While loop Algorithm to Enhance the Efficiency of Work Sampling Method in Performance Measurement

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Abstract

This research covers, in part, the growing need of computerization in the construction industry. The paper highlights the lack of computerized measurement of labor performance/productivity and proposes the optimization of an existing performance measurement method with the help of a computer software. After extensive literature review, Work sampling is selected as the measurement method while MATLAB is employed for its optimization. Data collected by observing a total of four workers from two construction sites (two from each) undertaking steel works is first analyzed using conventional Work Sampling method. The same data is them analyzed using an algorithm written in MATLAB that computes multiple iterations for all number of observations. The results obtained show that work done in each category by all the workers comes out to be approximately the same for a much lower number of observations as compared to the traditional practice of taking 384 observations. For example, the percentage value added work done by Worker A is 12.12% for 384 observations while for 155 observations it comes out as 11.92% giving a percentage error of just 1.65%. Similar pattern is observed for all the workers. It is also observed that the percentage of error below 150 observation remains quite significant even if the number of iterations are increased. This is due to the increased probability of missing certain categories of work because of reduced observations.

Keywords –
Computer Aided Engineering; Performance Measurement; Work Sampling; While loop Algorithm; Rebar Placement; Productivity; Case Study

1 Introduction

In industrialized countries, a major contribution towards the gross-national product comes from the construction industry (Allmon et al., 2000), hence national economies are greatly impacted based on the performance of the construction industry. The success of a construction project relies heavily on the preparation of an accurate estimate before the project commences, as it influences both the feasibility as well as the profitability of the project (Portas and AbouRizk, 1997). Cost of labor is a key part of the overall estimate of the project and is directly dependent on the accuracy with which the labor performance and productivity is measured. Recognizing the importance of labor performance measurement, significant research has been done and a variety of performance measurement techniques are developed over the last few decades. Some of the well-established methods that have been used over the last few decades are 1) Continuous Time Study 2) Work Sampling and 3) Five-minute rating (Thomas and Daily, 1983). Although each of these methods have been employed over the past few decades, deficiencies in these methods have observed and highlighted by researchers due the complexity and fast paced nature of the modern-day construction projects (Navon, 2007, Cheung et al., 2004, Saidi et al., 2003).

Traditional performance measurement methods are labor-intensive and rely on manually collected data that heavily depends on the experience and knowledge of the observer. Furthermore, the amount of data required is significantly increased with the increase in complexity and scale of the project which leads to more observation time along with greater chance of errors in the reading (Davidson and Skibniewski, 1995). In a study carried out in western Canada, it was observed that around 40% of the time, an error of plus or minus 15% is demonstrated in the labor productivity approximations by the observers (Portas and AbouRizk, 1997). This is where automation in the construction industry is vital moving forward. By minimizing the effort put in by the observer, not only will we be able to save time and cost, but the degree of errors in the reading will also be significantly reduced.

The purpose of this paper is to take an existing performance measurement method and optimize it as much as possible with the help of computer aided techniques. This will be done by selecting a performance measurement method, collecting data from a construction site by carrying out the observations of a steel crew and then interpreting these results through traditional method and then optimizing the method with the help of computer aided software and compare them. The performance measurement method selected for the purpose of this paper is “Work Sampling” and the software selected for the optimization of the method is “MATLAB”, both of which will be discussed in the following sections.

2 Literature Review

The technological advancements made in the 20th century have been unmatched over the course of human existence over a very limited period. This rapid development has led to discoveries, innovations and out dated many customary practices throughout every industry around the world. In regards to the construction industry, these advancements have provided many advantages to the betterment of the construction process, but lags other industries due to certain factors that are beyond the scope of this paper. Skibniewski (1989) suggested that all the industries are taking advantage by not only innovating and development of new technologies, but also improving on the existing practices. Henry (1994) states “soon the construction industry will experience what Alexander Graham Bell might have felt if he witnessed the evolution of fiber optics soon after inventing the telephone, or what Henry Ford may have felt upon seeing his assembly line augmented by automated robotics…”.

