Using SPC Chart Techniques in Production Planning and Scheduling : Two Case Studies

Operations Planning, Scheduling and Control

Thananya Wasusri* and Bart MacCarthy
Operations Management and Human Factors Research Group
School of Mechanical, Materials, Manufacturing Engineering and Management
The University of Nottingham
University park, Nottingham England NG7 2RD
Tel :+44-115-951-4118 Fax: +44-115-951-4000
e-mail : Epxtw@unix.nottingham.ac.uk*
Bart.maccarthy@nottingham.ac.uk

Abstract: Theoretical scheduling has reached a mature state but there are difficulties in using the theory in practice. One of the issues is the occurrence of disturbances. Studies have been done to investigate the possibility of using control chart techniques to detect disturbances in production planning and scheduling. Appropriate control chart techniques have been developed that avoid statistical problems, assuming that the whole system may be viewed as a dynamic process. To validate the new techniques, data have been collected in two different business sectors. The control charts show their ability to detect changes and their potential for practical implementation.
Key words; production planning and scheduling, dynamic process, control chart

Introduction

Statistical Process control (SPC) is a tool which has been successfully used in both manufacturing and non-manufacturing sectors. SPC charts were first developed to distinguish between common causes and special causes of variation. The ability to distinguish between the two causes results in improvements in a process by reducing the variation. If no points fall outside the control limits and non-random trends are not evident, the process is said to be stable or in statistical control. Reduction in process variation can be achieved even when the process achieves stability, but radical change may be required. Therefore, SPC charts are tools that can be used to achieve process stability, to provide a guideline to reduce process variation, to assess a process's performance and to provide information for management (Dale ,1994).

Classical production planning and scheduling have been viewed as being in a mature state (MacCarthy and Liu, 1993), but there are difficulties in using the theory in practice and many organisations continue to have problems in planning, scheduling and control. Stoop and Wiers (1996) give a number of causes which affect the applicability of scheduling techniques in practice. Disturbances from machine breakdowns, unavailability of raw material, rush orders and human factors may occur frequently. To achieve the stability of production planning and scheduling, Wasusri and MacCarthy (2000) have proposed that production planning, scheduling and control be looked at as a dynamic control process. SPC techniques could be applied in order to detect all changes in the process.

However, many caveats have been raised in implement SPC charts in non-manufacturing applications (Humble, 1998), (Lewis, 1999), (Finison, et al., 1993), (Wood, 1994). MacCarthy and Wasusri (2000) conducted simulated experiments with different control chart types, dispatching rules and performance measures in order to provide control charts that can work well under production planning and scheduling environments. The data found from experiments simulated environments show correlation and deviate from normally distributed. The classical Shewhart control chart does not work well and tends to give many false alarms. They conclude that the Exponential Weighted Moving Average chart (EWMA) may work well in many circumstances. The EWMA chart generates less type I errors because the EWMA chart is more robust to data which are correlated and non-normally distributed (Wardell, et al., 1992), (Borror, et al., 1999), (Lu and Reynolds, 1999). The EWMA chart is used to monitor the mean value, while the Exponential Weighted Moving Variance chart (EWMV) is used to monitor variance of the performance measured (Montgomery, 1996) , (MacGregor and Harriss, 1993). The formulation of the EWMA and the EWMV charts are below.

The EWMA chart

$$\overline{Z}_i = \lambda \overline{X}_i + (1-\lambda)\overline{Z}_i \qquad (1)$$

$$UCL = \mu_0 + L\sigma_{\bar{x}}\sqrt{\frac{\lambda[1-(1-\lambda)^{2i}}{(2-\lambda)}} \qquad (2)$$

$$CL = \mu_0 \qquad (3)$$

$$LCL = \mu_0 - L\sigma_{\bar{x}}\sqrt{\frac{\lambda[1-(1-\lambda)^{2i}}{(2-\lambda)}} \qquad (4)$$

Z_t is the value plotted on the control chart and is a weighted average of all previous plotted values

$Z_0 = \mu_0$, the estimated process mean and a starting value for the EWMA

λ is a smoothing parameter

L is a parameter defining the width of the control limits

$\sigma_{\bar{x}}$ is the standard deviation of the observations $\overline{X}_i$

