Maintenance Workorder Nonconformity and the TQM Process

Andrew Luna
THE UNIVERSITY OF ALABAMA

INTRODUCTION

For many years Total Quality Management (TQM) has been used successfully in the industrial sector. The question is, can TQM work for higher education and other service environments? Higher education, including auxiliaries such as student housing, are not manufacturers. Rather, they are based on service to the student, staff, faculty, and community. The use of TQM within higher education should be to meet customer needs. This ensures satisfaction, student retention, and increased community support. TQM is defined as a customer-focused approach which seeks changes as directed by the customers' needs in the form of continual improvement (Shaw, 1993). This basic concept of TQM should hold true in either the manufacturing or service environment, because both are concerned with meeting customer needs as well as improving the many processes contained within the operation.

Currently, the processes of TQM within higher education center on employee involvement and teamwork, following the Plan-Do-Check-Act TQM guidelines. However, it is not enough to Plan, Do, and Act on a process. To effectively use the concepts of TQM, an organization must have individuals with a working knowledge of basic statistical procedures to Check and measure the results of any process change. Because control charts and frequency distributions are paramount to TQM, it is important to understand the quantitative procedures used to generate these useful tools (Whiteley, Porter, & Fenske, 1992).

The act of eliminating programs and departments without rethinking or measuring the process may lead to a less productive organization, because some of the eliminated elements may actually contribute to the success of a particular process. To enhance the results of any process, the institution must continuously improve the efficiency and effectiveness of the operational process while constantly measuring outcomes (Seymour, 1993). Within the TQM philosophy, this can be accomplished only through statistical process control. It is the purpose of this article to only address the measuring component used in TQM and not the components leading up to measurement.

The most fundamental concept of TQM is the ability to count or measure a particular characteristic of a product, process, or service (Whiteley, Porter, & Fenske, 1992). However, counting and measuring are considered two different functions in statistics and should be treated differently in TQM. The process of counting involves a finite scale. For example, the total number of students enrolled in school or the total number of completed workorders are situations where one asks "how many?" The process of counting creates a situation where a half of a student or a third of a workorder does not exist. Therefore, the type of data generated when counting is discrete. The process of measuring involves infinite scales with just as many possibilities for outcomes. For example, average scores on an intelligence test, scores on satisfaction surveys, or the total amount of kilowatt hours used during a particular time frame are situations where one asks "how much?" During the process of measuring, numbers can be whole, fractions, or a combination of both. The type of data generated when measuring is continuous.

Because the TQM process originated from the manufacturing industry, it was applied mainly to the measurement of products or parts of products coming from a production line. Industry was interested in the variability of the product being tested and, therefore, used continuous data for most of its applications. Although it is possible to measure certain variables within higher education, discrete data can offer many more possibilities. This study is an example of the use of discrete data. All college and university housing departments have adopted a process for handling maintenance problems. The department may have its own maintenance staff, as does the institution in this study, or it may work directly with the institution's physical plant (Dillow, 1989). Either way, if the department's current process is significantly altered by nonrandom elements or variables, inefficiency could result, leading to decreased student satisfaction which could ultimately lead to lower retention. If the process is affected by these elements or variables, it is considered out of control according to the terminology of TQM. One way of measuring

whether the housing department is in control or out of control within the maintenance area, is to study the completion rate of workorders. This study is designed to show the processes of TQM through a workorder system. Housing departments can use these concepts to improve the quality of any process within an institution.

Method

This study measured the effectiveness of the Department of Housing's workorder system in a large public research institution located in the southeastern United States. Measurement was directed toward the second phase of the system— from the time the facilities office received a request until the workorders were completed. The statistical concepts of Total Quality Management were used to measure variation within the system as it pertained to quality.

