DEVELOPMENT OF AN OPERATIONAL PARAMETER MEASURING SYSTEM

Antonio N. de Miranda Filho[1] and Emílio Araújo Menezes[2]

ABSTRACT

In search of a more comprehensive view of construction processes' true problems, this paper proposes an Operational Parameter Measuring System based on the principles of Lean Production. By measuring waste, activity rating, cycle time and cost, the System aims to provide accurate information to site management so that actions can be taken to correct the identified problems or to reestablish the process on its course.

In order to adapt Lean Production to construction peculiarities, a bridge was built between traditional practices and new developments. The Measuring System is in this way based on the integration of Activity Sampling and Activity Based Costing principles. The combination of both tools made it possible for the System to be conceived on the principles of focusing control on the complete process, increasing process transparency and building continuous improvement into the process.

The application of the Measuring System on the masonry process in a construction site during a period of 15 days allowed for the combined processing and information analysis of the performance measurements. This procedure pointed out opportunities for improvement and led to important conclusions about the influence of labor allocation on the increase of product costs and the occurrence of waste.

KEY WORDS

Lean construction, process control, performance measurement, waste control.

[1] Civil Eng., M.Sc, Lecturer at the Federal University of Ceará (UFC), Brazil, anmirandaf@yahoo.com.br

[2] Economist, PhD., Senior Lecturer at the Federal University of Santa Catarina (UFSC), Brazil, emilio@eps.ufsc.br

INTRODUCTION

Together with construction peculiarities and the lack of international competition, traditional construction management is pointed to as one of the main causes of the slow development of construction processes. Traditional construction management is based on the development of budgets, schedules and other requirements to be tracked and achieved by site management during project execution. According to Ballard and Howell (1997), planning at the beginning of the project is replaced by control during project execution.

Some problems due to traditional management practices are listed below:

- Ballard and Howell (1997) mention the lack of caution in making the established goals compatible with the resources available;
- Uncertainty and flow variations are usually not considered during planning. When they are considered, Ballard and Howell (1996) point out that there is an application of large time or resource buffers to assure flexibility;
- (Santos et al. 1999) comment that managers and workers often argue that measurements are not practiced in construction sites because it is a time consuming activity. Even when data is collected, very little time is spent on it's analysis;
- Alarcón and Serpell (1996) suggest that performance is strongly associated with a reward and punishment system. Besides, most traditional performance measurement activities are usually inadequate for measuring waste, value and variability;
- Another aspect mentioned by Alarcón (1997a), is that most models focus on a limited number of performance elements and they are restricted at some particular project phase or level.

Although costs and schedules have known importance, more comprehensive measuring tools are needed to sustain planning efficiency and controlling construction processes. Despite the limitations of traditional practices, traditional tools and performance indicators such as work sampling and utilization rates can be of great use in the effort for continuous improvement. Thus, Alarcón (1997a) suggests that it is important to build a bridge between traditional and new developments in construction performance improvement.

This study aims to provide building companies with an operational parameter measuring system based on the integration of traditional and new tools. The main objective of the combination of tools is to adapt Lean Production principles to construction peculiarities. The measuring system was developed following three guidelines: (a) provide feedback on process efficiency in short time; (b) adopt a broad definition of waste; (c) contribute to the application of Lean Production principles within the construction environment.

PERFORMANCE MEASUREMENT IN LEAN CONSTRUCTION

The operational parameter measuring system must support planning and controlling or reengineering business processes by measuring the current performance level and identifying improvement potential through benchmarking. (Tanskanen et al. 1997) summarize the requirements for lean construction controlling tools as following:

interactive way to process information; provide feedback on the actual trend of the performance of planned business process; support continuous improvement of performance; understand and specify the goals of planning and controlling; flexibility to fit different kinds of environments; graphical presentation of information.

Usually, lean construction control tools provide non-financial performance indicators such as variability and cycle time. However, Cooper and Kaplan (2000) add that these systems can be adjusted to contain an activity based sub-system capable of collecting financial information on resource costs consumed in the processes.

