JOURNAL OF PUBLIC PROCUREMENT, VOLUME 3, ISSUE 1, 29-42 2003

CONTROLLING WAREHOUSE PERFORMANCE WITH STATISTICAL PROCESS METHODS

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ABSTRACT. Agency management in the city of Houston, Texas, had a problem measuring and controlling maintenance, repair, and operations warehouse performance. This case study describes how better control can be achieved through application of statistical process control to certain activities. To develop the application, the agency viewed particular activities associated with warehousing as controllable processes. Historically, statistical process control has been applied mostly in a manufacturing or production environment as a means of maintaining an acceptable level of product quality. This case shows that statistical process control can be and is a useful tool for controlling and managing services in the public sector.

INTRODUCTION

To support maintenance activities, the city of Houston, Texas, operates 10 maintenance, repair, and operations (MRO) warehouses. The agency responsible for managing this inventory wanted a way to measure the performance of certain warehouse operations that would also alert them to developing and existing problem situations. After determining objectives and defining particular indicators to measure performance, the agency needed a way to track performance that would provide management reports of ongoing activity and exception reports usable to prevent and correct performance problems. While basic tabular

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reports of activity and performance would provide the required data, it was determined that, to identify developing or ongoing problem areas for process operations, statistical process control (SPC) methodology would be a more effective tool because of its graphical representation of trends and situations. While SPC has most often been applied to manufacturing processes, it has been applied in other areas including improvement of inventory accuracy (Hart, 1998). Historically SPC has been used to measure and control the quality of manufactured parts produced by a process. The resulting parts must be produced to a particular quality standard to achieve the required quality level. Certain aspects of the warehouse performance management problem faced by the city can also be viewed as controllable processes. Certain process tasks must be performed to deliver a service at a required level of quality. The only difference between the warehouse and a manufactured part is that the warehouse delivers a service and the manufacturing process produces a tangible part. This paper describes the quality measures decided upon and the application of SPC as a means of controlling process aspects of warehouse performance to desired levels.

THE SITUATION

The city of Houston, Texas is the fourth largest in the United States with about two million residents and a city budget of $2.5 billion for 2002. The city encompasses about 640 square miles. Ten maintenance, repair, and operations (MRO) warehouses serve a municipal maintenance operation for the Public Works and Engineering Department. While the warehouses vary in size, number of items stocked, and personnel, all provide essentially identical services under the same set of operating procedures. An approach was desired to measure the efficiency and effectiveness of performance of all ten warehouses that would provide data with which to compare and control performance of the warehouses overall, to each other, and over time, and that would identify developing and existing performance problems to facilitate preventive and/or corrective action.

OBJECTIVES AND PERFORMANCE MEASUREMENTS

The objectives of both inventory management and warehouse management can be stated as (Arnold & Chapman, 2001):

- Maximize customer service

- Minimize costs

The agency decided use the terms "efficiency of operations" to represent cost minimization, and "operational effectiveness" to represent customer service maximization.

Because it may be difficult to directly measure how well these objectives are being met, research indicated a number of possible performance measures that can be used for this purpose: Possible measures of efficiency performance: inventory turnover, equipment utilization, personnel productivity, space utilization, budget performance; Possible measures of effectiveness performance: on-time delivery of orders, completeness of orders, number of complaints received, avoidance of damage, accuracy of order filling (Ackerman, 1997; Duncan, 1986). The following measures were selected for use:

Efficiency

Measure by inventory turnover. Inventory turnover is an indication of how efficiently inventories are being used by relating inventory quantity to inventory usage. Because of different supply and demand characteristics, it was decided to use two turnover measures to indicate warehouse efficiency.

- Turnover of commodity materials inventories – measure by dividing the value of warehouse issues of these materials by the average inventory of them

- Turnover of spare parts inventories – measure by dividing the value of warehouse issues of spare parts by the average inventory of them.