Quality, as defined in TQM which is a derivative of statistical process control, is a measurable characteristic of a product, process, or service (Montgomery, 1985). The housing workorder system is considered both a process relative to the overall system and a service relative to the student resident. Workorders by craft (i.e. painters, carpenters, plumbers, etc.) and by month, from October 1991 to September 1993, were retrieved from the facilities data base for use in this study ($N = 26,956$). The quality characteristic measured was the duration of active workorders each month to determine if a nonrandom variation (assignable cause) existed. Any workorder exceeding five days was considered nonconforming. This five-day time limit represented the anticipated average completion time of workorders and was set by housing staff during the planning stages of TQM.

The purpose of this study was to determine any assignable causes that were linked to the workorder system within Housing and to make recommendations to control the causes, therefore improving the quality of the workorder system. Assignable cause is defined as a nonrandom cause of variation in a process (Montgomery, 1985). This can be any identifiable factor which, if corrected, can increase efficiency within a process. Random variation is defined as variation within a process that is due to a multitude of unidentifiable causes occurring with no established pattern (Montgomery, 1985). Subsequently, when a process is in control, it is subject only to a stable system of random causes. When a process is out of control, it is subject to

an assignable cause or causes of variation. Stated another way, the TQM philosophy assumes that all processes have internal and external factors that affect the efficiency or reliability of a process. When these factors occur randomly, it is assumed that they are caused by chance circumstances which cannot be controlled by the workers or the institution. However, if these factors occur in a nonrandom fashion, it is assumed that there is an underlying cause which can be pinpointed and corrected. These underlying causes are called assignable causes because they are identified as an assessable variable which can be manipulated and controlled.

Variables and Attributes are two groups of characteristics that exist within statistical quality control. When a quality characteristic of a process is observed by use of continuous measurement, variable data result. However, when another quality characteristic of a process is observed only as to its presence or absence, attributes data result (Braverman, 1981). Because this study was concerned with workorders that did not conform to Housing's five-day standard, the attributes data characteristic was used.

The attributes characteristic assumes that dichotomous data, which are based on the binomial distribution, were used. Therefore, a fraction defective control chart was used because this study examined the total number of late workorders as compared to the total number of workorders issued for a particular period. The fraction defective or p chart is the basic attributes control chart and provides information about the fraction or proportion of nonconformities within a process or service (Braverman, 1981). This chart displays the proportion of nonconformities to total number of workorders as a fraction or percentage.

All workorders within the time frame of October 1991 to September 1993 were retrieved for each rational subgroup (month), so the total population was used instead of a sample. Because workorder quantities generally varied from period to period, the subgroup sizes also varied. This presented a problem in constructing and maintaining a p chart. Because the control limits were based upon the standard error of p, and the standard error formula contains the factor n, the distance between the control limits will change as n varies. The procedure used in this study to avoid the problem of computing variable control limits when subgroup sizes vary was the

TABLE 1
OBSERVATION CHART FOR THE HOUSING WORKORDER SYSTEM

Month/Year	N	$\sqrt{N}$	X	P*	σ_p**	Z***
Oct 91	1320	36.332	119	0.09	0.010074	-6.94871
Nov 91	1353	36.783	113	0.08	0.00995	-7.68646
Dec 91	725	26.926	96	0.13	0.013593	-2.02946
Jan 92	1467	38.301	271	0.18	0.009556	2.588041
Feb 92	1013	31.828	136	0.13	0.011499	-2.23883
Mar 92	921	30.348	109	0.12	0.01206	-3.45357
Apr 92	746	27.313	89	0.12	0.0134	-3.03705
May 92	972	31.177	302	0.31	0.011739	12.83702
Jun 92	1050	32.404	203	0.19	0.011295	2.951157
Jul 92	962	31.016	201	0.21	0.0118	4.147323
Aug 92	2534	50.339	540	0.21	0.007271	7.303509
Sep. 92	1479	38.458	298	0.20	0.009517	4.359334
Oct 92	1104	33.226	130	0.12	0.011015	-3.83524
Nov 92	962	31.016	136	0.14	0.118	-1.57859
Dec 92	571	23.896	141	0.25	0.015317	5.675873
Jan 93	1106	33.257	172	0.16	0.011005	-0.4075
Feb 93	994	31.528	105	0.11	0.011690	-4.68318
Mar 93	775	27.477	83	0.11	0.01332	-3.7587
Apr 93	743	27.258	105	0.14	0.013427	-1.39128
May 93	1105	33.242	306	0.28	0.01101	10.61941
Jun 93	895	29.917	161	0.18	0.012234	1.625651
Jul 93	808	28.425	189	.023	0.012876	5.740279
Aug 93	2015	44.889	578	.029	0.008153	15.55759
Sep 93	1356	36.824	252	0.19	0.009939	2.599879
Total				$\overline{P}$		
26,956				0.16		