APPLICATIONS FOR PERFORMANCE MEASUREMENT

According to Koekela (1992), some authors argue for the need to tailor measurements closely to the requirements of the situation. A system developed for lean construction must attend site management’s needs by:

- Identifying current performance levels before any intervention is made in the process. A key element for process development, this initial diagnosis supplies information that will facilitate the posterior monitoring of changes;
- Controlling processes after the company has established performance patterns. With the establishment of these patterns through benchmarking the "best practices", the objective is to identify possible deviations that demand corrective actions;
- Comparing performance against a goal or established pattern or against its initial diagnosis. In this case, the objective is to verify the impact of improvement actions on the process.

LEAN PRODUCTION PRINCIPLES IN CONTROL SYSTEMS

The proposed measuring system must be capable of: providing better operational control; identifying potential problems; and supplying site management and workers with opportune information on process efficiency. In order to achieve this and based on conclusions drawn from previous studies (Koskela 1992; Ballard and Howell 1996; Alarcón 1997, 1997a), the measuring system must be conceived on three Lean Production principles:

- **Focus on complete process:** control must focus on the complete process making possible the analysis of global improvements. Performance measurements also have to give the company a clearer vision of its effectiveness in satisfying customers' needs and in the accomplishment of its work;
- **Increase process transparency:** measurements must detect the problems as they occur and identify critical situations before even becoming problems. Information, such as productivity and waste, can only be visible if data is collected and transformed into performance measures;
- **Build continuous improvement into the process:** measurements should monitor performance identifying deviations or showing it heading towards the established goal to support an attitude change of all employees.

DESCRIPTION OF THE OPERATIONAL PARAMETER MEASURING SYSTEM

The operational parameter measuring system is based on the integration of principles and concepts of two tools, work sampling, well known in construction studies, and activity based costing. One of the objectives of the integration is to supply site management with a wide range of information on the process. Thus, an adaptation was made in the way of collecting data through instantaneous observations, so that some performance measures could initially be obtained and then inserted in a costing sub-system to calculate others (Miranda Filho 2001). This procedure agrees with Ballard and Howell (1997), who believe that performance measures must be coherent and related in order to facilitate an integrated analysis of production planning.

The system was developed to focus control on the workers involved in construction processes and to analyze the effects of managerial decisions on their work. Although labor work is not the most expensive resource consumed in construction processes, it can be the objective of studies and improvement efforts due to the current technological stage of the construction industry. Many activities in construction (bricklaying, material movement, etc.) are executed manually by groups of workers. Besides, it is through the observation of the workers that certain flaws caused by managerial decisions can be more easily identified, such as an inadequate layout of the construction site.

PRESENTATION OF THE TOOLS

The technique known as work sampling is a visual way of obtaining data for control. It consists on regular or random instantaneous observations to estimate, with statistical validation, how labor or machine time is being used in construction. Because construction peculiarities cause variations on work patterns and process output, Harris and McCaffer (1989) say that this is the most suitable time study method for controlling productive efficiency in construction.

According to these authors, in construction work, activities by their very nature take a random time to complete and thus the observations can be taken at regular intervals. This turns the technique of work sampling into a very useful tool for measuring variability. The observations can also be used to identify the percentage of labor time spent on productive, contributive and non-contributive activities.

Activity based costing is a two phases method that allows management to know the costs of business processes and products. First, resource drivers are used to track resource costs consumed by activities in the process. Second, cost drivers are used to track the amount of each activity necessary to manufacture a product.

Koskela (1998) affirms that such approaches as activity based costing and process based organizations are intimately linked to the conceptualization forwarded by lean production. In fact, the benefits resulting from the use of an activity based costing system do align in concordance with some Lean Production principles as discussed below (Miranda Filho 2001):

- **Reduce the share of non value adding activities:** waste control is more accurate using an ABC system because it measures the costs of waste categories and allows the improvement efforts to be made directly on the activities;

- **Increase output value through systematic consideration of customer requirements:** the "new" activity based organization becomes more agile in fulfilling costumer and market requirements;
- **Increase output flexibility:** an ABC system allows the company to know the cost of customizing products for certain clients;
- **Increase process transparency:** activity based costing and management help the organization to obtain better information on activities and processes by turning visible its costs;
- **Focus control on the complete process:** the information provided by an ABC system gives management a better view on the consequences of actions taken on a process;
- **Build continuous improvement into the process:** an ABC system reveals inefficient processes, non-profitable products and customers, poor relationship with suppliers and badly designed products;
- **Benchmark:** activity costs can be added to make possible internal and external process benchmarking.

