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ABSTRACT

An examination was conducted of the control chart as a quality improvement statistical method often used by Total Quality Management (TQM) practitioners in higher education. The examination used an example based on actual requests for information gathered for the Director of Human Resources at a medical center at a midwestern university. The request was for an analysis of the relationship between the number of hours for which employees were being paid, the employees' budgeted full-time equivalency, and the actual hours being worked. The data were illustrated using three types of control charts--two described controlling process variability and one described controlling a process mean. The analysis showed that for the most part the number of regular hours being worked was stable, with the only exceptions occurring during pay periods which included holidays. The graphics of the analysis and an accompanying report were reviewed with a favorable reaction from the Human Resources department due to the informative nature of the data. The study concluded that TQM methodologies provided the researcher with tools to aggregate and present data in an informative manner. Included are five figures, two tables, and eight references. (JB)

TOTAL QUALITY MANAGEMENT: STATISTICS AND GRAPHICS II – CONTROL CHARTS

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Jean Endo
Chair and Editor
Forum Publications
Editorial Advisory Committee

Abstract

The application of Total Quality Management (TQM) analytical methods has been stressed in recent years as an effective tool for Institutional Researchers. Its growing importance to the field is reinforced by the devotion of a New Directions for Institutional Research issue to the topic this past fall. This paper elaborates on the types and usage of control charts as discussed in the 1991 AIR Forum paper, 'Total Quality Management: Statistics and Graphics.'

Total Quality Management:

Statistics and Graphics II — Control Charts

The application of Total Quality Management (TQM) analytical methods at institutions of higher education has been stressed in recent years as an effective tool for Institutional Researchers (Sherr, 1989). The devotion of an issue of New Directions for Institutional Research (Sherr & Teeter, 1991) on the topic of 'Total Quality Management in Higher Education' illustrates the importance of TQM principles to Institutional Research practitioners. This paper elaborates on one of the TQM graphical methods presented previously in 'Total Quality Management: Statistics and Graphics' at the 1991 AIR Forum (Schwabe, 1991).

The understanding of the basic TQM concepts and principles as developed by Deming (1986) and how these concepts are germane to higher education are discussed in greater detail elsewhere (Miller, 1991; Sherr & Teeter, 1991). This paper concentrates on one of the quality improvement statistical methods often used by TQM practitioners — the control chart. There are many kinds of control charts available, with one quality improvement textbook describing over 30 types of control charts (Ryan, 1989). For the illustrative purposes of this paper, examples will be used which were based on an actual request for information by an administrative department. The use of quality improvement statistical methods illustrated in this section were helpful in providing summarized information to a Director of Human Resources across a range of administrative units at a medical center of a midwestern university. The information was not used as a complete evaluation of the administrative units, but instead as a general indicator of working patterns within administrative areas and employee classifications.

The ability to find techniques that are objective and fair in analyzing administrative units is an important part of evaluating administrative programs and services (Wilson, 1987). The use of control charts with their upper and lower control limits provides a method for viewing administrative areas in a graphical manner with the required objectivity and fairness as discussed by Wilson (1987). The quality improvement statistical tools such as those used in TQM activities equip the Institutional Research practitioner with the tools to give policy makers the data requested in a concise yet informative manner. This goal may be achieved in situations involving an actual TQM program as well as those situations where a TQM program may not exist but general descriptive information is required.

In addition, the quality improvement statistical methods used in TQM are readily adaptable to commonly available statistical packages. All the examples given in this paper were analyzed using base SAS and SAS/Graph, a common statistical package available on multiple computing platforms.

In this paper three control charts will be examined; two which describe controlling process variability, the *R* chart and the *s* chart, and a third which describes controlling a process mean, the $\bar{X}$ chart. In addition, the use of Tukey's Box Plots (Tukey, 1987) as a method to visually emphasize a distribution will be discussed.

Control charts are based on statistical distributions, usually the normal distribution, and indicate when a process or activity is 'out of control.' A process is 'out of control' when the distribution of the process fluctuates widely or in an unexplainable pattern. Juran and Gryna (1980) describe process instability as the following:

1. A single point falls outside the 3 standard deviation limits.
2. Two of three successive points fall outside the 2 standard deviation limits.
3. Four of five successive points fall outside the 1 standard deviation limits.
4. Eight successive points fall above or below the mean (or centerline).