$* P = \frac{X}{N}$ Note: The percentage of nonconformities to conformities per month.

$** \sigma_p = \dfrac{\sqrt{(\overline{P})(1 - \overline{P})}}{\sqrt{N}}$ Note: The population standard deviations of the fractional nonconformities for each month.

$*** Z = \dfrac{P - \overline{P}}{\sigma_p}$ Note: The Z scores for the nonconformities.

stabilized p chart. In a stabilized p chart the variable that is plotted is expressed as a deviation from the mean in units of its own standard deviation (Braverman, 1981). The new variable is then based on z scores with zero (0) as the mean and +3 and -3 as the control limits above and below the mean respectively.

If the workorder system was deemed out of control, then a multiple regression procedure was used to predict workorder nonconformity based on certain assignable causes. Five assignable causes, which were chosen among Housing staff during the planning phase of TQM were used to predict factor nonconformity: (a) total on-the-job-injury (OJI) hours per month, (b) total sick hours per month, (c) total vacation hours per month, (d) total overtime hours per month, (e) total aggregate monthly craft demand. Total OJI,

sick leave, overtime, and vacation hours were generated from the monthly maintenance personnel files within the facilities area and addressed worker performance and absenteeism as it related to workorder nonconformity. Total aggregate monthly craft demand was generated by computing the ratio of workorders within each craft to the number of qualified individuals assigned to work within that craft. A higher number indicated more demand for a particular craft. When all of the craft demand values were totaled by month, higher numbers indicated more overall demand for maintenance (see Figure 1).

RESULTS

Over 26,000 workorders from the previous two years were retrieved to construct an observation table (see Table 1). The observation table
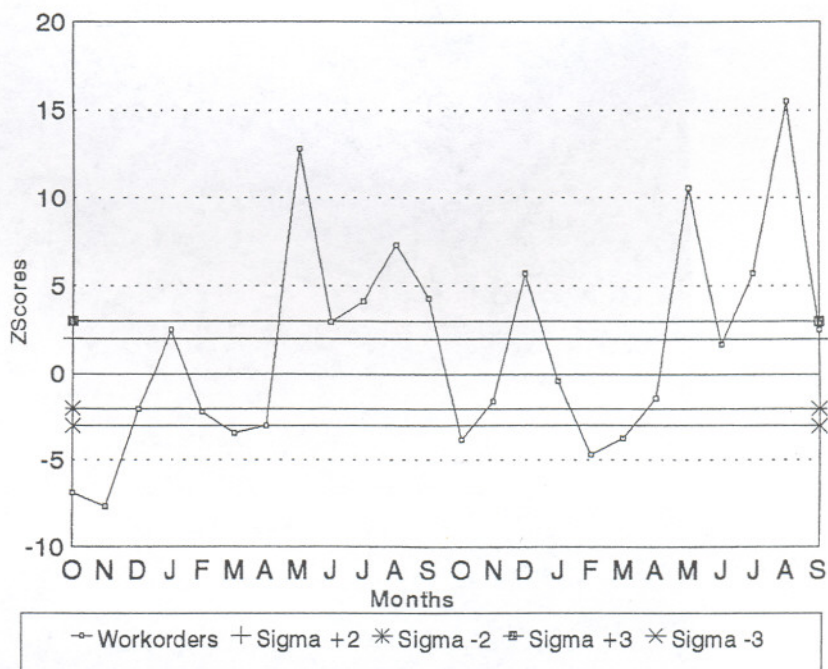
***Figure1.* Workorder control chart.**

