REVIEW AND ANALYSIS OF WORK SAMPLING METHODS: THE CASE OF AN AUTOMATED LABOUR PERFORMANCE MEASUREMENT SYSTEM USING THE WORK SAMPLING METHOD

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ABSTRACT

This paper analyses work sampling and time study as work measurement methods with the view of employing them in an automated labour performance measurement system. These are compared with respect to Hawthorn effect, labour intensiveness, cost, tediousness and knowledge extensiveness. The analysis proves that work sampling is a better option for developing an automated labour performance measurement system that employs computer vision. Web cameras are used to feed real-time images to a central computer via USB extenders. The computer runs a standalone C++ application that uses a random function to establish when measurements are to be taken. The developed video camera footage is converted into a pixel matrix using OpenCV. This matrix is then filtered and analysed, enabling the tracking of a worker. The data generated is stored in text files. After the work sampling period has elapsed, the data is transferred into Microsoft Excel for analysis. Finally a report of the labour utilisation is generated in Microsoft Excel and then send to the analyst for review.

Keywords: Work sampling, time study, work measurement methods, labour performance measurement, C++ and OpenCV.

1.   INTRODUCTION

This paper investigates suitability of work sampling and time study as work measurement methods for an automated labour performance measurement system. In our current climate, technological advancements enable the minimisation of the length of time required to carry out labour performance measurements. This paper presents the development of a system that automates labour performance measurement from the data gathering phase through to the analysis.

2.   LABOUR PERFORMANCE MEASUREMENTS

Cornwel & Reid Cornwell (2006) assert that, "You can't manage what you can't measure". Measurement is crucial before a management activity is executed. However, it should be noted that an incorrect measurement of labour performance can lead to incorrect and warped decisions by the management team. Therefore, the importance of measuring the right thing at the right time to reflect the true conditions of a company cannot be over emphasized. The measurements should offer the management an opportunity to make effective

and accurate decisions.

The various techniques available to supply information need to be explored so as to identify the right measurement technique for prevalent conditions. These techniques include: time studies, work sampling, subjective evaluations (Przemeck & Grund, 2008), review of records (Andrews et al, 1985), and personal recording of activities (Sitting, 1992). Many of these techniques have evolved over time. Use of technological advances makes it easier to efficiently acquire accurate results.

The first two techniques mentioned earlier namely time studies and work sampling are widely used and well documented. These are discussed and compared in this paper.

2.1. Time study

Time study is a method used to determine the actual time required to complete a task. It takes into account time allowances and delays. Time studies enable the management to make effective decisions aimed at improving the efficiency of the entities operating within the system. It is important to realize that accurate time studies yield positive results and inaccurate time studies can create many problems (Freivalds, 2009; Pigage & Tucker, 1954) as mentioned earlier.

2.1.1. Performing time studies

The following methodology should be followed when a time study is conducted. It includes all the tasks that should be completed from preparation through to the start of the study (Freivalds, 2009; Booser, 2009).

1. The first step is to choose the worker to be studied. An average, properly trained worker should be selected for the study as this typically yields better results. The operator should understand the purpose as well as the time study methodology. The worker and the analyst should communicate freely, effectively and truthfully.

2. The next step is to gather information about the task to be studied. This includes:

   • The working conditions at the time of the study,
   • The tools used and their inventory,
   • The operators name,
   • The analysts name,
   • The station where the study is conducted.

3. The third step is to determine where the analyst should be positioned. The analyst should not interfere with the movements of the operator.

4. The fourth step is to divide the task into sub-components. The subcomponents should be as short as possible, thereby improving the accuracy of the study. However, they should not be less than 2.5 seconds long. The following guidelines should be followed when breaking tasks down into their sub-components:

   • Both sight and sound should be used to determine the start and end of each sub-component,
   • Manual and machine elements should be kept separate,
   • Elements that vary in completion times should be separated from those that do not,
   • For a repeated movement, do not record the data, but refer to the first repetition.

5. The fifth step is to do the timing of the work using either of the following techniques:

   • Continuous timing - where the clock is reset at the beginning of a new sub-component.
   • Snap-back timing - in which the cumulative time is recorded.