The EWMV chart

$$\sqrt{\overline{S}_i^2} = \sqrt{\lambda(\overline{X}_i - \overline{Z}_i)^2 + (1-\lambda)\overline{S}^2_{i-1}} \qquad (6)$$

$$UCL = \sigma_0 * C_8 \qquad (7)$$

$$CL = \sigma_0 \qquad (8)$$

$$LCL = \sigma_0 * C_7 \qquad (9)$$

Where; C_8 ,C_7 are given in (MacGregor and Harriss, 1993)

$$\sigma_0 = E[\sqrt{\overline{S}_i^2}] \qquad (10)$$

The above conclusions were based on simulated experiments. The question then arises about the potential, advantages and disadvantages of using SPC charts as control mechanisms in real production planning ,scheduling and control environments. This paper investigates the possibility of applying SPC charts in production planning, scheduling and control in two different business sectors. Studies were conducted with two companies based in Thailand. The advantages and disadvantages of the techniques are discussed, as well as the wider implications for using SPC charts in monitoring planning, scheduling and control systems.

Performance measures of interest

In conventional applications, the control chart plays an important role in monitoring and controlling some physical quality characteristics of interest such as the weight of lubricant oil and the proportion of C_3 and C_4 in Liquid Petroleum Gas (LPG). These measures will already have been defined relating to their product specification. Flow time, WIP and proportion of tardy jobs are typical examples of performance measures of interest in planning and scheduling, in theory and in practice. The two companies in this study are interested not only how is to utilise their resources in order to obtain optimal flow time or minimising the proportion of tardy jobs, but also the ability to meet the organisations' targets on flow time per job and monitor the amount of output per day. The differences between target output and actual output per day and the actual and target flow time per job represent the organisations' target for control and ultimately variance reduction. The application of SPC to planning, scheduling and control must consider the execution of planning and scheduling.

Company A

Company A produces standard semiconductors and electronic components for its parent company, which is based in Japan. The company production system is make to stock (MTS). Production plans are established by following the parent company's forecasts and its stock status, which are given every month for the next three months. After receiving the sales forecast from the parent company, company A then establishes its own main production schedule (MPS) by having a meeting between the inspection department, production department, engineering department and purchasing department. The monthly, weekly and daily plan are given to departments that are related with the production department. The performance measure used to control production planning and scheduling of company A is the differences between planned flow time per job and actual flow time per job. There is no other tool used to control or monitor the performance measure of interest. The execution of production planning and scheduling is reviewed every day, but without collecting and doing charting to see its trends or behaviour.

Constructing control charts

To investigate the possibility of applying SPC charts as a control method in production planning and scheduling, the authors were allowed to collect data from the inspection department which is the final operation before the packing process. The planned flow time and actual flow time of 5 and 10 jobs per day were selected randomly-there are about 15-20 jobs per day. The best fit of the data distribution was found to be a lognormal distribution. Two subgroup sizes -5 and 10- were selected because small subgroup size such as size n = 4, 5, or 6 is said to be reasonably effective in detecting moderate to large process shifts (Montgomery, 1996). On the other hand, if small process shifts are of interest, a larger sample size should be considered. Experimentation with different control charts is needed to investigate which control charts can give good results with respect to type I error. Classical Shewhart control charts (with mean and range chart) and the EWMA with the EWMV charts have been constructed for data from company A for 73 working days. The data from the thirty working days were collected to set up the control limits. The data for the remaining other forty-three working days were plotted with the control limits obtained.

See figure 1
See figure 2
See figure 3
See figure 4

Results

The control charts provide visibility to help to control production planning and scheduling at company A. It shows that before the 24th day, the inspection department could execute its production plan within the control limits, which were set from its previous data. An out of control state has been detected in figure 1 and figure 3 with a point outside the upper limit on the 24th day. On checking the 24th day, it was found that one job had been delayed by about 50 days. The Shewhart chart in the figure 3 also shows some other points out of control which may be type I errors. On the other hand, it may be type II errors for the EWMA chart as the EWMV and R charts could detect some changes within subgroup before the 24th day. It cannot be concluded definitely either way unless a very detailed made. However, it is noted that the authors computational experiments in simulated environments found significant type 1 error problems with the classical Shewhart approach.

For the EWMA and EWMV charts, the need to recalculate the Z_i value after a point is plotted outside the control limits must be noted. For monitoring the difference within a subgroup, both R and EWMV charts are constructed. The R and EWMV charts can detect changes within a subgroup, but the EWMV chart may give less type I errors. It can be seen that both the EWMA and EWMV charts have many points outside the control limits after the out of control state has been detected. The Z_i and S^2_i value have not been recalculated in figure 1 and 2.