Effectiveness

Measure by using the following indicators of customer service and maintenance staff productivity:

- Service delivery performance – measure by completeness of orders (the number of line items issued as a percentage of the number of line items requisitioned)

- Service delivery time – measure by the time taken to locate, pick and deliver to a requestor (the total person-time required to deliver an order to a requestor)

- Production downtime due to stockouts – measure by the time equipment is out of service due to inventoried parts being out of stock

- Lost maintenance productivity due to stockouts – measure by the time maintenance personnel are idle due to needed parts being out of stock

Turnover measures for efficiency are calculated from monthly summary data on average inventory and material issued. These are not "process" elements. Therefore they were not included in the SPC application and are controlled by analysis of monthly summary data. The same is true for production downtime and lost maintenance productivity. The remaining two effectiveness measures, service delivery performance and service delivery time, are the core of the warehouse service process and the locus of application of SPC methodology.

SPC METHODOLOGY

SPC methodology is well established so only a brief summary is presented here. A more detailed discussion can be found in various references, (e.g. Summers, 2000; Mitra, 1998; Evans & Lindsay, 2002). Every process, whether to produce a physical product or a service, has common ingredients of people, equipment, inputs, methods, and environment. All of these interact to produce an output. The intent of every process design is for the process to function identically each time it is executed to provide consistency of output. However, the natural variations that occur in materials, people, equipment, and environment, and in how they interact introduce an element of variability of output. If the variability in a process is from such random causes and not from some specific cause affecting the process, over time the random variability often causes the frequency of occurrence of different amounts of variation to take on the characteristics of a normal distribution. If the production capability of the process is sufficiently centered on the target or desired value of the output, then the actual values over time will be symmetrical around the target value. Where these conditions exist, SPC is a method that can be used for monitoring the variability to ensure it does not exceed a tolerance required to produce an acceptable quality of output.

To use SPC, the process is monitored by taking periodic samples of output. The characteristics of the samples are measured and plotted to detect unacceptable output or trends toward exceeding acceptable tolerances. When such output or trends are found, corrective action can be taken to stop or prevent the production of defective units.

Various charts of performance can be used with SPC (Summers, 2000). For the warehouse application, the basic X-bar and R charts are used. These charts indicate the average value and the range of data, respectively, of samples taken from the process. For the X-bar chart, the average value of the measured service criterion is plotted while for the R chart, the range of the criterion is plotted. The X-bar chart compares the current value to a desired value and the R chart indicates the current range of data compared to a desired range.

APPLICATION OF SPC METHODOLOGY TO WAREHOUSE CONTROL

To apply SPC, control limits must be set. These values indicate the range of acceptable process outcomes and values outside the limits or trending toward them indicate existing or developing non-random process problems (or, in SPC terminology, problems from assignable causes). For X-bar and R charts it is common to set the control limits to achieve a particular objective probability that if the process is in control, the sample value will fall within the control limits. For example, using a commonly applied control objective of 99.7%, the control limits are set at plus or minus three standard deviations from the desired value. This is termed 3-sigma control. The result of this is, if the values are normally distributed and the process is in control, 99.7% of the sample average values will fall within the control limits.

For the city of Houston situation, it was determined from histogram analysis of samples of performance measurements that the distributions of variation in the processes were approximately normal and the means of the measurements were at acceptable levels of performance. Thus, the current processes over all warehouses were approximately centered on the desired performance levels, and the application of SPC to control warehouse performance was appropriate. Since current overall performance of all warehouses together was acceptable, the mean values of current performance were used as the target or desired performance values for all warehouses and overall. If current performance had not been acceptable, different target values could have been used with the data determining control limits from those values. To determine the variability and normality of distribution of the warehouse process results, samples of activity data were collected for 16 days' operations for each of all ten warehouses. From this data, average performance values and ranges were obtained. Agency management determined that they wanted a 99.7% control objective, and therefore based control limits on plus or minus three standard deviations of the target performance value. For the X-bar charts, control limits for performance were determined using the widely accepted relationships:

$$UCL = \overline{X} + A_2\overline{R}$$

$$LCL = \overline{X} - A_2\overline{R}$$

Where: UCL = upper control limit
LCL = lower control limit
$\overline{X}$ = average (or desired) performance value
$\overline{R}$ = average range of sample data
A_2 = a standard statistical factor