2.2. Work sampling

On the other hand, work sampling was developed for the first time in 1935 by L.H.C. Tippet (Fitzgerald, 2009). Work sampling is the activity of taking randomly distributed observations of activities; these activities can include both humans and machines, with the objective of determining their utilization (Fitzgerald, 2009). The fundamental principle of work sampling is that it is based on the laws of probability (Freivalds, 2009). Work sampling only takes samples rather than continuous observation of the object being studied. This allows for the acquisition of reasonably accurate representations of the work under study, without the drawbacks of continuous monitoring. Work sampling is also observed as a low cost alternative method for determining of workforce utilization (Fitzgerald, 2009). In work sampling, the accuracy of the results is linked to the number of samples taken in the study (Sitting, 2000), as well as the time period during which the analysis is performed (Freivalds, 2009). It is, therefore, important that the analyst understands the operations of the company so as to identify an appropriate time frame for the study. The analyst needs to select a sample size that represents the true conditions of the system accurately, while also understanding the capabilities of the observer. Some standards have been developed to aid in making selections about the number of samples in a study. One such guideline is not to exceed 8 observations per hour (Sitting, 2000).

With the understanding that statistical methods form the basis of work sampling, the input data needs to be randomly collected and unbiased (Fitzgerald, 2009). If these conditions are not met the data will not deliver reasonable results. These inaccuracies can include continuity errors (in which small changes in input data represent small changes in the output data), and consistency errors (in which similar runs will not reflect similar results), (Bekker, 2010).

Traditionally work sampling does not determine the effectiveness of workers but rather whether they are working or not. It does this by recording the amount of time workers spend on certain activities (Fitzgerald, 2009).

2.2.1. Performing work sampling

Thorough planning needs to be done prior to the start of the work sampling study. The following procedure covers the work sampling process from the objective identification step through to the analysis of the results (Freivalds, 2009, Fitzgerald, 2009).

1. The objective of the study as well as the population of the study needs to be clearly defined. A list of the reasons why the study is being considered should be compiled. This might include the recording of excessive idleness. The area within which the study is to be conducted should also be defined.

2. The organization and its components should be understood. Included in this step is the acquisition of:

   - Layout plans, flow charts and shift schedules from management,
   - The policies and schedules for shifts, breaks and work hours,
   - Job classifications and position descriptions,
   - Union agreements,
   - Computer access required to facilitate the study.

3. The different classification fields for the study should be documented.

4. Design and create a work sampling form to be used in the study.

5. A preliminary estimation of critical factors should be determined from historical data or from a pilot study.

6. The desired accuracy of the study should be specified by the analyst. The confidence interval and the tolerance should be stated.

7. The estimate of the number of samples required for the work sampling study should then be determined. The number of samples

required for the study is dependent on the required accuracy of the results, the confidence interval and the probability of an event. The validity of the model increases as the number of samples increases.

8. The frequency of the observations should then be determined. In order to ensure that the data is representative of the true conditions in a working environment, random samples should be taken throughout the day over a relatively long a period.

9. Folders for observers should be prepared in which schedules, forms and layout plans are kept.

10. The observers should be trained.

11. Data should then be collected and analysed.

2.3. Comparison of work sampling and time studies

A comparison of work sampling and time studies is represented in Table 1.

Table 1 From the comparison it is clear that both techniques have a number of advantages and disadvantages. The two techniques also have a number of similarities.

Table 1: Comparison between work sampling and time studies

Time studies	Work Sampling
Subject to both observer and worker biases	The effect of biases is limited because it is only present when performance ratings are selected
Many trials must be recorded to obtain reliable results	Many observations are required for accurate results
Easy to understand	The statistical basis of the study may be difficult for workers and/or management to comprehend.
Hawthorn effect is likely to influence results	Hawthorne effect is less likely to influence results due to the large number of observations made
Accurate timing figures are obtained	Enough samples need to be made to ensure that the desired accuracy of the final results are achieved
Expensive to perform	Far less expensive to perform.
One on one (observer worker ratio) and therefore labour intensive.	One observer can perform studies of different workers. Fewer observers required
Study is continuous uninterrupted process	The study can be interrupted at any time with a minimal effect on the results
Tedious to perform	It is not as tedious to perform as the observer moves between workers to make observations
Establishes a systematic understanding of job tasks and therefore facilitates the determination of the best methods which aids in the development of training programs.	Provides no specific information about the job
The quality of the work produced can be taken into consideration	WS does not provide any measure of the quality of the work performed
If more than one observer is used, different rating may invalidate the results	If more than one observer is used, different levels of detail may invalidate the results
Cyclic variations are not as well compensated for	Observations can be made over an extended time period which decreases the effects of cyclic variations
Helps to identify labour costs	Helps to identify labour costs
Analyst does not move between workers	It is not an economical solution if workers are spread out over a wide area
Requires extensive knowledge and understanding of the task	Does not require an understanding of the task

An evaluation of the contents in Table 1 with respect to Hawthorn effect, labour intensiveness, cost, tediousness and extensive knowledge of a given task proves that work sampling is a better option for a development of an automated labour performance measurement system.