The boundaries of what is considered normal are often set at three standard deviations above and below the mean of the measurement of interest used to evaluate the process. The boundary three standard deviations above the mean of the measurement of interest is referred to as the Upper Control Limit

(UCL), while the boundary which is three standard deviations below the mean is called the Lower Control Limit (LCL). If a process follows a normal distribution, over 99 percent of the process should fall within the UCL and LCL boundaries.

The control charts which will be examined in this paper are based on these principles and were calculated in the following manner (Ryan, 1989):

R chart parameters = $\overline{R} \pm 3\hat{\sigma}_R$

s chart parameters = $\overline{s} \pm 3\hat{\sigma}_s$

$\overline{X}$ chart parameters = $\overline{\overline{x}} \pm 3\hat{\sigma}_{\overline{x}}$

When working with a sample of a population, an estimate of the population standard deviation for the different types of control charts can be found using the equations and tables provided in quality improvement statistical textbooks such as Ryan (1989).

As Ryan states, "Control charts can be used to determine if a process has been in a state of statistical control by examining past data. More importantly, recent data can be used to determine control limits that would apply to future data obtained from a process, the objective being maintained in a state of statistical control" (1989, p. 73). The purpose of our analysis involves the latter, our policy makers desired to know what were the 'Paid FTE' baselines and if the institution's system for personnel FTE allocation was 'in control' when compared with the actual payroll hours.

Method

The Human Resources department at a midwest university with an average full-time equivalent (FTE) work force of over 4,700 requested from the university's Institutional Research office an analysis of the relationship between the number of hours for which employees were being paid, the employees' budgeted FTE, and the actual hours being worked. To perform this analysis the time history records for each pay period in fiscal year 1991 were analyzed. The employees are paid biweekly, which means that each employee would have 26 records if he/she had worked an entire year. Each record contained an employee ID, the pay period, and codes for job title, classification, department, and gender. Total hours paid, regular hours worked, sick hours taken, vacation hours taken, holiday hours taken, and other hours were also read from the data files. These different categories of hours which Human Resources maintains allowed an analysis of the distribution of 'Paid FTE' by the different hourly categories. This distribution was calculated as follows:

$$\textit{Paid FTE} = \frac{\textit{Hours Paid (by category)}}{80 \textit{ Hours per Pay Period} \times \textit{Budgeted FTE}}$$

Table 1 illustrates how these calculations would work for some employee examples based on regular hours worked, with regular hours representing non-overtime hours at work. To calculate the desired distributions, PROC SUMMARY in base SAS was used with programming code such as that given in Table 2.

Table 1
Sample Calculations of Paid FTE

Employee Examples		Budgeted FTE	Regular Hours Worked / pay period	% of FTE paid - Regular Hours
#1.	Full-time	1.00	80	100.0%
#2.	Part-time	0.50	40	100.0%
#3.	Student	0.05	4	100.0%
#4.	Full-time	1.00	70	87.5%
#5.	Part-time	0.50	100	250.0%
#6.	Student	0.05	80	2,000.0%

Table 2
Sample SAS programming code for calculations of
R, s, and X control chart distributions

```
*****************************************************************
*****************************************************************
**  Calculate the Range, Standard Deviation, and Mean for      **
**  PAIDFTE by the Pay Period and Employee Classification.     **
**  Save results in data set called SUM_PP.                    **
*****************************************************************
*****************************************************************;
PROC SUMMARY NWAY DATA=PERIOD;
     CLASS PAYPRD CLASSIF;
     VAR PAIDFTE;
OUTPUT OUT=SUM_PP
     RANGE=RANGE STD=STD MEAN=MEAN;
RUN;
*****************************************************************
*****************************************************************
**  Calculate the Mean and Std Dev of the following: Range,    **
**  Standard Deviation, and Mean for the entire fiscal year.   **
**  By the Employee Classifications.  Save results in data set **
**  called SUM_FY.                                             **
*****************************************************************
*****************************************************************;
PROC SUMMARY NWAY DATA=SUM_PP;
     CLASS CLASSIF;
     VAR RANGE STD MEAN;
OUTPUT OUT=SUM_FY
     MEAN=AVGRANG AVGSTD AVGMEAN STD=STDRANG STDSTD STDMEAN;
RUN;
*****************************************************************
*****************************************************************
**  Calculate the UCL and LCL for the different Employee       **
**  Classifications, and the different control charts.         **
**  Save in data set called LIMITS.                            **
*****************************************************************
*****************************************************************;
DATA LIMITS;
     SET SUM_FY;
     UCLRANG=(3*STDRANG)+AVGRANG;     /* UCL & LCL for R chart */
     LCLRANG=(3*STDRANG)-AVGRANG;
     UCLSTD=(3*STDSTD)+AVGSTD;        /* UCL & LCL for s chart */
     LCLSTD=(3*STDSTD)-AVGSTD;
     UCLMEAN=(3*STDMEAN)+AVGMEAN;     /* UCL & LCL for X chart */
     LCLMEAN=(3*STDMEAN)-AVGMEAN;
RUN;
```

