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Quality Control Measurement of an Engineering Productivity Index

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In the business community, it has become critical that companies know how productive their engineers are. Organizations find it very difficult to measure the productivity of their knowledge workers (e.g., engineers) because their work output is cognitive. Because the nature of the work is "thinking" or "knowledge application," which brings important ideas and breakthroughs to organizations, this challenging task must be undertaken. Quality control (QC) charts were used to measure cognitive indexes of a group of knowledge workers, working engineers. These statistical process control charts measured previously developed cognitive indexes. The QC chart components were created from a representative group of working engineers, and then another sample of engineers were tracked over time for out-of-control run patterns. The results indicate that the cognitive behavior index would show out-of-control patterns for low productivity engineers. Substantial performance improvements are possible for engineers, resulting in cost savings from reduced negative turnover and lowered productivity giving better returns on engineering salaries.

Keywords Statistical process control; Employee productivity; Employee turnover.

INTRODUCTION

In today's society, there appears to be a growing trend of individuals who believe they should give themselves a raise by cutting back the hours they work to spend more time on side businesses or hobbies that bring them more satisfaction. This contradicts some of the older Taylor-oriented philosophies of a fair day's work for a fair day's pay. Organizations should expect some form of commitment to productivity by their knowledge workers, in order to get the return on investment they expect from the higher salaries paid to knowledge workers. Because of economic pressure and the use of business process reengineering, corporate right-sizing, and corporate restructuring, employees are not as likely to have one job throughout their lifetime as in previous generations. Nevertheless, companies should expect good work from their personnel while they are on the job (Amabile et al., 2002).

Knowledge work requires a special set of skills related to an area of expertise, such as those of a project manager, an engineer, a salesperson, a consultant, a manager, or a health care professional. However, it requires much more than a technical competence to be successful as a knowledge worker. Savvy knowledge workers understand that these additional skills include the ability to acquire and transfer knowledge effectively. Knowledge is the stock in trade of knowledge workers—it is both the process and the product of their work (Fisher, 1998).

Knowledge workers resist any attempt to have their productivity "measured" in any traditional sense. Given the complex nature of their work and the multiple relationships between various factors to be considered by these workers, traditional performance measurement techniques such as work measurement have not been very effective in identifying best practices. Most see themselves more as "artists" or "brain workers" than production workers, and most believe there are no fair and equitable measures that could be used to establish how well they perform. However, management maintains that "what you cannot measure, you cannot control."

Many of the fundamental quality control (QC) principles have been well proven in academic studies and in practice from industry. Data collection of meaningful data and proper statistical analysis has lead to improved quality through process control actions. This study aims to demonstrate how QC concepts can be used to efficiently measure knowledge worker productivity.

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This research provides a new approach for measuring cognitive or knowledge productivity. This approach is called the Statistical Evaluation of Cognitive Turnover Control System (SECtCS) methodology.

This study presents performance analysis of an engineering productivity index using statistical process control (SPC) charts. The data obtained on working engineers leads to improved measurement and control, which includes analysis of a powerful method for establishing control limits, identifying run patterns, and finding statistical outliers of performance.

BACKGROUND

This research focuses on the productivity of the engineer as the knowledge worker. To measure the statistical components of the engineering productivity, a cognitive productivity index for engineers was created. A questionnaire was created to test a representative group of working engineers for cognitive turnover (CT). CT is a condition in which knowledge workers are judged to have lower productivity because of lack of motivation related to thoughts of quitting the job and to extreme burnout. A linear regression model was used to validate the independent variables for the questionnaire, which included variables for turnover, burnout, and job satisfaction against a self-scored dependent variable for CT.

The CT model was developed based a total of 51 engineers and related service providers. Tables 1A and 1B contain demographics of the respondents.

The age of respondents ranged from 20 to 64, with a mean age of 25. The length of service for respondents ranged from 1 month to 480 months with a mean of 35 months. In the study, there were 15 females, which represented 29% of the test population. Also, there were 34 respondents who, while working, were looking for a better job, which represents 67% of our population. Finally, there were only 8 respondents working a secondary job or activity.

