cut/uncut/bent), the size of the steel used, the type of the equipment used (bending machine/cutting machine)
Masonry work	The location of the work, weather conditions, the thickness and the height of the wall, the type of the wall elements (brick/block/lightweight block), the size of the wall elements

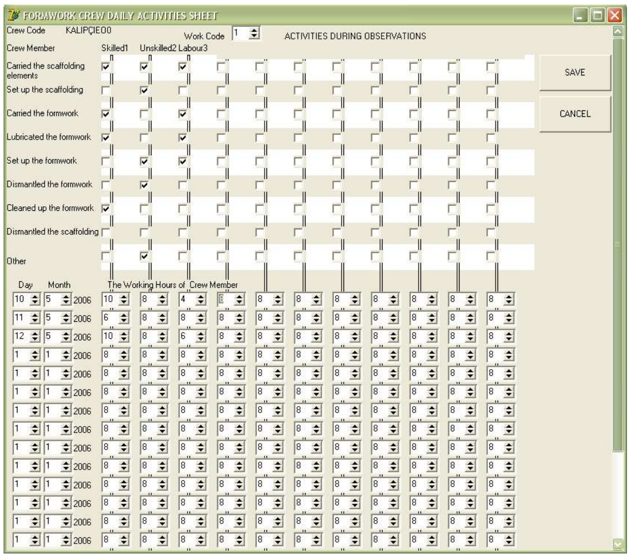

Figure 2. 'Daily activities' sheet for formwork.

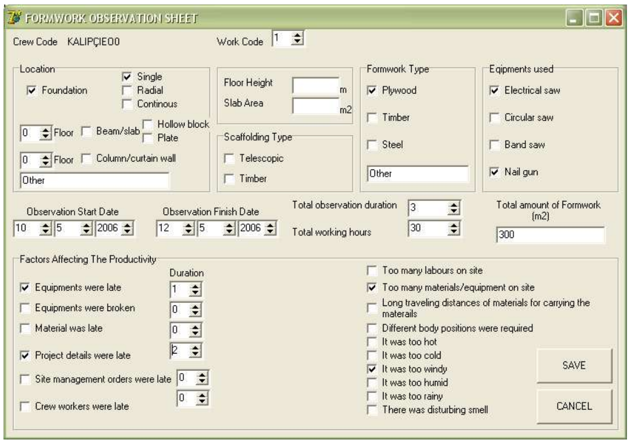

Figure 3. 'Observation' sheet for formwork.

A separate sheet called 'crew information ' is also available to record labour related factors like the age, the education, the experience, the working/non working hours, the payment method, the absenteeism , the crew size, the extent of supervision on the site and the travelling distance between the residence of the crew members and the construction site. Figure 4 presents a typical ‘crew information’ sheet.

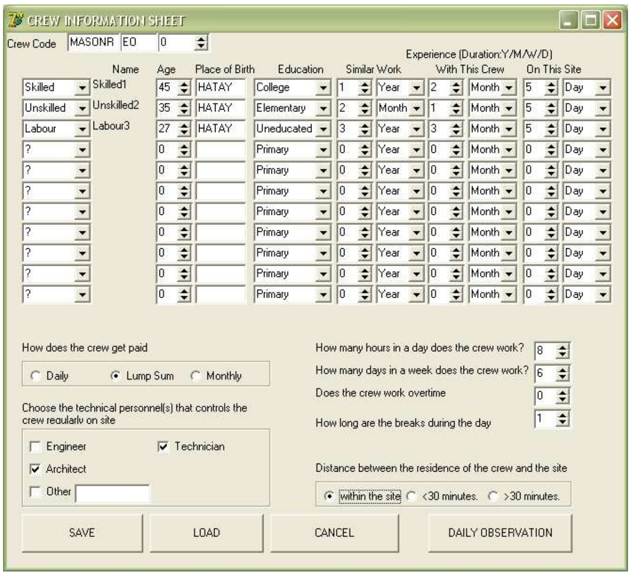

Figure 4. A typical ‘crew information’ sheet.

3.2 *The programming perspective*

The developed system can be divided into two main sections; ‘Data Acquisition’ and ‘Data Analysis’ (see Figure 5). Data Acquisition section employs a dynamic form generator. Dynamic form generator is responsible for creating user friendly sheets for the work items. A typical ‘crew information’ sheet (Figure 4) has a standard layout for any work item. The sheet is facilitated with list boxes, spin edits, radio buttons and check boxes to avoid typing as much as possible. A unique identification tag is attached to each ‘crew information’ sheet for the association of the same crew’s daily observations and activities data. ‘Daily observation’, ‘daily activities’ and ‘observation’ sheets are the other three types of forms that their layouts differ for each work item. Each crew may have more than one set of observation and activity sheets. Each of these activity and observation sheet sets are identified with a work number and strongly linked to its crew information form. All of the forms produced by Dynamic Form Generator can be edited or destroyed at any time by the user. In the case of multiple observations or activities of a crew, the crew information is not duplicated, instead the crew code is inserted into the observation and activities sheet. This behaviour provides great flexibility for the management of data.