contains the total number of workorders per month (N), the total number of nonconformities per month (X), the percentage of nonconformities to conformities per month (P), the population standard deviations of the fractional nonconformities ($\sigma_{p,}$) and the z scores for the nonconformities (Z). The z scores were then used to create the control chart (see Figure 1). This chart is a graph representing the variability of a process variable with respect to time. The horizontal axis on the graph represents time. Each point on the horizontal axis coincides with observations made on a rational subgroup that was drawn from the process at a particular point in time. The rational subgroups were divided into each month within the two-year period. The vertical axis is scaled in z score units.

The center line is drawn horizontally across the chart to represent an average value. Lines above and below the center line represent the upper control limits (UCL) and the lower control limits (LCL) of the average respectively. The upper and lower control limits are based on three standard deviations above and below the mean (referred to as 3 sigma in TQM terminology). The control chart may indicate an out-of-control condition either when one or more points fall beyond the control limits, or when the plotted points exhibit some nonrandom pattern of behavior. Tests for determining an out-of-control

condition are as follows: (a) one or more points plot outside the 3 sigma control limits, (b) two out of three consecutive points plot beyond the 2 sigma warning limits, (c) four out of five consecutive points plot at a distance of 1 sigma or beyond from the center line, (d) eight consecutive points plot on one side of the center line (Montgomery, 1985 p. 114). By plotting the observations from this study to a control chart and following the tests to determine an out-of-control condition, it is clear to see that the workorder process was out of control Out of the four tests for noncontrol, the workorder chart shows that tests one, two, and three occurred at frequent intervals. Peak observations of nonconformity occurred during May, June, July, August, and September, while much lower observations were present in February, March, October, and November. This suggests that workorder nonconformity was due in part to an increase in the number of workorders turned in after the spring semester and before the following fall semester.

A regression analysis was used to predict workorder nonconformity based on five assignable causes. A chart of the values of these assignable causes by month is contained in Table 2. Because this study involved five assignable causes of OJI, sick leave, overtime, vacation and total task demand, it was important that the

Month/ Year	Sub Group	Total W.O.*	Total Non Control	% Non Control	% OJI	% Sick	% Vac.	Total** OT	Total Task Demand***
Oct 91	1	1320	119	0.09	0	4.76	5.29	93	795.19
Nov 91	2	1353	113	0.08	0.98	60.9	8.76	96	791.59
Dec 91	3	725	96	0.13	0	1.25	7.65	234	374.57
Jan 92	4	1467	271	0.18	0.64	5.31	10.7	168	817.52
Feb 92	5	1013	136	0.13	0.72	4.78	3.7	96	588.45
Mar 92	6	921	109	0.12	0	2.07	3.65	92.5	539.47
Apr 92	7	476	89	0.19	0	3.06	5.96	110	435.64
May 92	8	972	302	0.31	0.65	1.8	4.14	103	367.83
Jun 92	9	1050	302	0.19	0.04	2.93	3.87	56	530.33
Jul 92	10	962	201	0.21	0.05	1.84	5.44	781	475.57
Aug 92	11	2534	540	0.21	3.35	1.82	7.11	463	1234.4
Sep 92	12	1479	298	0.2	0	3.73	6.77	98	818.36
Oct 92	13	1104	130	0.12	2.42	3.39	8.52	136	623.92
Nov 92	14	962	136	0.14	0	2.25	8.16	112	564.35
Dec 92	15	571	141	0.25	0	2.16	7.88	89	323.67
Jan 93	16	1106	172	0.16	0	6.4	6.4	104	624.97
Feb 93	17	994	105	0.11	0.42	5.3	4.56	68	579.03
Mar 93	18	755	83	0.11	1.82	3.97	6.44	95	435.9
Apr 93	19	743	105	0.14	0	4.87	6.63	134	429.72
May 93	19	1105	36	0.03	0.53	3.11	4.64	76	463.97
Jun 93	21	985	161	0.18	0	2.56	7.89	52	441.08
Jul 93	22	808	189	0.23	1.33	2.33	8.78	58	391.01
Aug 93	23	2015	578	0.29	2.69	3.6	7.51	426	972.91
Sep 93	24	1356	252	0.19	1.51	3.39	7.23	178	814.91
Totals		26286	4533						

* Total Workorders does not include housekeeping and carpet cleaning.