Table 1A
Demographics of respondents

Category	Mean	SD	Min	Max	Number of participants
Age (years)	25.5957	7.496	20	64	51

Table 1B
Demographics of respondents

Category	Number	Percent to total	Number of participants
Male	36	71%	51
Female	15	29%	51

Table 2
CT index score description table

Score	CT	Considering leaving	Description
1–2	No	No	Not burned out, high productivity
3–4	No	Occasionally	Light burnout, good productivity
5–7	Yes	Open for other jobs	Medium/high burnout, low productivity
8–10	Yes	Strongly considering	High burnout, low productivity, possible sabotage

The variables used to measure CT were challenges, depersonalization, personal achievement, and promotion. These variables were selected based on the research by the researcher on job turnover, burnout, and work motivation (Mobley, 1982). The questionnaire was tested for reliability and validity using Cronbach's alpha and R-square, respectively (Spector, 2002).

Multiple linear regression was used to develop a model shown in Eq. (1).

$$\begin{aligned} CT = {} & 1.1986(\text{mean challenges}) \\ & + 1.5749(\text{mean depersonalization}) \\ & - 1.7123(\text{mean personal achievement}) \\ & - 0.9351(\text{mean promotion}) + 5.1224 \qquad (1) \end{aligned}$$

CT is the dependent variable, which represents the degree of CT ranging from 1 to 10 (Table 2). Scores of 1 to 4 represent low cognitions to leave and generally low burnout indications. Scores 5 to 8 represent moderate burnout and leaving cognitions, with expected lower productivity. Scores 9 and higher may represent detrimental burnout and possible sabotage if departure is not eminent; lower productivity is expected.

APPLICATION OF QUALITY CONTROL PRINCIPLES

The idea that statistics may be important in assuring the quality of products and processes goes back to the advent of mass production. Statistical quality assurance includes mainly three techniques, quality control, establishment of tolerance limits, and acceptance sampling. The word quality, when used technically, refers to some measurable property of a product, process, or in our case, condition.

To ensure quality, a process has to have variability that does not fluctuate greatly between products or process. When the variability present in a process is confined to chance variation, the process is in a state of statistical control. This state is usually attained by finding and eliminating the problem that is creating the assignable variation. Most processes have this variation, and the most common method for detecting serious deviations is by using QC charts. There is a differentiation between control charts for measurements and control charts for attributes, depending on whether the observations are measurements that count data or monitor attributes. This research is a control chart for measurement. (Johnson, 2000).

The most common working statistical tools in QC are control charts. Control charts are characterized by a process mean and upper and lower control limits. As data are gathered about the performance measure, control charts portray the data as a function of time and change of performance (mean and variation) and can be monitored. Trends can be seen and data outside the control limits indicate that the process is no longer in control. The use of control charts is frequently called "statistical process control" (SPC).

USE OF CONTROL CHARTS FOR COGNITIVE TURNOVER

After the questionnaire and regression model development, turnover participants participated in a 12-week charting of responses for the control chart development of CT.

The control chart used in this study, called the SECtCS CT, is very similar to a typical X bar or R chart. They are similar with respect to the central line, the UCL, and LCL lines, zone calculations, axes normalization, and the pattern-analysis rules.

In the development of SECtCS CT, we first use historical data on the different CT mean scores for similar professionals. This approach is related to the chart of individuals for manufacturing processes (Montgomery, 1999).

Second, the CT scores from a questionnaire are plotted on the y-axis. SPC charts plot actual measurement values. Each point on the chart is intended to reflect the current state of the system. This approach allows for instantaneously detecting changes in the normally stable process. It has been noted in our research that the length of time that an individual stays at a company may keep him or her from leaving due to benefits and pension investment. This propensity to stay may cause CT to increase over time and may distort the findings.