The A_2 factor is available in quality control texts and references. It varies with sample size and causes the A X R terms to be approximately equal to 3 standard deviations, or 3 sigma. Thus the control limits are about 3 standard deviations above and below the desired value and result in the desired 99.7% control objective. In our situation with a sample size of 10, A_2 is .31 (Summers, 2000, Appendix 2). For the R-bar charts, control limits were determined for the range of performance:

$$(3) \quad UCL = D_4\overline{R}$$

$$(4) \quad LCL = D_3\overline{R}$$

Where:
UCL = upper control limit
LCL = lower control limit

$\overline{R}$ = average range of values of samples of the performance measure

D_3 and D_4 = standard statistical factors

D_3 and D_4 are similar to the A_2 factor discussed above for equations (1) and (2) for calculating control limits for performance. The D_3 and D_4 factors also vary with sample size and cause the D x R terms to be approximately equal to 3 standard deviations, or 3 sigma, to provide the desired 99.7% control objective as discussed previously. Using standard quality control tables (Summers, 2000, Appendix 2), D_3 is .22, and D_4 is 1.78.

To illustrate the application, we will discuss the control data across all warehouses. In practice, however, in addition to evaluating overall performance, each warehouse can be evaluated and controlled separately to enable identification of developing or existing problems specific to particular locations. In the Application section following, some examples of individual warehouse performance data are discussed.

Service delivery performance was defined as number of requested warehouse stock items issued as a percentage of the number of items requested. Service delivery time was defined as total person-time required to deliver an order to a requestor. For service delivery performance, the 16-day test period resulted in average performance (X-bar) of 96.3% and an average range (R-bar) of 15.2% (range was calculated by subtracting the lowest performance percentage from the highest percentage for each daily sample and taking the average of the resulting daily ranges). For service delivery time, we obtained an average performance (X-bar) of 42.4 person-minutes to deliver an order and an average range (R-bar) of 137.2 person-minutes (range was calculated in the same manner as for delivery performance). Using these values in equations (1) through (4), we obtain the following:

Service Delivery Performance:

(1A) UCL = 96.3 + .31 x 15.2 = 101%

(However, since 100% is the maximum performance possible, the upper control limit becomes 100%)

(2A) LCL = 96.3 - .31 x 15.2 = 91.6%

Service Delivery Performance Range:

(3A) UCL = 1.78 x 15.2 = 27.1%

(4A) LCL = .22 x 15.2 = 3.3%

Service Delivery Time Performance:

(1B) UCL = 42.4 + .31 x 137.2 = 84.9 minutes

(2B) LCL = 42.4 - .31 x 137.2 = -.1

(However, since 0 is the minimum time possible, the lower control limit becomes 0)

Service Delivery Time Range:

(3B) UCL = 1.78 x 137.2 = 244.2 minutes

(4B) LCL = .22 x 137.2 = 30.2 minutes

If any changes are made to the process, variability should be reassessed and control limits recalculated using a test period. If different target performance values were desired, the control limits would also need to be recalculated.