IMPLEMENTATION PHASES

The operational parameter measuring system can be used for identification of current performance levels, for process control and for verification on the impact of improvement actions. Whatever the purpose, a sequence of steps must be followed. For a better understanding, these steps will be described for an application of the system with the objective of determining an initial diagnosis on current performance level.

The first step is a preliminary survey that should last three to five days. This survey is necessary to collect information on the process and plan the observations. It consists on:

- **Calculating the number of observations:** a minimum number of observations are required for the diagnosis to reflect reality as close as possible. The number of observations (N) required for a certain proportion of ineffective or productive time within ± 5% (S) with 95% confidence can be found using the formula below. The percentage of ineffective or productive time observed (p) can be assessed from a pilot study done during the preliminary survey or drawn from previous studies;

$$N = 4.[\,p.(1-p)\,/(S.p)^2$$

- **Defining the number of daily observations:** this decision has to be taken in regard to site management's needs. However, the chosen number of daily observations will determine the duration period spent identifying current performance levels. The only requirement is for the observations to be taken at regular intervals;
- **Listing activities:** in order to avoid mistakes during data collecting and processing the number of listed activities must not be very long. Thirty at the maximum. The listed activities have to be detailed and described in a dictionary to provide a common understanding along the organization;

- **Determining waste categories:** the measuring system is capable of monitoring seven different forms of waste in labor work: waiting time; transportation; processing; movement; production of defective products; substitution; and others. The last two forms of waste have been proposed by (Formoso et al. 1999). It is important to identify which listed contributive and non-contributive activities fit these categories;
- **Identifying workers**: the number of workers involved in the process has to be determined and an identification by code has to be established. For example, three workers can be identified as 1, 2 and 3;
- **Identifying products:** A simple code is also adopted to identify process outputs. For example, masonry process outputs can be identified as w1, w2, w3 and w4.

The second step is data collecting. A slight adaptation has been made in the form of recording each activity that is in operation at the instant it is observed. The observation sheet used for recording information and the collecting procedure are described next:

- **Observation sheet:** the sheet must show what activity the worker was involved with and what product was consuming it at each observation round. The sheet shows the activities listed horizontally in the lines and segregated in productive, contributive and non-contributive. The columns show the number and time of the observation rounds. All cells have to contain subdivisions with the workers code on top and empty spaces just below so that the code of the product that's consuming the activity can be written;

PLANILHA DE COLETA

N. do dia da observação:______ Observador:_____________________

Data:_______/ ______/ _______ Obra:__________________________

Atividades			07:30									07:40								
			1									2								
Produtivas																				
1	Espalhar Massa	Funcionário(s)	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
		Parede trabalhada																		
2	Colocar blocos na linha	Funcionário(s)	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
		Parede trabalhada																		
3	Colocar blocos nos cantos	Funcionário(s)	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
		Parede trabalhada																		
4	Encher juntas	Funcionário(s)	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
		Parede trabalhada																		
Auxiliares																				
5	Montar / desmontar andaime	Funcionário(s)	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
		Parede trabalhada																		
6	Quebrar blocos	Funcionário(s)	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
		Parede trabalhada																		
7	Transportar material p/ o posto	Funcionário(s)	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
		Parede trabalhada																		
8	Medir (prumo, etc...)	Funcionário(s)	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
		Parede trabalhada																		
Improdutivas																				
9	Parado (sem motivo)	Funcionário(s)	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
		Parede trabalhada																		
10	Deslocamento dentro do posto	Funcionário(s)	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
		Parede trabalhada																		
11	Deslocamento fora do posto	Funcionário(s)	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
		Parede trabalhada																		
12	Parado (falta de material)	Funcionário(s)	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
		Parede trabalhada																		

Figure 1: Observation Sheet

- **Collecting procedure:** When a worker is observed involved in a productive activity, the product's code he is working on is written below the worker's code in the activity's line. If the worker is observed in a contributive activity, the observation should take a little longer just to see what product will consume it. In case of a non-contributive activity, it will be considered that it was consumed by the first product the worker is observed working on in the following observation rounds.