Company B

Company B is a high quality garment factory. It produces women's clothing, women's underwear and children's clothing. Each product needs highly skilled workers. It takes about three months on the job training for a new worker before they are allowed to perform any jobs in the main production line. Company B has two policies for production. Firstly, in Make-To-Stock, every month, the production planning department receives a master plan from the sales department as a rolling three month order. Secondly, in Make-To-Order, the company receives orders from its main customer, which is based in Japan. From the master order, stock status and orders from its external customer, the production planning department establishes a master production plan and a monthly plan for the production department. The production department will then establish weekly and daily plans for each working team. To make a daily plan, work standards, which are established on a work measurement basis, are used to consider how long each job order should take. Each working team has its own output target per day and at the end of the day its actual output will be compared with the target. As the production system is mainly based on human skill, it may take a longer time than expected when a new pattern is introduced. Human factors such as illness and available skills play an important part in production planning and control.

Constructing control charts

The data from two working team, T1 and T2 team, have been collected to construct the control chart. The differences between target output per day and actual output per day were used for monitoring. The best fit of T1 data was found to be normally distributed and that of T2 was Beta distributed. The combined measurement target output of T1 and T2 and the actual output of T1 and T2 have been collected in order to monitor the overall production using one mean chart. This enables total production to be viewed with only one control chart. Data from twenty-six working days data have been collected to set up the control limits for the EWMA chart with subgroup size = 1.

See figure 5
See figure 6
See figure 7

Results

The control chart of T1 shows a state of statistical control while the out of control state is shown on the T2 and T1&T2 control charts. The T2 data was confirmed to be under the working standards, but the root causes have not been investigated. However, it is clear that the use of a control chart is able to detect the problem. The details of each working team will need to be analysed when an out of control state is detected. Therefore, a control chart for each working team may be avoidable. This supports the work of the authors with simulated data in complex environments.

Discussion

The application of SPC charts in production planning and scheduling is different from conventional applications in the manufacturing sector. In the manufacturing sector, SPC charts are used to quickly detect the occurrence of special causes of process shifts. Investigation and corrective action can be undertaken before many defective products are manufactured. Therefore, an on-line process control chart technique has been widely used. On the other hand, the performance measure used to construct SPC charts in production planning and scheduling can be obtained only after a job has already been done. Investigation and corrective action cannot be undertaken at the time the job is being produced. There may be a longer time lag.

However, the ultimate goal of SPC is to eliminate special variability, which affects the process stability. This issue is important in production planning, scheduling and control just as it is in conventional applications in the manufacturing sector. Prevention of special causes is more important than quickly taking action in order to ensure a job is not behind schedule. Looking at company A, the control charts show that the process is not in control and the process capability index is about 0.52. It can be said that there is a lot of chance that an out of control process can occur again. The process cannot guarantee an in statistical control state. The main factor affecting the process capability index is the major delay of some jobs, caused by unavailability of materials from the parent company. If this point can be sorted out, the process may be more stable which complies with the assumption of SPC that when the in-control state is shown, it will tend to maintain its state without continual adjustment.

A control chart can be used to monitor an overall production planning and control system. Company B, has one of the working teams working below the company's standard. Both the control chart constructed by using the under standard working team and the control chart constructed from the overall data showed the out of control state. This provides evidence that a control chart can be used to represent one overall system. When an out of control state is shown, investigation of each working team will need to be done. Construction of the sub-control charts may be done, but it might be costly in terms of time and labour. The sub-control charts may provide natural performance limits for each working team which can be useful as a management tool and the control charts can be used to trace back when the overall control chart shows an out of control state.

Both the classical Shewhart charts and the EWMA and EWMV charts detect changes in a process. The classical Shewhart charts can give more false alarms when the underlying data is not normally distributed or is strongly correlated. Although the EWMA/EWMV chart is robust with respect to type I errors the problem of re-calculate after an out-of-control signal must be considered. In addition to these, even where the data is not normally distributed, the Shewhart chart may be useful. When the cost of investigation is reasonably low, comparing the cost might occur if a company cannot meet its customers satisfaction (Montgomery, 1996).