The data was illustrated using the three types of control charts described earlier: an *R* chart, or a chart which describes the distribution of the data's range, an *s* chart, or a chart which describes the distribution of the data's standard deviations, and finally, the $\bar{X}$ chart, or a chart of the distribution of the data's means. Tukey's Box Plots were used to illustrate the extreme variability of the Paid FTE of one employee classification.

Results

The analysis showed that, for the most part, the amount of regular hours being worked was stable. The only exceptions occurred during pay periods which include holidays. During these periods, there is greater variation in the hours worked. But this is an anticipated, seasonal fluctuation and, thus, not a true 'out of control' process. Because this is an illustrative paper, only a few of the control charts will be presented and discussed. For those wishing to examine all the control charts created for each employee classification, please contact the author.

The advantage of a *R* chart is illustrated in Figure 1. This control chart of the range of Paid FTE for Health Care Employees illustrates the erratic process of reconciling Budgeted FTE with the actual number of hours worked for this employee classification. This group of employees have irregular hours due

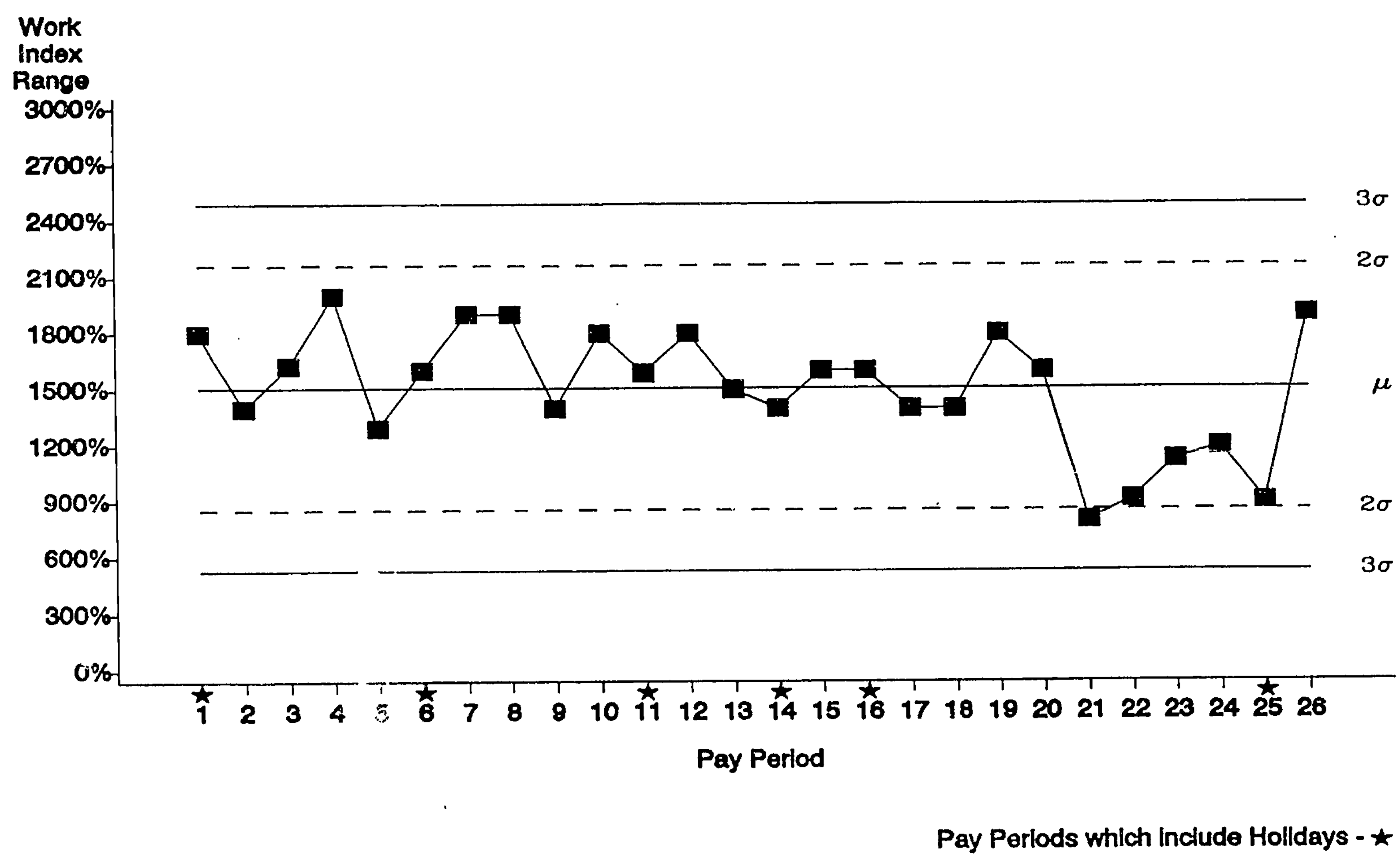


Figure 1: R Chart for Health Care Employees' Paid FTE

to a dependence on patient load. In addition, a very flexible work schedule is available to employees in this classification for recruitment purposes. The control chart shows that there are some extreme differences between an employee's Budgeted FTE and the actual number of hours worked by the employee in a given standard 80 hour pay period (Paid FTE). However, notice that this distribution is in a state of control, even with these extreme levels of variation.

To help illustrate the extremeness of the values in this distribution to the administrative end user, Tukey's Box Plots were utilized. Figure 2 shows the entire distribution of Paid FTE for the health care employees during the fiscal year. As one can see, the number of extreme outliers is few compared to the majority of this group of employees, but that the extremes also exist throughout the fiscal year. To better help illustrate a Box Plot, Figure 3 is presented. Figure 3 is the same as Figure 2 but with the vertical axis truncated at 200 percent. In a Box Plot the lower boundary of the box represents the 25th percentile of the data distribution and the upper boundary represents the 75th percentile of the distribution. The median or the 50th percentile of the distribution is connected by the line on the graph. Extreme values are those which fall above or below the 'whiskers,' or the vertical lines extending from the upper and lower boundaries of each box. If the data is normally distributed, then data points outside the 'whiskers' are