The third step is data processing, which starts by storing and organizing the collected data. This is done using a sheet very similar to the observation sheet. The difference is that each column represents a different product. The column shows the total number of rounds that the worker spent on each activity to produce the product.

With this, the performance measures are calculated in a sequence to provide information on process efficiency. The sequence is presented below:

- **Cycle time:** since the observations are taken at regular intervals, it is possible to calculate the cycle time as the total number of rounds each worker spent on the product times the interval's duration;
- **Activity rating:** by analyzing the organized data it is possible to extract the total number of rounds the workers were observed in each activity. This way, the proportion of time the workers spent on productive, contributive and non-contributive activities can be obtained.
- **Waste costs:** by using activity rating as a resource driver the labor costs are tracked to the activities that consume them. Adding the individual costs of the activities that belong to the seven waste categories allows waste costs in labor work to be found;
- **Product costs**: activity time consumed in product manufacturing will be used as a cost driver to calculate product's labor costs. The cost driver is estimated as the worker or team activity ratings multiplied by the product's cycle time.

The last step is the information analysis. Two aspects have to be considered to obtain the best results from the analysis. These aspects are discussed below:

- **Presentation:** the presentation should be made in a way that suits best site management's needs. The only advise is to present the information in a graphic manner if it is in a more aggregate level and through tables if it is in a more specific level;
- **Analysis:** the analysis of the measures result's should be made in a comparative form to allow a more comprehensive view on the processes' problems or progress. The measures results must be compared to each other and with results drawn from other studies.

When using the system for process control or improvement measurements, the data collecting periods have to be frequent and must not take as long as the period spent measuring the current performance levels. It is necessary that the measures provide a quick feedback on process efficiency to give sustainability to the planning process.

To maintain the results' required confidence and accuracy, the data obtained in the next collecting periods must be added with the data previously collected in order to calculate the new activity ratings. This way, process improvement will be reflected in the new activity ratings and consequently on the other performance measures.

To present the control measurement's results, the graphs should always compare the new results with the established pattern or goal. On the other hand, to present the improvement measurement's results, the new results have to be compared with the ones found in previous collecting periods or with those obtained in the initial diagnosis on current performance level.

PROJECT

A practical application was conducted in the masonry process on a multi-story residential building construction site. Located in the town of Fortaleza (Brazil), the building has twenty two-floor apartments, each with 61,56 m² of floor area. The constructor is Placic S/A construction company which is both a developer and builder, being mainly involved in residential building projects.

The application began in the second half of January 2001. At the time, the building tower's concrete structure and bricklaying was in execution. The masonry process completion date was scheduled for July 2001. Fourteen professional workers were involved with the process. The site was managed by a civil engineer, two foremen and two undergraduate trainees.

CASE STUDY

Since site management had little information on process efficiency, the operational parameter measuring system was first used to identify current performance levels. This application of the system and its results will be discussed in this paper.

The system's practical application began with a preliminary survey that lasted five days. During this period, the data collecting procedure and its objectives were explained to site management and workers involved.

Initially, the number of workers exclusively involved with internal bricklaying was determined. Four masons were identified and codified as workers 1, 2, 3 and 4. Each was responsible for an apartment. Three assistants were also identified and codified as workers 5, 6 and 7. Worker 5 supported workers 1 and 2, while workers 6 and 7 provided exclusive support to workers 3 and 4, respectively.

A total number of 24 different walls (products) in each apartment were identified and codified. Because the size of some external walls varied from one apartment to the other, it was chosen to not consider them in the posterior calculations of cycle time and product costs in order to avoid problems during information analysis.