According to Allmon et al. (2000), 10% of the “gross national product” is as a direct result from the contribution of the construction industries in industrialized countries. This is one of the major reasons why performance of the construction industry is under the microscope and greatly scrutinized given the chance. In a survey carried out by Scott et al. (1994), it was concluded that the acceptance of computers within the construction industry varies between consultants, contractor and clients. While it is almost equally accepted for engineering purposes by all the concerned parties, in case of computerization of construction management is concerned, a significant drop is observed. This is one of the reasons behind the relative underperformance of the construction industry and can only be resolved by the integration of computers in Construction Management.

2.1 Computer Aided Construction Management

In the past, use of computers in the construction industry was scarce and was restricted to particular areas, if at all. However, the development in computers over the past decades has taken the world by storm and has become a necessity for survival in every industry due to the fast paced and competitive environment. Computerization of construction management has become essential moving forward, as computers are considered a vital management tool for achieving the targets efficiently and effectively. Yamazaki (1992) stated that automation of the construction industry has already begun and developments are underway that would soon be applied practically in every construction project across all its different phases which include designing, manufacturing and construction. The construction industry is heavily reliant on the effective cooperation between all the concerned parties which calls for widespread organizational planning and management structure to the complexities and scale of construction projects these days. These management tools would not only bridge the gap between the different parties, but also provide new and efficient methods to optimize the construction phase will lead to problems such as inadequate monitoring of activities, inefficient evaluation of works and lack control over the pace of the project which would consequently reduce the productivity triggering hefty losses.

Skibniewski (1989) believed that computers not only provide new and efficient techniques, they have also enabled the modification of existing methods. This provides us with more accurate results with minimal effort and saves time and cost. The improvement in the existing construction management techniques is down to the ever-advancing technology sector. Apart from the modification of existing methods, the advancement in computer technology has led to the possibility of coming up with unique and innovative designs, better visualization and communication, efficient scheduling and much more. The use of computers is important in all the aspects related to construction management, but the most common areas of computerized construction management are as follows (Meredith and Mantel Jr, 2011, Rizki, 2003)

- Project Planning
- Resource Management
- Tracking/Monitoring
- Report Generation
- Decision Making

Estimations are a key aspect related to each construction activity and detailed estimates are carried out even before the tendering stage. Almost all the construction activities can be estimated to a higher degree of accuracy as they depend on costs that are quantifiable easily such as equipment, repairs and resources. But the one factor that is dynamic in nature and is difficult to predict is the performance and productivity measurement of labour (Henry, 1994). This is because of the various factors involved while measuring the performance such as the condition of the site, the scope of the work, overtime, ability of the crew, unexpected delays, changes in plans and much more. Due to these factors and the amount of data to be processed, efforts have been made to introduce computer aided methods for effective and easier evaluation. Some of the methods have been discussed in the following section.

2.2 Computerized Labor Performance Measurement Methods

The complexity and various factors involved (such as on-site conditions, over time, worker proficiency etc.) in the measurement of labour performance and productivity has resulted in very little research in the area (Navon, 2005). However, some efforts in labour tracking have been made over the past few years with each method having a human factor involved in it.

"Radio frequency identification" RFID or barcodes have been suggested to gather data on workers (Jaselskis and El-Misalami, 2003). Electric forms along with the use of spreadsheets has also been proposed as a method to gather data by different researchers (Fayek et al., 1998, Hegazy and Ersahin, 2001). Echeverry and Beltrán (1997) suggested a method that consisted of three components for labour tracking 1) Construction project's plans in a database 2) manual or automated data entry 3) module for carrying out the analysis.

A more frequently used and industry approved approach to measure labour productivity/performance which widely is the "Work sampling" technique.This employs an observer who takes readings at random intervals during the day and notes the activity being undertaken along with the detail of the work being done by each worker at that observation interval. Data collected is then classified into a pre-set work categorization. The categorization is into productive, contributory. unproductive, personal and ineffective (Bernold and AbouRizk, 2010). Relating work percentages based on the categorization gives the performance measure for each worker which is generated either manually or through computers, the latter being the more obvious choice as already discussed.

The one drawback observed in all of the above mentioned methods is the reliance on observers and/or the workers themselves for entering the data into the model/system. This leads to uncertainties and inaccuracies that are observed in the existing manual procedures of data collection and performance measurement (Navon, 2005). Hence, to find remedial measures computer software can be utilized in order to maximize the efficiency of the existing measurement techniques. For the purpose of this paper, work sampling is considered as the measurement technique that will be studied and optimized with the help of computers. In order to accomplish that, there is a need to first understand the concept behind work sampling followed by the selection of a software that will help us improve the method.