Furthermore, the automation of work sampling is far less complex than that of a time study because an operator may be tracked and simply be classified as either "idle" or "busy". On the other hand, time studies are far more complicated. The operator's movements would need to be broken down into

sub-movements which may require unique programming. Therefore, it is preferable to automate work sampling procedure because it allows for the employment of a flexible labour performance program. The most common applications of work sampling are (Freivalds, 2009):

- Determining machine and operator utilisation
- Determining allowances
- Establishing time standards

There are several work sampling software packages which can save up to 35 percent of the time required to perform work sampling analysis (Freivalds, 2009). However, the data has to be gathered, which is a time consuming and tedious process. Therefore, a further improvement would be to automate this part of the work sampling process as well.

3. THE CONCEPT OF AUTOMATING WORK SAMPLING

The system used to automate the work measurement method consists of a number of cameras linked to a central computer via high speed USB extenders. The computer runs a stand-alone program written in C++. The program uses a random function to determine when "observations" of a worker are to be taken. The real time video camera footage is analysed with Open Source Computer Vision (OpenCV), (Levin, 2006).

The limiting factor in the automated system is the maximum cell range of the spreadsheet application (65 536 in Microsoft Excel 2003 and 1 048 576 in Microsoft Excel 2007). The program is limited to take a maximum of 325 samples per shift if the sampling duration is 10 seconds and a 20 fps (frames per second) camera is used. This limit was determined by dividing the maximum cell range of 65 536 (in Microsoft Excel 2003) by the maximum frame rate of the camera and the sampling duration. The automated system, therefore, enables a far greater number of samples to be taken per day than would be possible if done manually.

 A further requirement of work sampling is that the observations need to be taken over a long period of time, preferably several days or weeks. This ensures that the data is more representative of the true performance of the operator. The use of the automated system does not require constant attention from the operator and the period of the study may easily be extended.

3.1. The program

The program is written in C++ using NetBeans IDE 6.8. Netbeans creates a stand-alone application. The program needs drivers for the webcam to be installed on the computer for it to operate. The program consists of the following elements: random function, sorting function, OpenCV and a text file

(Van Blommestein et al, 2010).

3.2. Random function

The program employs a random number generator to establish when observations of the worker are to be done. In this case a built-in random function in C++ (rand()) is used. This function has an upper limit of 32 768 which entails that the random times can be generated for a maximum period of 9 hours 6 minutes and 8 seconds (Deitel & Deitel, 2007; Van Blommestein et al, 2010).

3.3. Sorting function

The random numbers generated should be sorted into sequence. The bubble sort function is used together with the random number generator to ensure that the measurements do not overlap and that the recordings are processed in sequence (Deitel & Deitel, 2007; Van Blommestein et al, 2010).

The bubble sort principle works as follows: consider z random numbers, where z equals the number of random samples required per day. The ith random number is subtracted from the (i+1)th number. If the difference is less than zero then the numbers are swopped around.

Once all the numbers have been placed in order then the numbers are tested to ensure that the observations do not overlap. This is done by subtracting the ith random number from the (i+1)th number. If the difference is less than the length of time per observation then the ith number is discarded and a new random number is generated. The numbers are then bubble sorted again. This process is continued until z random numbers are determined.

3.4. Open CV

A fundamental element in the construction of the system is OpenCV. The OpenCV libraries are used to access the image captured by the web-cameras. OpenCV generates a pixel matrix of the image which enables tracking of the target worker through the frame. The image captured by the webcam is converted by OpenCV to a pixel matrix. This matrix is then edited by the program which enables the target object (worker) to be filtered. Each pixel in the image frame consists of a level for Red, Blue and Green (RGB). RGB is, however, difficult to work with. Hence, it is first converted by an OpenCV function to its equivalent Hue, Saturation and Luminosity (HSL) value.