** Overtime does not include compensatory.

*** Total Task Demand = Ration of craft specific workorders to craftsmen.

regression analysis address parsimony to ensure that only those causes that have the greatest contribution to the model were used. The analysis also addressed multicollinearity to ensure that two or more assignable causes were not measuring the same phenomena. By testing the basic assumptions as well as multicollinearity, it was found that no outliers existed, which could skew the results of the regression model, and that multicollinearity did not exist among any of the five variables.

By looking at the regression model, the tests for statistical and practical significance were determined. Statistical significance was set by the researcher at the .05 level and practical significance was the percentage of change within the dependent variable (workorder nonconformity), which was attributed to change from one or more of the independent variables (OJI, sick leave, vacation, overtime, and total task demand). The analysis of variance procedure within the regression model (see Table 3) shows an F value of 6.210 and a prob. > F of .0016, which was less than the .05 level. Therefore, the model was statistically significant and supported the alternative hypothesis that the independent

TABLE 3
ANALYSIS OF VARIANCE TABLE WORKORDER NONCONFORMITY

Source	DF	Sum Squares	Mean Square	F Value	Prod > F
Model	5	249232.15795	49846.43159	6.210	0.0016*
Error	18	144485.80038	8026.98891		
Total	23	393717.95833			

*$p < .05$

variables can predict the dependent variable. The R-Square statistic indicated the measure of practical significance. For this study, if the R-Square value was greater than 20 percent, the model was considered practically significant. Because the R-Square value was 63%, the model was considered practically significant.

This study has shown that the predictions made from the dependent variable were both statistically and practically significant. It was also evident that the independent variables show no signs of multicollinearity and that there were no outliers among the observations. It is now possible to achieve parsimony by determining which of the five variables were the primary contributors to the model. To do this, the backward approach was used, whereby all predictor variables were initially included in the regression model, and the individual predictor variables were deleted as they did not significantly contribute to the model. Results from this method indicated that OJI and total task demand were the primary contributors in the prediction of workorder nonconformity.

RECOMMENDATIONS

Although the control chart for workorder nonconformity shows the workorder process to be out of control, further study revealed that the control chart could be improved to increase accuracy and predictability. Because the TQM methods used in the study had never been tried within the department, team members were quick to point out any inherent problems while, at the same time, identifying the benefits of the TQM process as it related to workorder nonconformity.

First, the control chart for workorder nonconformity combined all tasks or crafts. If the problems of nonconformity exist within only one or two crafts, it would be impossible to pinpoint those crafts when all of them are represented within the same control chart. Furthermore, because some crafts may show greater nonconformity than others, skewness could result making the entire workorder process appear to be out of control when, in fact, it may not be.

Second, the control chart for workorder nonconformity combined all types of workorders and did not differentiate between emergency workorders, routine maintenance workorders, or workorders issued for renovation projects. It is clear that maintenance makes these distinctions within its daily operations and places greater

priority on emergency workorders than any other type of workorders.

Third, by using a five-day period as the standard for nonconformity, an inaccurate measurement of conformity may be present. For example, plumbing and electrical problems arising in occupied residence halls should be completed as soon as possible for health and safety reasons. Therefore, any of these workorders that take over two days to complete should be considered nonconforming. Some renovation projects will take far more time to complete than five days. These workorders should be given more time than the five-day period. Another problem with the five-day period was the current inability of the computer system to differentiate between workdays and weekends.