2.3 Work Sampling

The basis of this method was laid by Tippett (1935), when he suggested a different method from continuous time study. He proposed that at random intervals "screenshots" should be saved of the work going on, which would save time and will be mostly accurate.

Malisiovas (2010) suggested that work sampling is a method to measure the time taken by a worker in the defined categories of work with the help of statistical sampling theory. The observation in this method is carried out at random intervals and the results are inferred from this information. Statistical sampling theory is employed because a limited group is observed for a limited period as it establishes a limit of confidence interval which caters for the error that might emerge. The idea of this method is to figure out the categorization of work being done out by the workers and spot the reasons and areas where the work efficiency is being affected to make the required changes (Liou and Borcherding, 1986).

Following are the requirements that must be fulfilled for conduction of work sampling. (Baxendale, 1998):

- "The work to be observed must be cyclic in nature
- The work cycles must not be repetitive
- The work must have multiple workers and sufficient observation time"

2.4 Computer Software

There is a wide range of computer software available that can be used in this research. Microsoft Visual Studio (C/C++), Python, Fortran and MATLAB are some examples. After reviewing the literature MATLAB was selected based on its variety of features. According to Hanselman and Littlefield (1997), MATLAB has a huge database consisting of built-in algorithms that can be tried immediately without recompilation. The desktop environment helps the user to interact with the data while working and keeping track of the files and all the different variables at the same time. They further describe the software as easy to use and the code written in it can be exported to other software which can be very useful in future studies. As already established, MATLAB has a wide range of functions that can be utilized depending on the use of the programmer. For the purpose of this research, the functions used in the code are discussed in detail under the Research Methodology section.

After reviewing the literature, it is evident that computer integration in the construction industry is imperative and although it is gaining popularity in most of the areas concerning construction processes, a gap in knowledge regarding the automated measurement of labor performance and productivity is observed due to the various factors discussed in the above sections. This gap in knowledge will be addressed in this paper by selecting a labor performance measurement technique that is being frequently used and come up with a solution, using computer software that will reduce the human involvement, utilize less time and effort while reducing the cost of the procedure.

3 Problem Statement and Research Hypothesis

The current performance measurement methods are time consuming, costly, labor-intensive and highly dependent on the competency of the observer. This is the reason construction managers avoid the use of these methods as much as possible which leads to insufficient information on the labor performance and productivity that may cause harm during the construction phase or at the later stages of the project. Utilizing the massive advancements in computer technology for the upgrading/optimization of these existing methods will help overcome these issues and encourage construction managers to adopt these methods which will be beneficial for their projects.

Reducing the number of observations required in the current Work Sampling technique for the measurement of labor productivity with the help of an algorithm developed in MATLAB, a computer software that will reduce the effort, time and cost required to undertake the procedure while maintaining its accuracy.

4 Research Methodology

After extensive literature review, the performance measurement technique nominated for this paper was Work Sampling and the computer software used for the improvement was MATLAB. The procedural explanations for both have been discussed in the previous sections. The distinctive characteristic about the construction industry is the uniqueness of each construction project and provides a different challenge each time. Keeping this in mind, the measurement procedure employed must be adjusted accordingly. For the scope of this paper, the work sampling was performed on a steel fixing crew and the data collected was through two mediums; digital and real time. The digital recording served as a purpose of keeping a back-up as well as a source of double checking the observations.

The data collected was then evaluated through traditional work sampling methods by calculation the percentage of work done in each category. The same data was then run through an algorithm generated in MATLAB to find out the best way to maximize the efficiency in terms of time, cost and effort utilized to carry out the procedure.

5 Case Studies

For this paper, data was collected by observing steel workers from two different construction sites. The description of each is as follows

5.1 Case-1: Steel Fixing Works for Residential Apartments

This construction site was located in South Yara in Melbourne, Victoria approximately 6km from CBD. The building has a planned capacity of housing 92 apartments, has 9 floors and stands 28.1m above the ground. The concerned authority is the Stonington Local Government. The project was a development by "Salta Properties" while the construction responsibilities were undertaken by "MERKON Construction".