In Figure 1, it can be seen that any specific colour consists of corresponding HSL and RGB values. The advantage of the HSL values is that the values vary specifically with regard to the direction of movement on the colour plane.
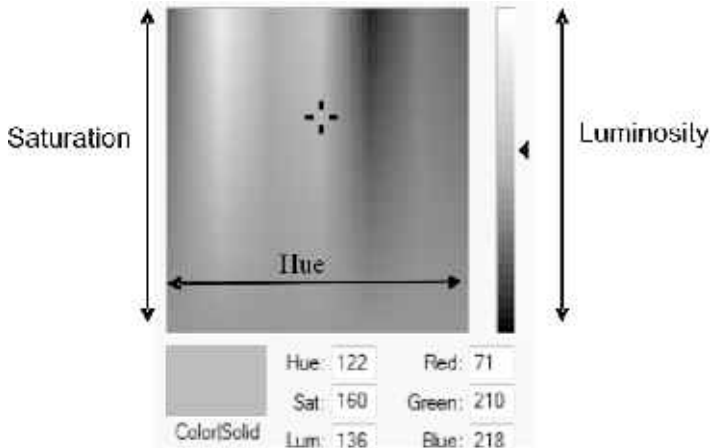
Figure 1: Fundamentals of colour

A bandwidth filter, represented in Figure 2, was created to allow a range of colours to pass through the filter. The filter is used by setting maximum and minimum values for each of the HSL values. Each of the HSL values range between 0 and 255. The values between the HSL "+" and "-" values are passed through the filter and all colours not falling within that spectrum are zeroed out. The filtered object is seen as a white object against a black background as in Figure 3. The user can adjust the values on the scale thereby making the program flexible and ensuring that the target object (or observed worker) can be of any colour. Each of the cameras has its own filter.
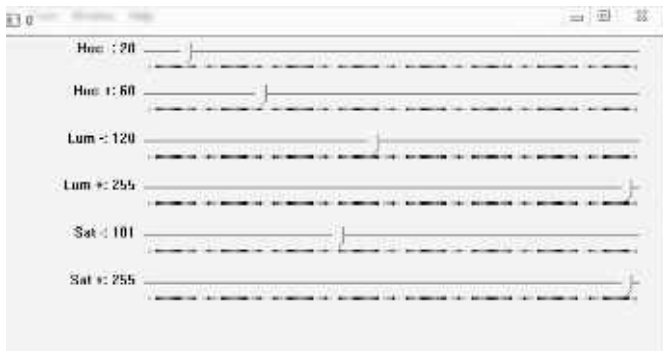
Figure 2: HSL Bandwidth filter

A function is then created to find the centre-point of the target object's pixels. The function counts each of the filtered pixels and plots a mid-point, for example in the hand of a target worker as shown in Figure 3. Equations 1 and 2 are used to determine the centre point. The x and y in the equations represent the x and y coordinates, in terms of pixel values. The program plots a green point at this location allowing the user to view the movement of the centre point throughout the frame. This point is tracked and analyzed in the program.

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad (1)$$

$$\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n} \qquad (2)$$

The centre-point's location is determined every time the frame is refreshed. Its data is analysed in real time and a moving average pixel speed is determined. The filtered image and the centre point are represented in Figure 3. In the case when the target object (in this case, a worker's hand) is moved out of the screen as in Figure 4, a large negative value is communicated to C++. This number is then converted to zero. This in turn means that when the target worker moves out of the screen a 0.00 velocity value is recorded (Joines & Roberts, 1995; Levin, 2006; Chentao & Feng, 2009; Yu, Cheng, & Zhou, 2004).

It is important that only the target object is passed through the filter and that only one such object be present in the frame. A prerequisite of the program is that the target worker should wear distinguishing item. In this case a yellow glove is used as shown in Figure 3. This in turn requires that no other items of the same or similar colour be present in the frame.
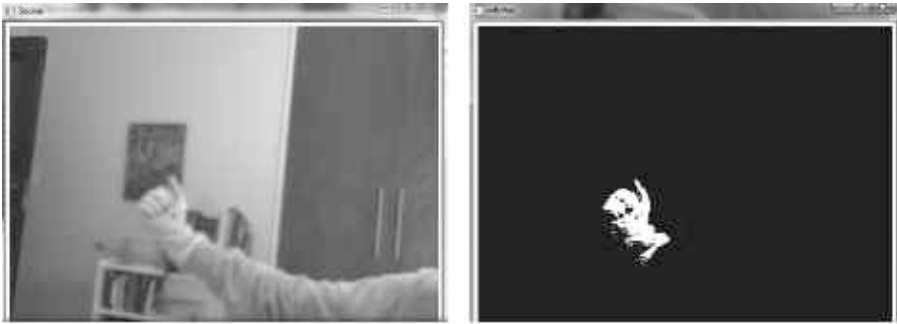
Figure 3: Simple hand movement screenshots of both the source and the filtered images. The green dot is located at the centre of the filtered object (Van Blommestein et al, 2010).