CT scores were charted on an individual event as opposed to the averages of the CT scores for the individual. With this type of chart, the sample size for process control is 1 as opposed to the traditional sample size of 5 to 6. Because the sample size is not 5 or 6, the assumption of normality is challenged. In this study, the respondent's scores were tested for a normal distribution using a K-S test, and the null hypothesis could not be rejected. The main differences between the control charts for individuals and the traditional X-bar control charts are that the control chart for individuals tracks independent variables.

The traditional X-bar chart plots the average of some defined variable like a process (Grant, 1988). This distinction is focused because for this research the individuals CT score is tracked over time, not their average CT score.

Chart Run Rules

With typical SPC charts, six generally accepted patterns indicate that the process is out of statistical control (Evans, 1993). The rules are as follows: SPC Rule 1—1 point beyond zone A, SPC Rule 2—9 points in a row in Zone C or beyond, SPC Rule 3—6 points in a row steadily increasing or decreasing, SPC Rule 4—14 points in a row alternating up and down, SPC Rule 5—2 out of 3 points in a row in Zone A or beyond, and SPC Rule 6—4 out of 5 points in a row in Zone B or beyond. If any of these patterns were observed, a typical response would be to investigate the process for potential problems. Once the source of variation is corrected, the process should return to under control. More details are available in the literature (Bauch et al., 2001).

CHART DEVELOPMENT

The test population and sample group were the respondents who identified themselves as non-CT because we are testing to identify respondents who have excessive CT trauma, we used a chart that was derived from a normal group (Figure 1). This allows the identification of excessive CT to be identified by the SECtCS control chart.

Previously, 51 working engineers' CT index scores were predicted using the linear regression model. After taking the questionnaire, the valid independent variables were placed in linear regression equation Eq.(1), and their CT score was predicted. This

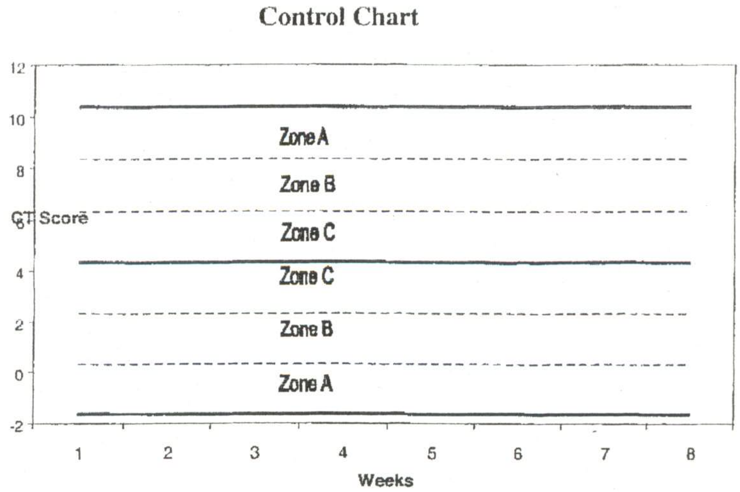

Figure 1. CT control chart.

predicted value was called the CT index. Twentyeight of the 51 respondents, through self-assessment, identified themselves as non-CT respondents. The normalized questionnaire variable data for the respondents who identified themselves as non-CT was used to calculate the central line, UCL, and LCL lines, and the zone boundaries. A chart of individuals approach was used; the central line will be defined as the mean of the CT indexes.

For our research, the following control chart components were calculated from our 28, non-CT respondents.

Table 3 depicts the information from non-CT respondents with respect to the SECtCS CT. The information gives X-bar as 4.3571, which represents the mean for people who were not CT. The standard deviation is given as 2.0040. Then using the traditional UCL and LCL calculation, the upper and lower limits for the given zones were listed on the charts.

RESULTS

Because this research is more focused on the CT scores that are out of control, more emphasis was placed on CT scores that violate the run rules with respect to the upper control limits. In other words, values below the CL are not considered relevant because they would represent CT scores that would not indicate a problem for this research. The most relevant analysis would be those scores that are measured above the CL, and these are the CT scores that are analyzed for violation of the run rules.