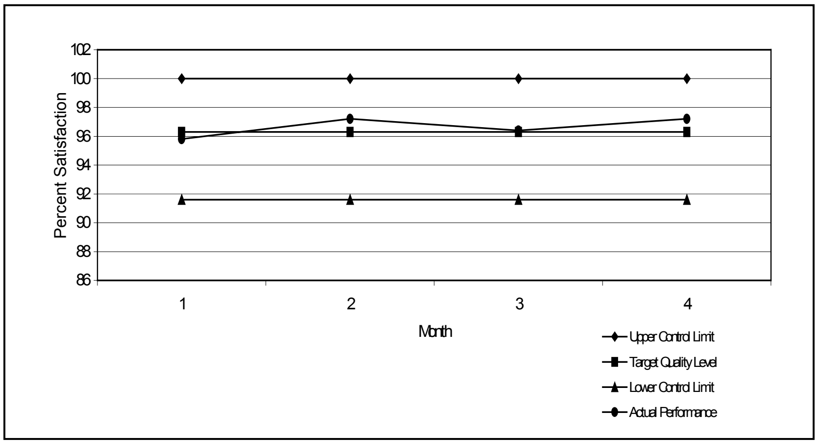
After establishing control limits, the control process was implemented on a test basis. Testing and evaluation is continuing with final implementation pending completion of evaluation of test results. During the first four months of operation, the monthly averages of samples taken across all warehouses for service delivery performance and service delivery time are shown in Figures 1A, 1B, 2A, and 2B. Table 1 contains individual warehouse data for a four-week period.

APPLICATION OF THE DATA TO IMPROVE WAREHOUSE MANAGEMENT AND DISCUSSION OF RESULTS

Control Chart Results

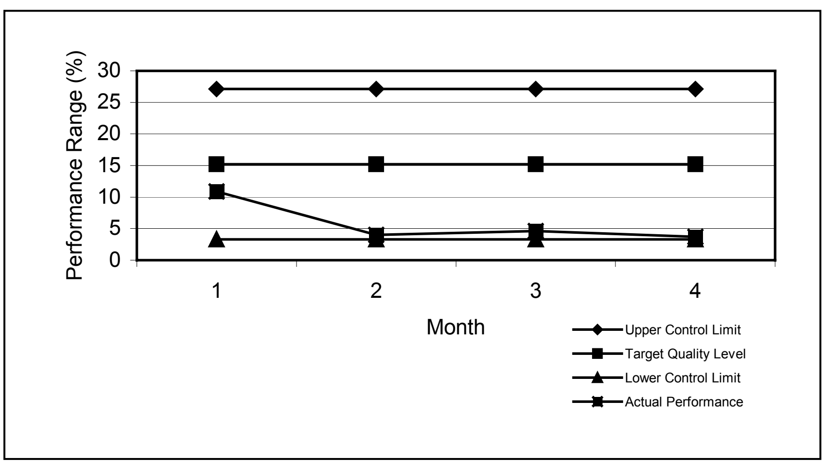
Indications for all warehouses overall from Figure 1 are that overall the process is in control with no apparent developing trends

FIGURE 1A
Service Delivery Performance



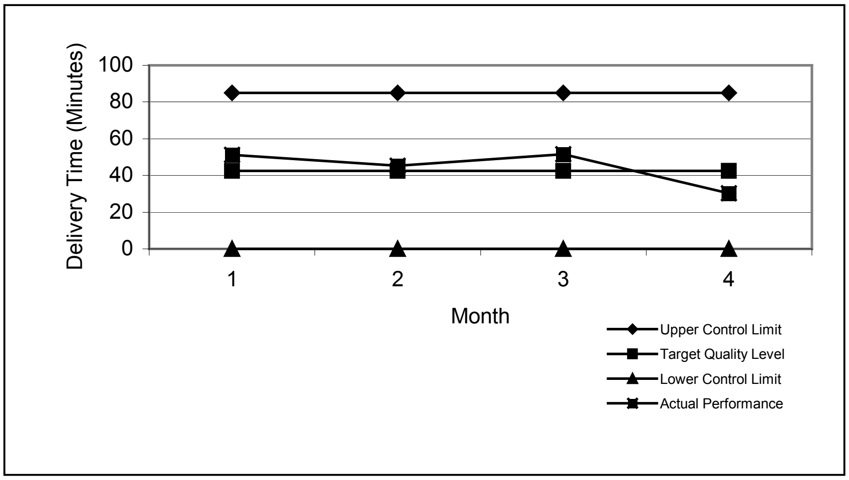
Notes: Percent delivered: Month 1 = 95.8, Month 2 = 97.2, Month 3 = 96.4, Month 4 = 97.2
Upper Control Limit = 100, Target Quality Level = 96.3, Lower Control Limit = 91.6.