It can be concluded that the use of the SPC chart in production planning, scheduling and control has potential in practice. The main advantage is that the control chart can help management to understand the nature of the company's production planning, scheduling and control process. The main disturbances which affect the company's production planning and its execution will be found and its effect will be clear in a quantitative way. This can help management to decide which disturbances must be eliminated and their priority Once the process is in statistical control, the reduction of process variation can be investigated. This can be done by using other techniques such as simulation and experimentation and considering capability. Radical change may not be inevitable. The SPC chart has the potential to maintain stability in production planning, scheduling and control within the constraints of the design of the production planning, scheduling and control system However, the disadvantages of SPC charts must be acknowledge. It will take time for practitioners to understand and construct control charts and interpret correctly. The control chart cannot guarantee that the organisation is operating efficiently. It can show only how the organisation is or has been operating.

Reference List

Borror, C. M., D. C. Montgomery, and G. C. Runger. "Robustness of the EWMA Control Chart to Non-normality". *Journal of Quality Technology*. Vol. 31, No. 3 (1999). pp.309-316.

Finison, L. J., K. S. Finison, and C. M. Bliersbach. "The Use of Control Charts to Improve Healthcare Quality". *Journal of Healthcare Quality*. Vol. 15, No. 1 (1993). pp. 9-23.

Humble, C. "Caveats Regarding the Use of Control Charts". *Infection Control and Hospital Epidemiology*. Vol. 19, No.11 (1998). pp. 865-868.

Lewis, N. D. C. "Assessing the Evidence from the Use of SPC in Monitoring, Predicting & Improving Software Quality". *Computers & Industrial Engineering*. Vol. 37 (1999). pp. 157-160.

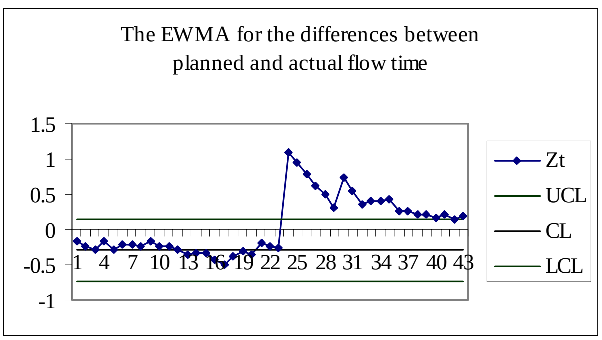
Lu, C. and M. R. Jr. Reynolds. "EWMA Control Charts for Monitoring the Mean of Autocorrelated Processes". *Journal of Quality Technology*. Vol. 31, No.2 (1999). pp.166-188.

MacCarthy, B. L. and J. Liu. "The Classicification of FMS Scheduling Problems". *International Journal of Production Research*. Vol. 31, No.1. (1993). pp.59-70.

MacCarthy, B.L. and T. Wasusri. "A Review of Non-standard Applications of Statistical Process Control (SPC) Charts". *Submitted to Journal of Operational Research Society*. (2000)

MacGregor, J. F. and T. J. Harris. “The Exponentially Weighted Moving Variance”. *Journal of Quality Technology*. Vol. 25, No. 2. (1993). pp. 106-118.
Montgomery, D. C. *Introduction to Statistical Quality Control*(3rd ed.) U.S.A.: John Wiley & Sons, Inc., 1996.
Stoop, P. P. M. and V.C.S. Wiers. “The Complexity of Scheduling in Practice”. *International Journal of Operations & Production Management*. Vol. 16, No. 10 (1996). pp. 37-53.
Wardell, D. G., H. Moskowitz, and R. D. Plante. “Control Charts in the Presence of Data Correlation”. *Management Science*. Vol. 38, No. 8. (1992). pp. 1084-1105.
Wasusri, T. and B.L. MacCarthy. “Scheduling Process Control”. *Proceeding of the International Conference on Production Research, special ICPR 2000, August 2-4, 2000, Bangkok Thailand*. (2000).
Wood, M. “Statistical Methods for Monitoring Service Process”. *International Journal of Service Industry Management*. Vol. 5, No. 4. (1994). pp. 53-68.
Zhang, N. F. “Process Capability Indexs for Autocorrelated Data”. *Journal of Applied Statistics*. Vol. 25, No. 4. (1998). pp. 559-574.