Figure 4: No target object in screen, (Van Blommestein et al, 2010).

Noise is always present in the system and it can be identified as white specks jumping around in the image screens. The noise plays an important role in the classification of the user states. In cases in which the target glove is in the screen, but stationary, noise (corresponding to insignificant movement) is recorded by the program. Therefore, a worker is classified as being idle as opposed to being out of screen. The noise is catered for by a median smooth function in OpenCV, and setting a minimum pixel-count threshold. The threshold ensures that the centre point is determined only when a certain number of pixels are present in the video frame. This value will vary for different set-ups and as such can be changed by the operator. The number of filtered pixels is presented in the top left corner of the filtered screen. In Figure 5 a similar colour to that of the target has entered the screen resulting in the presence of noise (white dots). The number of filtered pixels in the screen is 48 and is indicated on the top left corner, indicating that the target object is out of screen. This is because a threshold of 500 pixels had been set. In ideal conditions the pixel count when the target object is out of screen is 0.
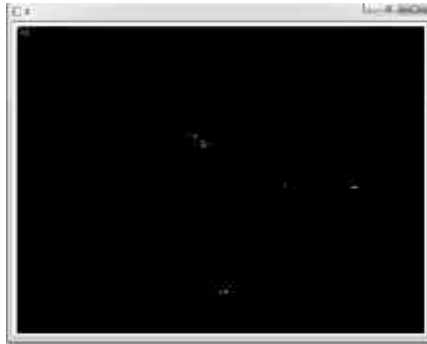
Figure 5: Noise and number of filtered pixels represented (Van Blommestein et al, 2010).

3.5. Writing to file

The data is recorded on a text file. This data can then be exported to any spreadsheet program where the analysis is done. This ensures flexibility in the processing of data (Deitel & Deitel, 2007). A text file is created for the data captured by each of the cameras. Hence a file is generated for every worker per given shift of the day. The pilot program considered in this case is set up to accommodate three eight hour shifts per day.

4. EXPERIMENTAL TESTING OF THE AUTOMATION OF WORK SAMPLING

Three hundred (300) random samples were taken over a three hour period. In the first hour the worker was busy doing work, in the second he was idle and in the third hour he was out of screen. In Table 2 it can be seen that in 99 out of the 105 samples taken, the individual was classified as working with an average pixel velocity of 67.5. Further investigation found that the values corresponding to the remaining six classifications were zero values, indicating that the worker was out of screen   Measurements for the third hour when the worker was out of the screen indicated an average velocity of a zero value. As for the second hour when the worker was in the screen, but stationary and idle, the prevalence of noise resulted in an insignificant average pixel velocity of 2.23 as shown in Table 2.

Table 2: Test data results (Van Blommestein et al, 2010)

Hour	Number of Samples	Working	Not Working	Average Pixel Velocity
1	105	99	6	67.5
2	108	0	108	2.23
3	87	0	87	0.00

The tests indicated that within a controlled environment, the system adequately classified a worker as busy or idle.

5.   CONCLUSION

The analysis and comparison of work sampling and time study against Hawthorn effect, labour intensiveness, cost, tediousness and extensive knowledge of given task proves that work sampling is a better option for a development of an automated labour performance measurement system. Furthermore, the automation of work sampling is far less complex than that of a time study because a tracked object can be classified as either busy or idle with less effort. On the other hand, time studies require the operator's movements to be broken down into sub-movements which need a complicated and unique programming.

Therefore, a labour performance measurement system based on work sampling is presented. It consists of a number of web-cameras linked up to a central computer via USB extenders. The computer runs a standalone C++ application. The application uses a random function to determine when "measurements" are to be taken. The developed video-camera footage is converted into a pixel matrix using OpenCV. This matrix is then filtered and analysed, enabling the tracking of the movements of a worker. The weighted average pixel velocity of the worker is determined by the program. This data generated by the system (time and velocity) is then stored in manageable text files. After the work sampling period has elapsed, the data is extracted into a Microsoft Excel (or any spreadsheet program) for analysis. Finally a report of the labour utilisation is generated in Microsoft Excel which is then sent to the analyst for review.

6.   REFERENCES

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