FIGURE 1B
Range of Service Delivery Performance



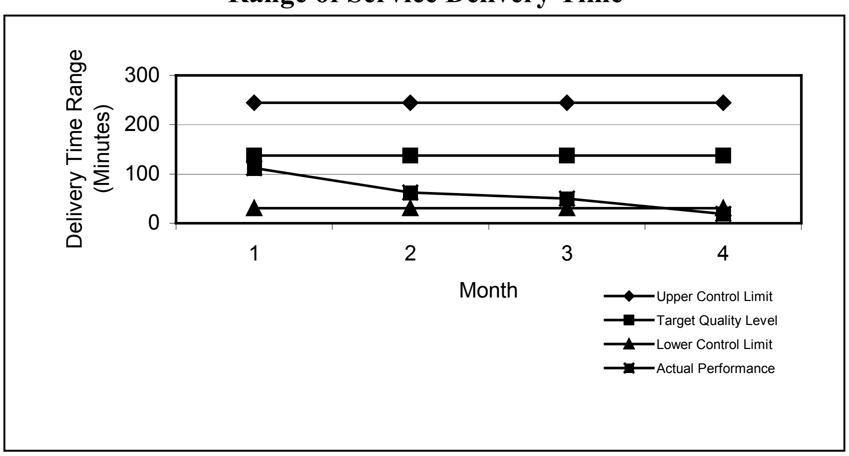
Notes: Range of Percent Delivered: Month 1 = 10.9, Month 2 = 4.0, Month 3 = 4.6, Month 4 = 3.7.
Upper Control Limit = 27.1, Target Quality Level = 15.2, Lower Control Limit = 3.3.

FIGURE 2A
Service Delivery Time



Notes: Delivery time in minutes: Month 1 = 51.3, Month 2 = 45.3, Month 3 = 51.5, Month 4 = 30.2
Upper control Limit = 84.9, Target Quality Level = 42.4, Lower Control Limit = 0.0.

FIGURE 2B
Range of Service Delivery Time



Notes: Range of Delivery Time in Minutes: Month 1 = 111.9, Month 2 = 62.1, Month 3 = 4.6, Month 4 = 3.7
Upper Control Limit = 244.2, Target Quality Level = 137.2, Lower Control Limit = 30.2.

TABLE 1
Weekly Warehouse Performance

Panel 1. Order Filling Percentage						
Warehouse	Week 1	Week 2	Week 3	Week 4	Average	Range
Alpha	100	96.6	94.4	95.2	96.55	5.6
Beta	100	100	100	98.4	99.60	1.6
Gamma	92.5	99.1	87.9	94.1	93.40	11.2
Delta	100	100	100	100	100	0
Epsilon	100	100	100	100	100	0
Zeta	94.2	91.8	95.8	93.7	93.88	4.0
Eta	85.6	93.6	95.9	88.6	90.93	10.3
Theta	98.0	99.1	99.5	98.5	98.78	1.5
Iota	100	100	100	97.2	99.30	2.8
Kappa	100	100	100	100	100	0
Panel 2. Transaction Service Time (in Minutes)						
Alpha	52.9	78.6	50.5	42.4	56.10	36.2
Beta	15.8	20.0	20.0	12.0	16.95	8.0
Gamma	29.7	22.1	34.1	28.9	28.70	12.0
Delta	14.3	14.7	12.9	13.8	13.93	1.8
Epsilon	24.1	15.9	20.6	17.3	19.48	8.2
Zeta	24.5	10.5	15.5	19. 1	17.40	14.0
Eta	18.6	26.2	33.8	23.7	25.58	15.2
Theta	24.0	14.3	23.8	18.5	20.15	9.7
Iota	47.1	49.0	43.6	37.0	44.18	12.0
Kappa	102.1	32.7	49.0	56.1	59.98	69.4

and no out of control indications. We also see that the range of outcomes has narrowed over the time period included. From Figure 2, we can draw similar conclusions. In both examples the range measure dropped (narrowed) over the time period indicating less variability in performance as the time period progressed.