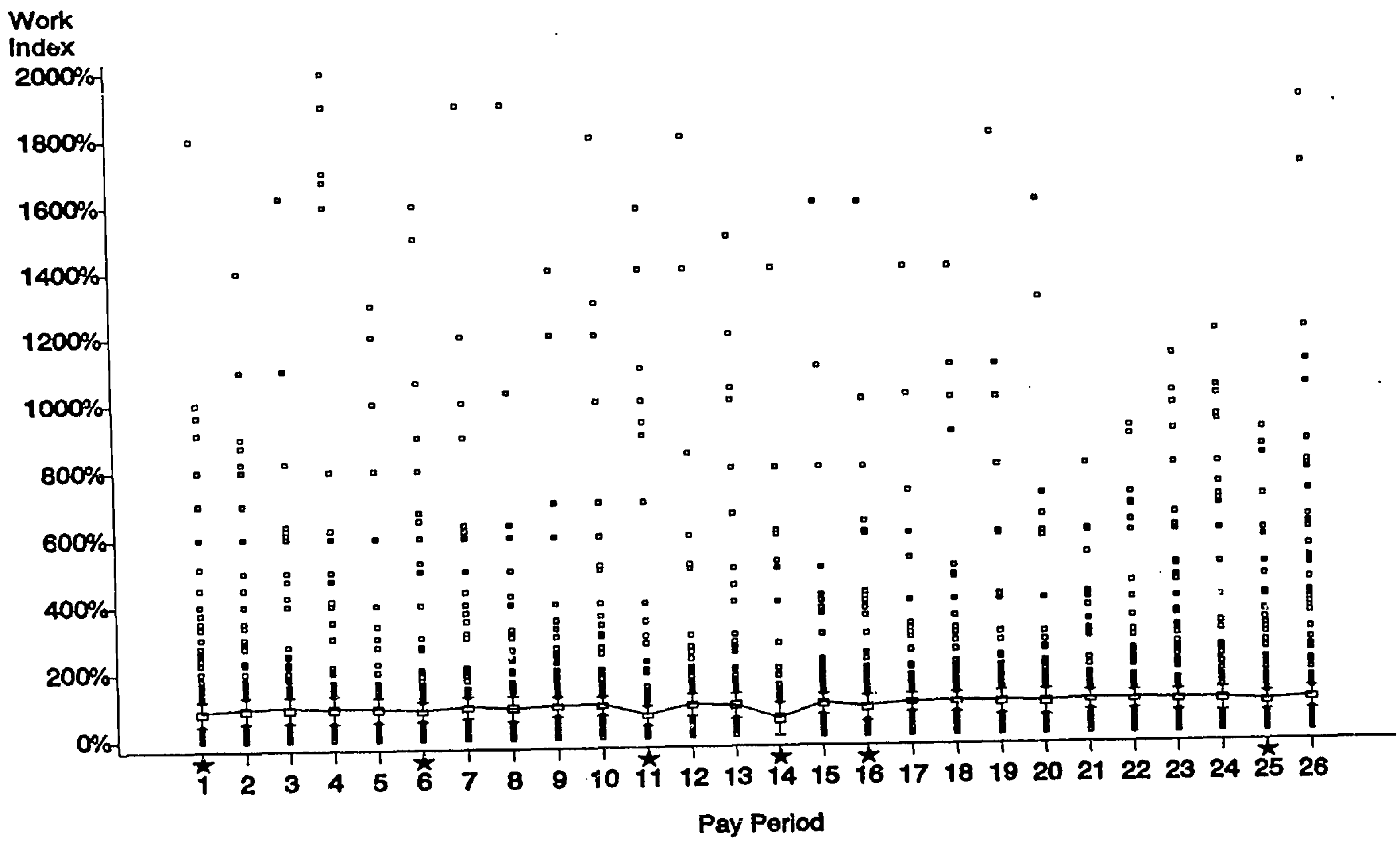


Figure 2: Box Plot of Health Care Employees' Paid FTE

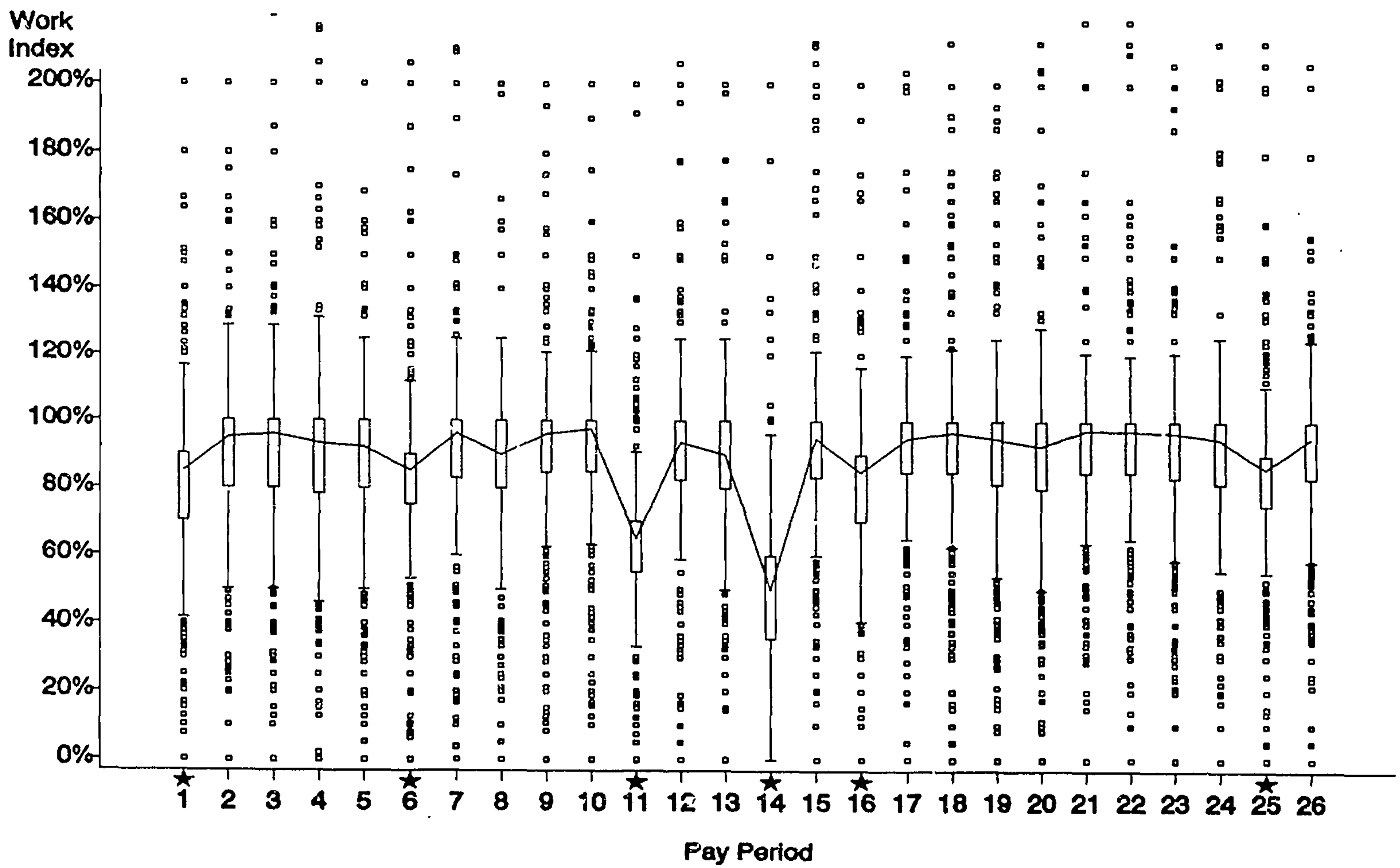


Figure 3: Box Plot of Health Care Employees' Paid FTE with a Truncated Axis

approximately 2.68 standard deviations from the mean (Ryan, 1989).

Ryan (1989) states that the *s* chart is considered a better indicator of process variability because it is based on all the observations in each subgroup (pay period), while the *R* chart is based only on two observations in each subgroup (pay period). Figure 4, which is a *s* chart of the Paid FTE for Student employees, shows that the largest variations in Paid FTE occur when the spring semester ends, around the 25th and 26th pay periods. This increase in variability is high enough to almost be considered an 'out of control' process because it reaches the upper control limit of three sigmas. This surge in variability is thought to be due to a combination of factors (e.g., departments attempting to use student assistant monies before the end of the fiscal year, students being free from class loads and able to work longer hours).

This hypothesis seems to be supported by the $\bar{X}$ chart illustrated in Figure 5. The $\bar{X}$ chart, which represents the process mean, gives an indication of the distribution of the average Paid FTE for the student employees. This figure shows a sharp increase in Paid FTE during these pay periods, with an average Paid FTE of over 170 percent. This reflects a Budgeted FTE which is smaller than the average hours actually being worked by the students.