Next, a pilot study was conducted to reveal the proportion of time spent on productive work, which was used to calculate the minimum number of 738 instantaneous observations required. With this, 51 daily observations were planned at regular intervals of 10 minutes, totalizing 15 days of monitoring.

The activities were identified and mapped through observations and interviews with workers. A total number of 28 activities were classified as productive, contributive and non-contributive. Eighteen activities were identified as being contributive and non-contributive and divided into seven waste categories.

During the data collection period, 741 instantaneous observations were accomplished. The observation sheets attended the previously described pattern. Its lines presented horizontally the 28 activities and the columns showed the time and number of the 51 daily observation rounds at the top. The upper part of the cell's subdivisions was filled with the seven workers' codes. An extra sheet with an illustration of the codified walls was attached to the observation sheets during the observations

The data processing began calculating activity ratings by extracting the organized collected data on the work done by each worker in all walls. With the activity ratings and the wage received by the workers at the same period, activity and waste costs in labor work were calculated.

As for cycle time and product costs, only the internal walls have been considered in the calculation. To find the product's labor costs, information was needed on product cycle time, total number of work hours and wage received in the period.

RESULTS

Comparison of the cycle time to complete bricklaying in twelve different internal walls showed worker 4 as the fastest and second fastest in 50% and 42% of the comparisons made, respectively. On the other hand, the comparisons showed worker 2 as the slowest. This worker appeared as the fastest in bricklaying in only 18% of the comparisons. Workers 1 and 3 came out with intermediate results, with a small advantage for worker 3.

During the observations it was noticed that worker 4 worked on a wall (product) until its complete execution. Worker 2 always left the two upper brick lines of each wall to be concluded later. This generated and consumed more contributive work every time worker 2 returned to finish bricklaying in these walls. This was registered and can be very clearly noticed when analyzing the observation sheets at the end of the collecting period. These results evidence a lack of process standardization, which is also worsened by planning problems and the inherent variability in human work.

The system's application was also important to verify that the assistants were not aware of their true responsibilities and functions in the process. Masons were very commonly observed involved in contributory activities while an assistant was standing nearby resting or talking. It is as if the assistants believe that their work is limited to moving material or equipment, cleaning workplace and tools. This had an impact on the workers utilization rates as presented on Table 1.

This analysis also gives a good idea on the effects of team size on the workers individual utilization rates. Workers 1 and 2 were both supported by worker 5 and could not count on his presence at all times. As a consequence, they presented the highest utilization rates in productive and contributive activities and the smallest rates in non-contributive activities. On the other hand, workers 3 and 4 could each count on the exclusive support of workers 6 and 7, respectively. Consequently, those workers presented a lower utilization rate in contributive activities than workers 1 and 2 and their assistant's utilization rates on contributive activities were higher than the rate presented by worker 5.

Table 1: Work Rates

WORKER / WORK	Productive	Contributive	Non-contributive
Worker 1 (mason)	45,9 %	34,9 %	19,2 %
Worker 2 (mason)	49,0 %	36,3 %	14,7 %
Worker 3 (mason)	41,0 %	29,7 %	29,3 %
Worker 4 (mason)	43,5 %	28,2 %	28,3 %
Worker 5 (assistant)	0,00 %	30,1 %	69,9 %
Worker 6 (assistant)	0,00 %	31,6 %	68,4 %
Worker 7 (assistant)	0,00 %	38,7 %	61,3 %

The system's practical application found the cost of the seven waste categories for the 4 masons. Waste classified as others (Formoso et al. 1999) consumed 10,4% of their labor costs in the period. This resulted, mainly, from the idleness caused by the workers 3 and 4 team sizes. Movement waste comes in second consuming 6,0% of their labor costs. Although the workers had to move in order to work on the products, the results were worsened by the fact that the masons frequently worked on two walls at the same time. Substitution waste consumed 4,7% of labor costs and was mainly due to the assistant's absence when needed or lack of instruction on their obligations. Waiting time waste also consumed 4,7% of labor costs and resulted from the lack of material in the beginning of work shifts. The other waste categories appear in smaller proportions.