Data Analysis Section, on the other hand, is responsible for ; identifying the required number of observations, identifying production rates, undertaking correlation and regression analysis between productivity rates and different site/work/labour related conditions. The work items and the sheets that contain input data for the analyses should be identified before processing the statistical analysis. Data Merger and Extractor Module is employed for combining the work items from various types of sheets for each crew as well as whole data set. Individual work items can be marked on the dummy sheets for filtering out the necessary information from the sheets. The user is, then, prompted for selecting the sheets that should be included in the analyses. The user may select either a directory or a collection of individual sheets. The output of the Data Merger and Extractor Module is comma separated text file that is a common format for many statistical software packages. Development of two different types of neural networks; Self Organizing Maps for the grouping of the input data and Back Propagation Error for the estimation of some items under various conditions, are planned for the future. The output of the neural network module will be supported and compared to those statistical findings of Statistical Analysis Module to generate the final report.

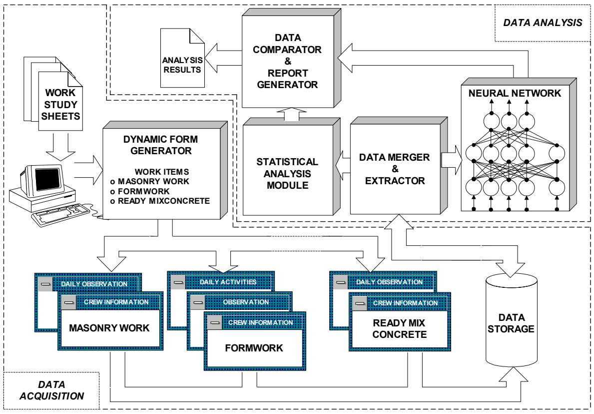

Figure 5. The programming structure of the model.

4 CONCLUSIONS

Substantial productivity changes can be achieved by continuous monitoring and documentation of labour productivity on site. Time study is a systematic approach to monitor labour productivity on site. However it may be an extra burden for the site management if a user friendly documentation system is not utilised. Literature shows three monitoring systems that have been used especially by British construction companies on site. A common disadvantage of these systems is the requirement of consultant(s) during the applications, which makes the systems expensive to operate. The aim of the current research, thus, has been to develop a user friendly monitoring and documentation system. The content of the system focused on reinforced concrete construction work and included the work items of ready mixed concrete, formwork, steelwork, scaffolding, painting, plastering and slab covering. While the structured and well defined content of the system may seem to be a disadvantage during implementations by the users looking for more flexibility, such a structured approach provides uniformity for analysis of the data from various observations.

Delphi programming language has been used to provide a user friendly interface. The system does not only have the data acquisition module for documentation purposes but also have data analysis module for statistical analysis. The future work will focus on development of the neural network module. Palm top applications of the system will also be investigated in order to provide direct data collection on construction site.

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REFERENCES

Akindele, O.A (2003), "Craftsmen and Labour Productivity in the Swaziland Construction Industry",CIDB 1st Postgraduate Conference, South Africa.

Assem I. (2000), "Estimating productivity Losses Due to Change Orders", Msc thesis, Concordio University. Montreal.

Construction Task Force (Sir John Egan) (1998), Rethinking Construction, UK.

Cook, A. (1999), "Made to measure (monitoring systems for construction sites)", Building, 264 (4), 46-47.

Courtney, R. (1999), "Letters", Building, 264(6), 35.

Jonsson , J.(1996), "Construction Site Productivity Measurements: Selection, Application and Evaluation of Methods and Measures", Phd. Thesis, Lulea University of Technology, Sweden.

Kobu, B. (1999), Üretim Yönetimi, Avcıol Basım, İstanbul.

Moselhi, O., Assem, I., El- Rayes, K.(2005), "Change Orders Impact on Labour Productivity. J. Construction Engineering and Management" 131 (3) , 354-359.

Sönmez, R., Rowings, J.E. (1998), "Labour Productivity Modelling with Neural Networks", J. Construction Engineering and Management, 124(6), 498-504.

Thomas, H.R., and Daily, J. (1983), "Factors affecting masonry-labour productivity", J. Construction Engineering and Management, 117(4), 626–644.

Thomas, R., Napolitan, C. (1995), "Quantitative Effects of Construction Changes on Labour Productivity", Journal of Construction Engineering and Management, 121(3), 290-296.

Winch, G., Carr, B. (2001), "Benchmarking On-Site Productivity in France and the UK: a CALIBRE Approach", Construction Management and Economics, 19 (6), 577-590.