Figure 1 The EWMA chart for the difference between planned and actual flow time, subgroup size 10, company A (left)
Figure 2 The EWMV chart for the difference between planned and actual flow time, subgroup size 10, company A (right)



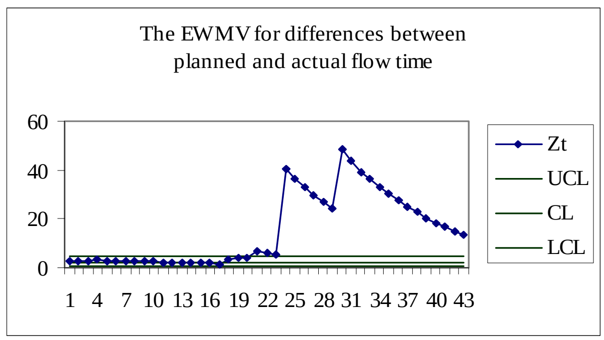
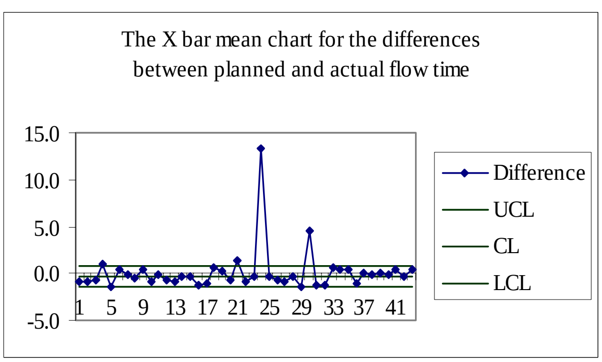


Figure 3 The $\overline{X}$ chart for the difference between planned and actual flow time, subgroup size 10, company A (left)

Figure 4 The R chart for the difference between planned and actual flow time, subgroup size 10, company A (right)



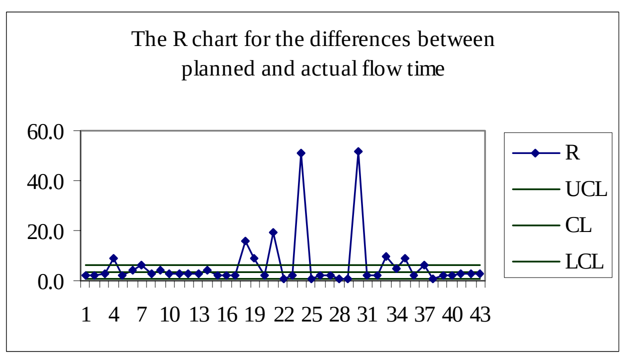
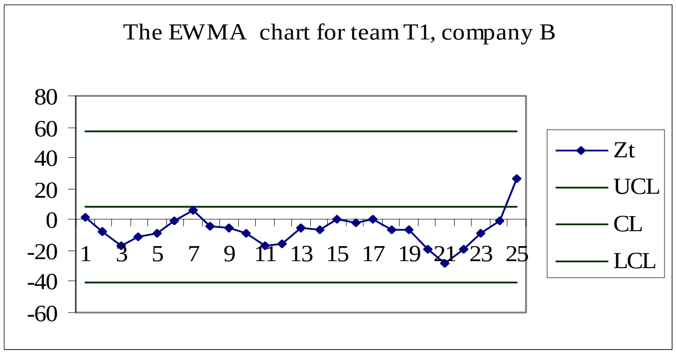


Figure 5 The EWMA chart for the difference between planned and actual output/day working team T1, company B (left)
Figure 6 The EWMA chart for the difference between planned and actual output/day working team T2, company B (right)



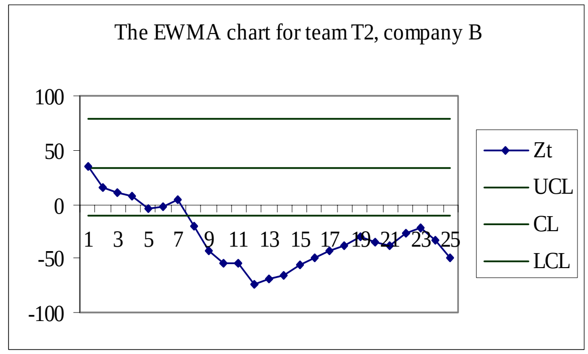


Figure 7 The EWMA chart for the difference between planned and actual output/day working team T1&T2, company B