The data was collected for the steel fixing of the top level by observing a three-man crew, which consisted of two steel workers and a foreman. The workers were referred to as Worker A and Worker B. For ease of shifting and avoiding disruptions during work, the steel was stockpiled at various intervals.

(1) Categorization of Work

The purpose of categorization of work has been discussed in the above sections. Following is the framework generated for this case study

Table 1. Categorization of work

Category	Content
Value Added Work	1. The work done that contributes directly to the physical completion of an activity, e.g. placing, aligning and tie works
Contributory Work	2. Managing and moving essential tools and materials within the workplace that contribute to the value added work. These comprise of reinforcement tie wires, torches, sledges, wire cutters etc. 3. Demarcation and clearing of work 4. Referring to drawings, resolving issues with the help of supervisor
Ineffective Work	5. Moving objects to a distance more than 35ft. 6. Walking bare handed

	7. Searching for materials or tools
Unproductive Work	8. Waiting for others to complete or the supervisor for instructions 9. Redoing of work
Personal	10. Undue breaks and idle time 11. Unobservable

(2) Analysis by Work Sampling

After the categorization of work is completed, the number of observations required for obtaining accurate results is determined. Bernold and AbouRizk (2010) came up with the following formula for the ideal number of observations

"N = k^2 x p(1-p) ÷ s^2

N = No. of observations

K = Standard Deviations for given confidence limit

s = absolute limit of error

p = unobservable probability (decimal)"

As a general rule, the confidence level is set at 95%, the limit of error as 5% and the "unobservable probability value" as 0.5. Z-score can be understood by referring to the concept of normal distribution. The k-value can be generated in excel which gives the standard deviation of the confidence level. Substituting these values gives the following:

Table 2. No of Observations

Confidence level	C.L	95
z-score	Z	0.025
		0.975
No. of SD for confidence level	k value	-1.959964
		1.959964
Chance that element might not be visible	p	0.5
Absolute level of error	s	0.05
No. of observations	N	384

This value of 384 observations is considered to give the most accurate measure of labour performance through work sampling. For comparison purposes, the results for just 20 observations were also calculated to show the significant difference in the results obtained. The results obtained from the actual work sampling carried out by taking 384 observations is shown in the following table. It is to be noted that the results obtained will be quite different as observed for number of observations less than 384.

Table 3. Work Sampling Results for 384 Observations- Case 1

Category of Work	**Percentage of Work Done for 384 Observations**	
	Worker A	**Worker B**
Value Added	13.76%	27.27%
Contributory	43.11%	27.00%
Ineffective	15.06%	17.66%
Unproductive	13.77%	15.06%
Personal	14.28%	11.43%

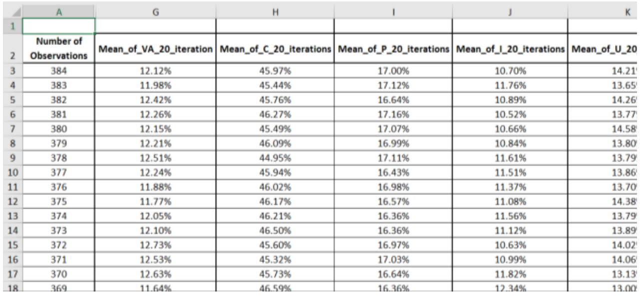
Table 3 gives the results for 384 observations. A. In case of Worker A, the results obtained from 20 observations (not shown here) show 20% of the work done as value added while it comes out only as 13.76% from 384 observations which is accepted to be more accurate. Similar observation can be made if the comparison between the percentages of work done for 20 observations is made against 384 observations, for both the workers. This emphasizes the importance of large set of observations. Having said that, there is need to find out the most efficient number of observations required to get accurate results which would make this method easier to apply.