Individual Warehouse Results

Table 1 contains four weeks of data that we use to illustrate application of individual warehouse data to compare performance across all ten warehouse locations for that time period. This data can also be displayed with control charts for each warehouse, but to conserve space we use the tabular format and refer to overall control limits in Figures 1 and 2 in this analysis.

Service Delivery Performance

The top part of Table 1 indicates that for percent requisitioned line items filled completely (service delivery performance), warehouses Delta, Epsilon, and Kappa had 100% performance, well above the 96.3% target during this period, and all locations averaged over 90% performance. While higher percentages are good because they indicate that more orders are more completely filled, consistent numbers in the vicinity of 100% may indicate excess inventory at particular locations. Our performance target is not 100%, it is 96.3% not only because management has determined that that is a satisfactory level of service but also for the obvious additional reason that higher percentages will usually require higher inventories. Location Alpha's average performance was best of all locations by coming closest to the target value of 96.3%. We see that location Eta had 2 individual weeks where performance was below the lower overall control limit of 91.6% for this criterion. Eta also had the second highest variability of performance as indicated by its data range. Location Gamma had the largest variability range and one week where performance was below the lower control limit. Additional weeks or a trend of below control performance would warrant investigation of the causes of these below-control performances. Warehouse Zeta came close to exceeding the lower control limit in Week 2 and is consistently below target for the other weeks. It may also merit investigation but, because it is within the control limits, it would rate a lower priority for investigation than Eta and perhaps Gamma.

Service Delivery Time

For transaction service time (service delivery time), less time is generally better, but consistently-reported very short service times at particular warehouses could indicate reduced activity and possibly excess personnel at those locations. Location Iota had the best average performance by coming closest to the target of 42.4 minutes per delivery.

During this period, warehouse Kappa had the worst average performance and also had one week where its delivery time exceeded the upper control limit. Kappa also had the highest range of data. The combination of these two factors may warrant investigating the situation at that location to determine if any assignable causes exist or are developing.

In our situation, the process in use at all ten warehouse locations was identical. Therefore, to provide overall control we use overall control limits calculated from performance data across all warehouses. To provide individual warehouse control we use control limits calculated from individual warehouse data. However, if processes vary across locations, or if it is desired to test the variability of processes at different locations, overall controls may be misleading and only individual location data should be used. In such cases samples of performance must be taken during test periods at individual locations and the resulting individual control limits calculated. It may also be determined that what were thought to be identical processes have differing variability by location and in fact some process element(s) may not be identical. The data can thus provide a basis for process investigation and improvement.

In general, data points that fall outside the control limits on the charts indicate that specific assignable causes likely existed at that time. These should be investigated to determine causes and action taken to prevent recurrence. Similarly, trends of sample values toward the control limits should also be investigated for underlying causes and corrective action taken before the control limits are exceeded. In the situation described here, current performance was acceptable overall and the technique functions mainly as a control mechanism. For certain locations however, potential problems have been identified in the discussion of the data in Table 1. In situations where current performance is not acceptable, process changes can be made followed by a new test period to determine the variability and capability of the revised process and control limits for it. Acceptable performance targets and revised control limits from the new test period can then be used to control the revised process.

CONCLUSIONS

This case study shows how a warehouse performance management problem can be effectively improved by applying SPC to warehouse operations. It also demonstrates that warehouses and other service-type operations where SPC has not traditionally been applied can be managed and controlled by using SPC. SPC can also be used as a tool to evaluate and control revised and improved processes in service-type situations such as warehouse operations.

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