As for the assistants, the application showed that waste classified as others corresponds to 36,7% of their labor costs in the period. It indicates that there is a considerable amount of idle time that could be used in contributive activities to avoid the occurrence of substitution waste in the masons' work. Movement and Transportation wastes answered for 22,4% and 10,6% of their labor costs, respectively. The amount of waste in both categories could have been smaller if a sequential order of execution of the apartment's internal walls was a planned. This way, internal material movement would have been faster and unnecessary movements done by the assistants would've been avoided.

Comparison of product costs demonstrated worker 2 as being responsible for manufacturing walls at a lower cost in 63,6% of the twelve comparisons made. Worker 1 came in second manufacturing walls at a lower cost in 44,4% of the comparisons. Worker 4 had the worse results, presenting the lowest production costs in none of the twelve comparisons made.

Comparing these results helps explain the conclusions and information drawn individually from each performance measure. In first place, as Alarcón (1997a) suggests, utilization rates do not directly provide labor productivity rates. That explains why worker 4 has the second lowest utilization rate in productive activities but at the same time is the fastest in manufacturing the walls. Second, there was not a great distance between the cycle times achieved by workers 3 and 4, the fastest, and those achieved by workers 1 and 2. This way, there was no compensation that justified assigning workers 6 and 7 to exclusively support them. The decision of assigning one assistant to support one mason made the products manufactured by workers 3 and 4 more expensive.

Finally, the system's application provided site management measures and a better understanding on the causes of process variability. One of the main causes is *planning inefficiency*. For example, it can be observed in the lack of material in the beginning and end of work shifts causing larger cycle times on product manufacturing. Another cause is the *type of product*, such as brick walls with different dimensions consuming different activity times to be manufactured. The *lack of standardization* in construction processes also contributes to increase variability as seen in this application. There is also the variability caused by *human work*, strongly employed in construction processes and possibly the most difficult to avoid.

CONCLUSION

This paper presents an operational parameter measuring system aimed to provide site management with information that will help monitor process performance and rationalize labor work. In this sense, the system proved to be an effective tool, mainly due to the way the performance measures are calculated which have shown to be quite coherent.

The system still needs to be used in other constructions sites and processes. But the practical application conducted in this case study with the objective of identifying current performance levels has already revealed the considerable amount of time spent on data collecting and processing as its' main weakness. A statistically significant sample has to be achieved in order to provide a correct diagnosis on process performance. Plus, the time spent on data processing has shown the need to restrict even more the number of monitored activities and codified products. Similar activities have to be aggregated and considered as one major activity. Data collecting using a palmtop and it's insertion in pre-programmed electronic sheets that automatically calculate the measures can also be useful in providing a quicker feedback on performance.

On the other hand, these problems were not so important when the system was later successfully used in the same site to verify the impact of improvement actions on the process. Feedback on process efficiency was given in short time because data collection was done a day per week during five weeks and thus the amount of processed data after each observation period was smaller.

However, this research has shown that Lean Production principles can be implemented in the construction industry if methods adapted to construction peculiarities are developed. A way to do this, as demonstrated in this research, is by combining traditional and new developments in construction control.

Some conclusions of the practical application are presented below:

- The lack of team size planning increases product costs and idle time. By comparison of two case studies in Brazil, Santos (1995) showed that labor time spent on non-contributive activities was reduced from 47% to 38% when team size proportion was planned and changed from 1:1 to 2:1;
- The need to better define the workers tasks, especially the assistant's obligations. Santos (1995) confirmed this pointing that 12% of the assistant's time is spent on activities that are not directly involved with the process;

- The importance of planning a sequential order for manufacturing the apartment's internal walls to help decrease the time spent on material movement and make available work place for the next process;
- The need to standardize the process establishing routines and previously instructing the workers on how to proceed in all activities. According to (Thomas et al. 1992), better operational management can provide a 64% increase of daily productivity in bricklaying.

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