It is with these problems in mind that this study recommends the following:

1. All crafts should have their own control charts with the appropriate nonconformity measure set for that particular craft.

2. Workorders should be coded into the computer data base according to priority. Therefore, it will be possible to determine nonconformity among the different priority levels and also determine the average length of completion time that should be given to each priority level.

3. The computer data base should be reconstructed so that weekends will not be counted within the total days for nonconformity.

The regression analysis shows that the primary contributors or assignable causes for workorder nonconformity were total OJI hours and total task demand. The individual correlation coefficients for these two variables show positive correlations with workorder nonconformity. This means that as OJI hours and task demand increased, workorder nonconformity increased. Task demand increases indicated an increased number of workorders and that the increased demand on each task or craft may cause workorder nonconformity.

4. Further study should be conducted toward the classification of workorder type and importance to the overall mission of Housing. The study needs to address those workorders which should be completed by Housing maintenance and those which could be completed by Physical Plant or outside contractors.

This study was unable to indicate whether increased OJI was caused by more work demanded or whether more work demanded was caused by increased OJI. Again, further study

will have to be conducted.

This study indicated a relationship between workorder nonconformity and various measures of worker performance. Therefore, it is recommended that further research be conducted concerning workorder nonconformity based on the recommendations made within. Although this study reflects past data, the control chart process can be used to measure more current data. In this manner, assignable causes can be pinpointed on a monthly basis and plans for changes in process can be made on a more timely basis.

CONCLUSIONS

This study dealt with the construction and analysis of a fraction nonconforming chart, which was used to determine whether the workorder system was out of control by containing nonrandom causes of variation that could lead to process inefficiency. According to the model, the process was, indeed, out of control. The next step in the study was to determine whether the independent variables of OJI, sick leave, vacation, overtime, and total task demand could be used to predict workorder nonconformity. After tests for multicollinearity were conducted, as well as testing the basic assumptions underlying regression, it was determined that OJI and total task demand were the primary contributors to workorder nonconformity.

The study also found that the maintenance staff could increase its efficiency by knowing which workorders should be completed within the department and which should be given to Physical Plant or an outside contractor. However, to achieve this efficiency, inherent problems existed within the study which, if corrected, would make the TQM process a more viable method in the continuance of measuring quality within the workorder system. The major recommendations of this study were to separate measurements by craft and by type of workorder and then to continue the TQM process under these new conditions.

Although this study shows that planning and research should continue, it is a good example of the TQM process of Plan-Do-Check-Act. First of all, the Housing Department planned the study based on information it gathered. Second, the Department performed the measurements to determine workorder nonconformity. Third, after reviewing the results, the Department recommended changes for future studies that should help to more accurately pinpoint problems resulting in workorder nonconformity. Fourth, the Housing Department is now acting on this new information in its formation of a better process for statistical process control.

This study also shows that while continuous data may be effectively used to measure processes within higher education, it is based on a manufacturing environment that is more sterile and more predictable than most processes within the education field. By understanding and using discrete data and fraction nonconformity (p charts), a wider range of processes may be observed and manipulated under the TQM system.

REFERENCES

Braverman, J. D. (1981). *Fundamentals of statistical quality control*. Reston, VA: Reston Publishing.

Dillow, R. (Ed.). (1989). *Facilities management: A manual for plant administration*. Alexandria, VA: The Association of Physical Plant Administrators of Universities and Colleges.

Fisher, J. (1993). TQM: Warning for higher education. *Educational Record, 74*(2), 15-19.

Montgomery, D. (1985). *Introduction to statistical quality control*. New York: Wiley.

Seymour, D. (1993). TQM: Focus on performance, not resources. *Educational Record, 74*(2), 6-14.

Shaw, K. (1993). Sunflower seeds at Syracuse. *Educational Record, 74*(2), 21-27.

Whiteley, M., Porter, J., & Fenske, R. (Eds.). (1992). *The primer for institutional research*. Tallahassee: Association for Institutional Research.