(3) Analysis through MATLAB

The broader range of MATLAB's capabilities have already been discussed earlier. The algorithm used for the purpose of this research was a combination of multiple separate algorithms. The first step was to define the number of observations to be carried out denoted by "x", these were taken as a variable with the purpose of finding out the minimum number of observations instead of the customary 384 observations. Using "while loop" the algorithm was made to run till the number of observations "x" reach 0 with the intention of getting an overview of the behaviour over all the number of observations. As the numbers "x" are generated randomly without any pre-set criteria, the algorithm was written such that it conducted 20 iterations in order to obtain an accurate result, the variable H was selected for it. The "x" number of observations were randomly generated from time 0 to the end of the observation period (5719 seconds in this case), stored under the variable "r". After this, the ranges observed for the work done in each category were defined under the letters VA, C, P, I and U denoting "Value added", "Contributory", "Personal", "ineffective and "unproductive", respectively. "for loop" was used to assign these letters to their corresponding randomly generated "r" values. Percentages of each category of work was calculated after each iteration and a mean of the 20 iterations was calculated for each value of "x". To keep count of the "while loop" for the number of iterations run, a variable "count" was set. In order to get the results in excel, the data was converted into cell using the "num2cell" function of MATLAB. After the algorithm is run, the results are generated and saved in an excel sheet. The results are also plotted with the help of "plot" function in MATLAB as shown in figure 2 and 3.

This algorithm runs 20 times for each value of "x" which starts from 384 observations and ends at 0. This comes out as 1,478,400 iterations in total which can't be shown in a table. The results obtained in excel sheet are the mean of each value of "x".

For example, for the value of x=384 the algorithm will run 20 iterations for 384 randomly generated numbers between 0 to the end of observation time (i-e.5719), assigning each number with its corresponding work category denoted by either VA, C, P, I or U and calculating their percentages in each iteration. After this the algorithm will run again for 383 observations and repeat the steps above till the time "x" equals 0. The mean of all the iterations will then be generated in excel followed by a plot in MATLAB. As the number of observations are a lot, only a screenshot of the means generated in excel file is shown in figure 1 for a few iterations carried out for Worker A.



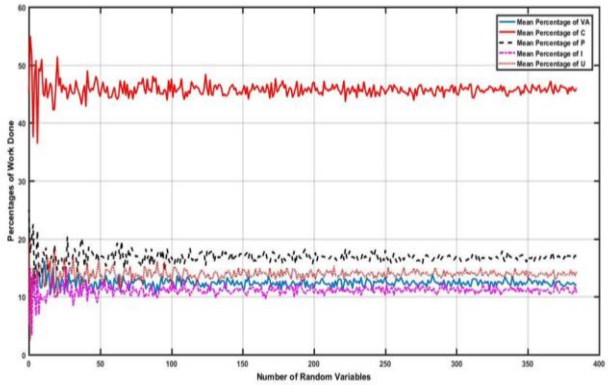
	A	G	H	I	J	K
1						
2	Number of Observations	Mean_of_VA_20_iteration	Mean_of_C_20_iterations	Mean_of_P_20_iterations	Mean_of_I_20_iterations	Mean_of_U_20
3	384	12.12%	45.97%	17.00%	10.70%	14.21
4	383	11.98%	45.44%	17.12%	11.76%	13.65
5	382	12.42%	45.76%	16.64%	10.89%	14.26
6	381	12.26%	46.27%	17.16%	10.52%	13.77
7	380	12.15%	45.49%	17.07%	10.66%	14.58
8	379	12.21%	46.09%	16.99%	10.84%	13.80
9	378	12.51%	44.95%	17.11%	11.61%	13.79
10	377	12.24%	45.94%	16.43%	11.51%	13.86
11	376	11.88%	46.02%	16.98%	11.37%	13.70
12	375	11.77%	46.17%	16.57%	11.08%	14.38
13	374	12.05%	46.21%	16.36%	11.56%	13.79
14	373	12.10%	46.50%	16.36%	11.12%	13.89
15	372	12.73%	45.60%	16.97%	10.63%	14.02
16	371	12.53%	45.32%	17.03%	10.99%	14.06
17	370	12.63%	45.73%	16.64%	11.82%	13.13
18	369	11.64%	46.59%	16.36%	12.34%	13.00