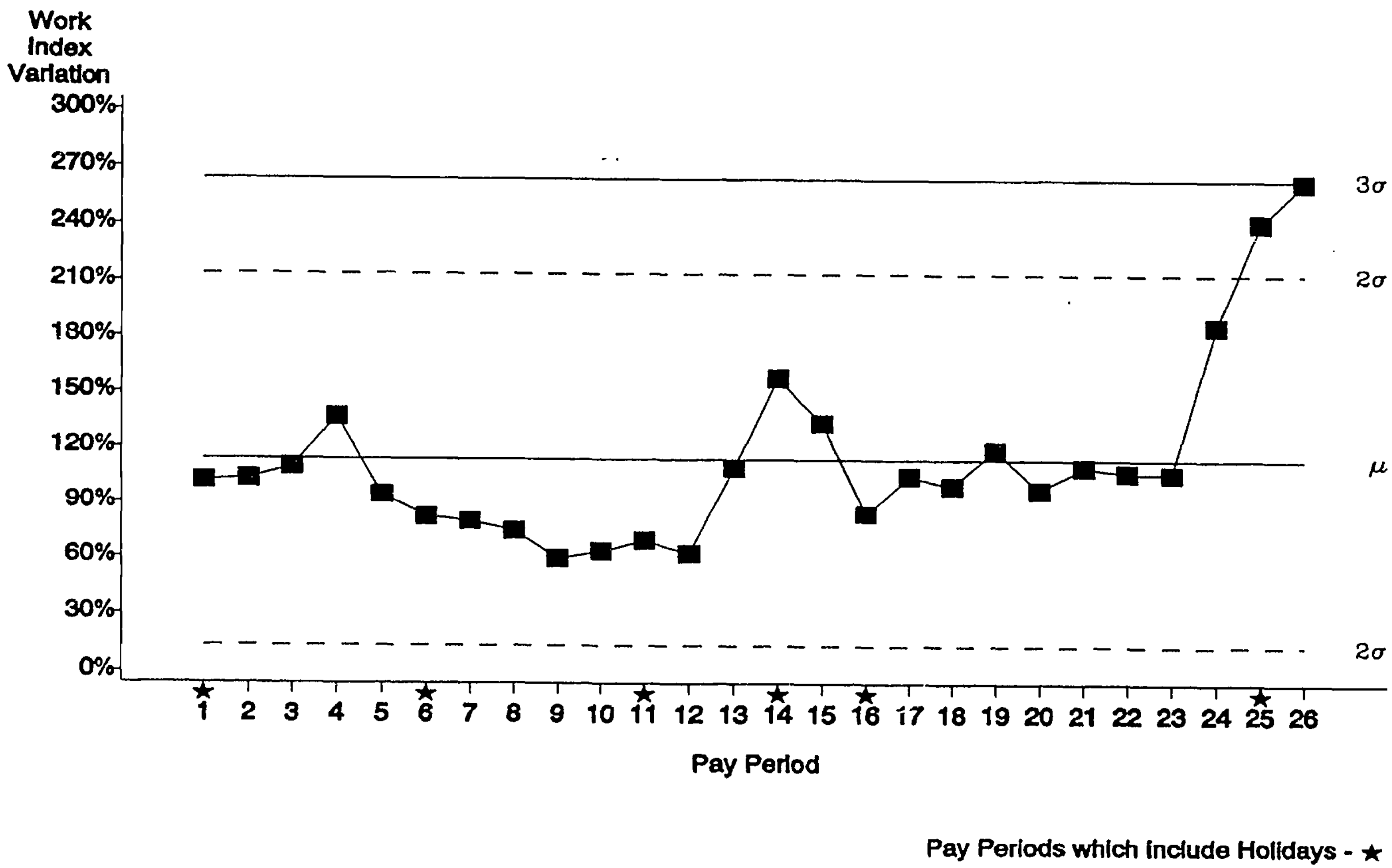
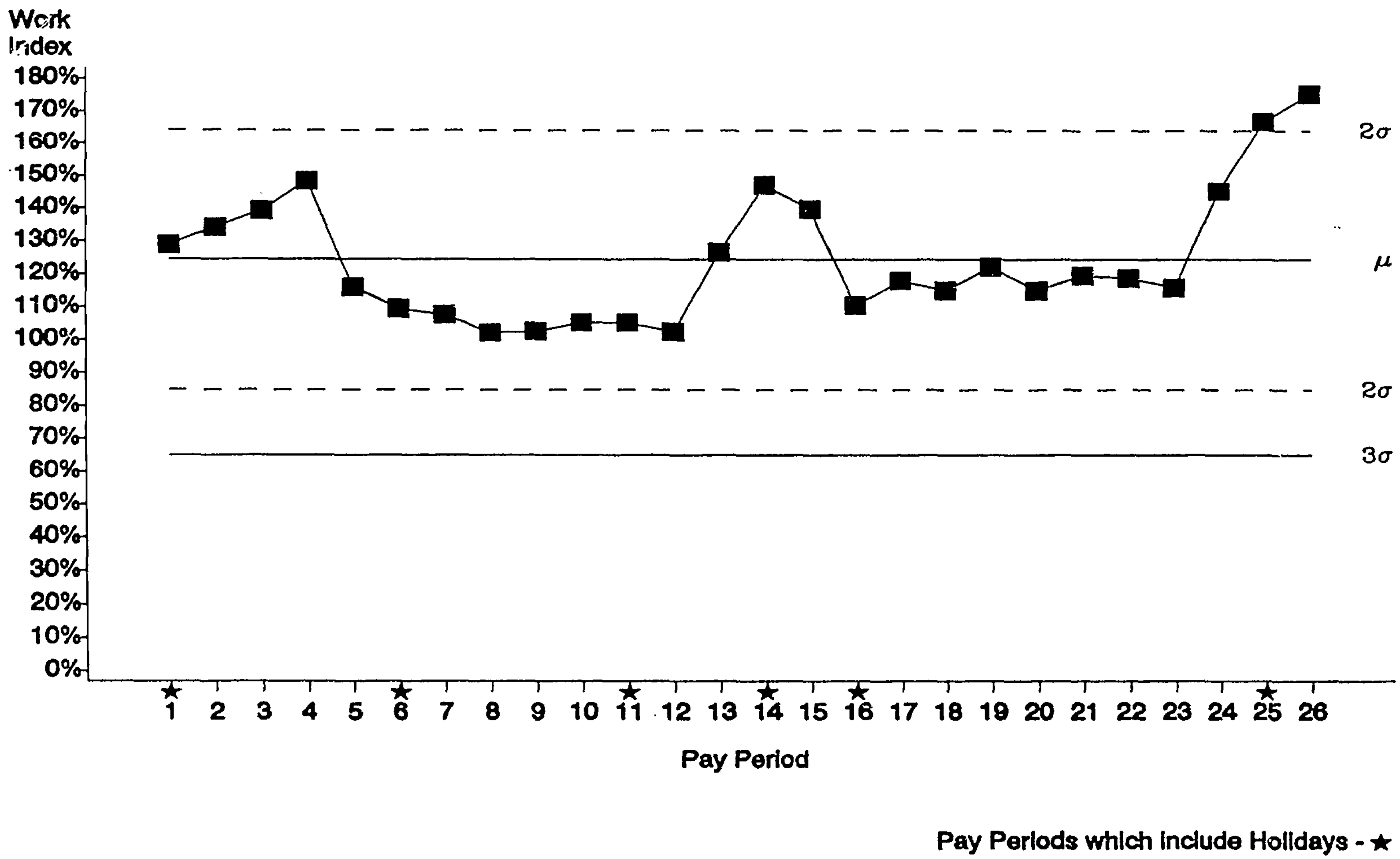


Figure 4: s Chart for Student Employees' Paid FTE



<u>Figure 5</u>: $\underline{X}$ Chart for Student Employees' Paid FTE

Discussion

The findings of the analysis were rather positive for the Human Resources department since there were not any employee classifications which were consistently 'out of control.' The graphics and an accompanying report have been reviewed by the Human Resources director and the initial reaction has been quite favorable due to the informative nature of the data. Our office has been requested to run a similar analysis on a fiscal quarterly basis so that trends can be watched and anticipated. Due to the unique nature of the working hours of health care employees and the working / funding patterns of student employees, the wide variability in the Paid FTE indicator may have to be overlooked.

This information can also be used to signal the effectiveness of any changes in budgeting or payroll procedures. This type of data allows for more effective planning by the Human Resources department by providing a basis for the anticipation of 'normal' working hours during the different times of the year. This type of data can be helpful when trying to explain to the university's high level administrators the proportion of human resources provided by the employees for regular work versus other activities.

Total Quality Management methodologies provide the Institutional Researcher with tools to aggregate and present data in an informative manner. These methods can be used to measure trends and assess the impact of policies in the area of Human Resources. The potential of this analytical tool is limited only by the user's resourcefulness.

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