Figure 1. Means generated in Excel

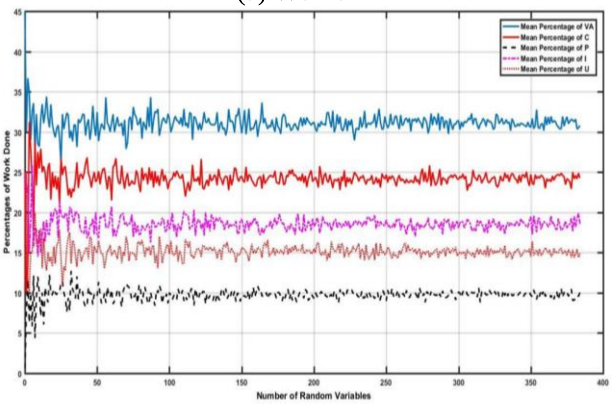
The plots for the means of all 384 observations for both Worker A and Worker B are shown in the figures below. The mean percentages of work done of 20 iterations for 384 observations by Worker A and Worker B comes out to be 12.12% and 30.78%, respectively (obtained from respective excel sheets). It is to be noted, that these results might differ from conventional WS methods as it is taking a mean of 20 iterations which provides a far more accurate result. Work sampling technique dictates that taking 384 observations results in the most accurate observations, but as seen from both the figures, the percentage of Value added work along with all the other categories remain approximately the same up to a much lower number of observations as obtained from 384 observations. In case of Worker A, the values remain approximately the same up to 150 observations while for Worker B the results start to deviate around 175 observations.

5.2 Case-2: Rebar-Placement for School Building

This construction site was located in Kensington, NSW, Australia for the development of Basser and Baxter College building. The study was undertaken for the performance measurement of rebar placement by observing four workers. Beams L4B10 situated on the west sector of the building and two workers working on the beam were selected for the experiment. The workers on L4B10 were referred to as Worker C and Worker D.



(a) Worker A



(b) Worker B

Figure 2. Percentages of Work Done for each number of observations

(1) Categorization of Work

The framework adopted is the same as used for case 1

(2) Analysis by Work Sampling

The comparison between 20 observations and 384 have been shown in the previous section.. For this case, only the results obtained from 384 observations are demonstrated below

Table 5. Work Sampling Results for 384 Observations- Case 2

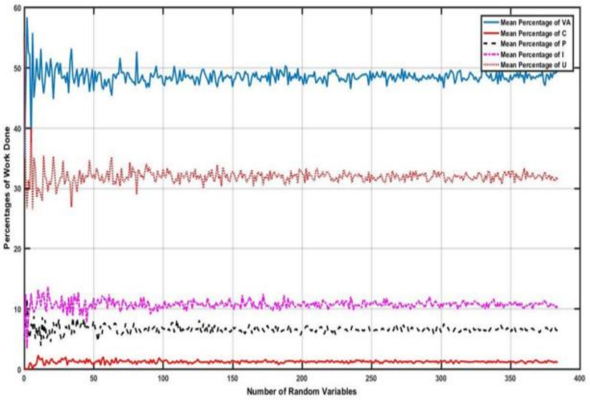
Category of Work	Percentage of Work Done for 384 Observations	
	Worker C	Worker D
Value Added	45.71%	31.17%
Contributory	0.52%	21.82%
Ineffective	13.25%	32.21%
Unproductive	33%	7.01%
Personal	4.94%	6.23%

Table 5 provides the percentage of work done in each category by the two workers. Worker C has more value added work with 45.71% while worker D has a higher percentage for contributory work with 21.82%. It is observed that worker D has relatively less time spent in unproductive works with a cumulative percentage of

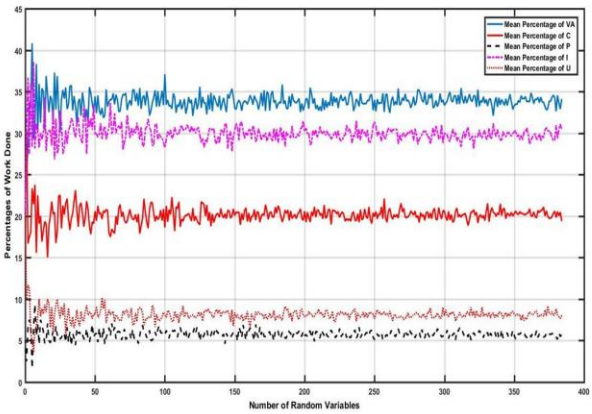
45.44% while Worker C, despite doing more value added work, spends 51.21% in the works that are unnecessary and avoidable.

(3) Analysis through MATLAB

The algorithm used for this case study is the same as the previous. The main difference is in the duration of the study undertaken and nature of the work. While the previous was approximately 90 minutes, this case study was done for the duration of an hour. The plot for the percentages of work done in each category by Worker C and Worker D are shown in Figure 3.



(a) Worker C



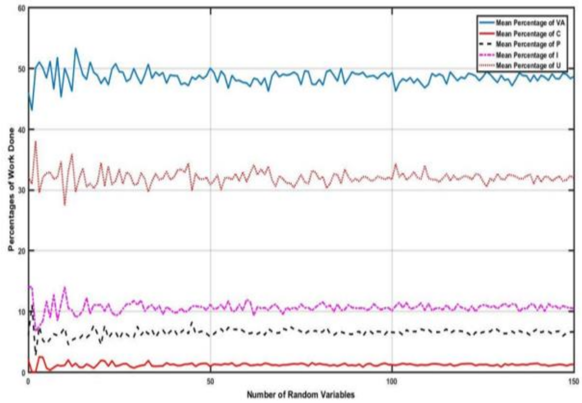
(b) Worker D

Figure 3. Percentages of Work Done for each number of observations

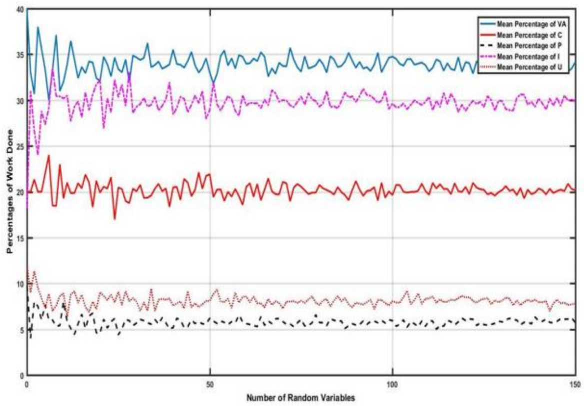
A similar pattern for this case study is observed as in the previous. Taking percentage of Value added work as an example, the percentages for Worker C and Worker D come out as 49.38% and 34.10% (obtained from excel sheets), respectively for the mean of 20 iterations carried out for 384 observations. This percentage of value added work along with the other categories of work remain approximately the same up to a much lower number in each case. The deviation is observed below 150 number of observations for both workers A and B.

Figures 4 represents the percentages or work done in each category by worker C and worker D for 150 observations and 50 iterations.

The results obtained with increased iteration and less observations than 150 show that the deviation is immediate and no pattern in observable. This concludes that while decreasing the observations is possible, it can only be done up to an extent. Afterwards the probability of not observing all the categorising of work increases and accuracy decreases.



(a) Worker C



(b) Worker D

Figure 4. Percentages of Work Done number of observations between 0 and 150

6 Conclusion, Limitations, and Future Works

The advancement in technology has benefited every industry over the past few decades. However, the construction industry is lagging in this regard as compared with manufacturing, medicine, etc. One of the major reason is the resistance and hesitation to adapt with new or improved methods. Computerization is observed in most sections of the construction industry, such as design, tendering, estimation (in most cases) etc. However, labour performance measurement is neglected due to dynamic factors that makes it very difficult to predict. Although many conventional performance measurement methods are available; the time, effort and cost associated with them restrains the construction managers from using them that often causes in the estimation or in the management of labour during the later stages of the construction phase. This paper addresses this issue by selecting one conventional method and optimizing it, as much as possible, such that it employs less effort, time and cost and encourages construction managers to utilize them. This would result in accurate estimates of labour that would consequently increase the productivity.

The conventional method selected was the Work sampling (WS) and the software used to optimize it is MATLAB. Two case studies are included in the paper, data from both of which is analysed through conventional WS method and MATLAB. It is concluded that the number of observations required to carry out WS are too many and can be significantly reduced. The results obtained from case studies show that the percentages of work done in each category for Worker A, C and D remains approximately the same for observation between 384 and 150 for 20 iterations, while for Worker B the results deviate below 175 observations. Hence, a lower number of observations yields the same results as from the conventional method, thus saving time, effort and cost and improving the productivity in the long run. The number of observations is further reduced if the iterations are increased as evident from the case studies.

Due to time constraints the number of workers observed are too less and recommends that future studies be carried out for more worker resulting in a firmer conclusion regarding the optimization. Another limitation was the lack of software knowledge, Software that can receive data in real time will greatly reduce the processing time and reduce human involvement in the labor performance and productivity measurement.

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