There were nine respondents who were tracked over a 12-week period. Of the nine respondents, four defined themselves as having CT; the others did not define themselves as having CT. Over the 12-week period, the most significant results are listed in Figure 2.

Respondent 1's control chart (Figure 2) shows that the respondent is out of control by violating SPC Rule 6, 4 out of 5 points in a row in Zone B or beyond. Also, Rule 3 is violated 6 points in a row steadily increasing. This respondent self-scored him- or herself as a CT.

Respondent 2 (Figure 3) does not have an out-of-control SPC chart. Furthermore, this respondent did not self-score him- or herself as CT, which is consistent with the chart.

Respondent 3 (Figure 4) violates SPC Rule 6, 4 out of 5 points in a row in Zone B or beyond. This respondent also did not consider him- or herself a CT on the initial dichotomous self-scoring questionnaire. This

Table 3
Construct means and standard deviations

X-bar	SD	CL	Upper zone C	Lower zone C	Upper zone B	Lower zone B	Upper zone A UCL	Lower zone A LCL
4.3571	2.0040	4.3571	6.3611	2.3532	8.3651	0.3492	10.3690	−1.6555

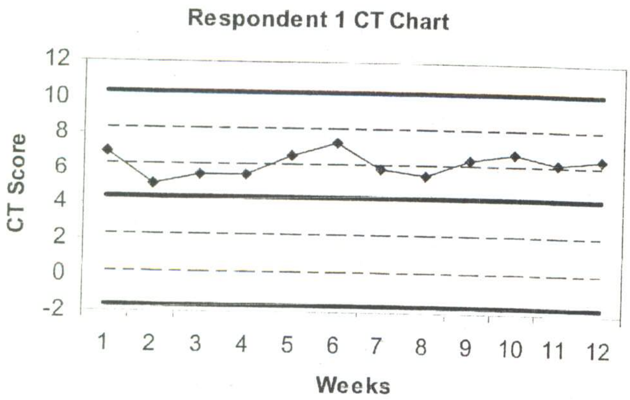

Figure 2. SPC chart respondent 1.

respondent's score barely exceeded Zone C into Zone B in the latter part of the study; this may be why this person considered him- or herself a non-CT because he or she appears to be on the borderline.

Respondent 8 (Figure 5) violates SPC Rule 5, 2 out of 3 points in a row in Zone A and beyond; SPC Rule 6, 4 out of 5 points in a row in Zone B or beyond; and SPC Rule 2, 9 points in a row in Zone C or beyond. This respondent also scored him- or herself as a CT on the self-scored CT dichotomous index. This respondent incurred quite a bit of added responsibility during this 12-week process, and some of the questionnaires were taken quickly.

The results confirm that respondents, who initially scored themselves as CT, also have SPC charts that showed that they were out of control with respect to normal respondents. Also, it appears that out of the four respondents who scored themselves as non-CTs,

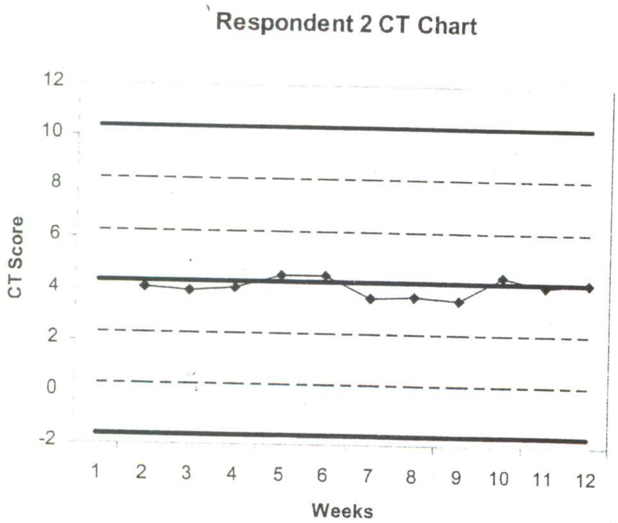

Figure 3. SPC chart respondent 2.

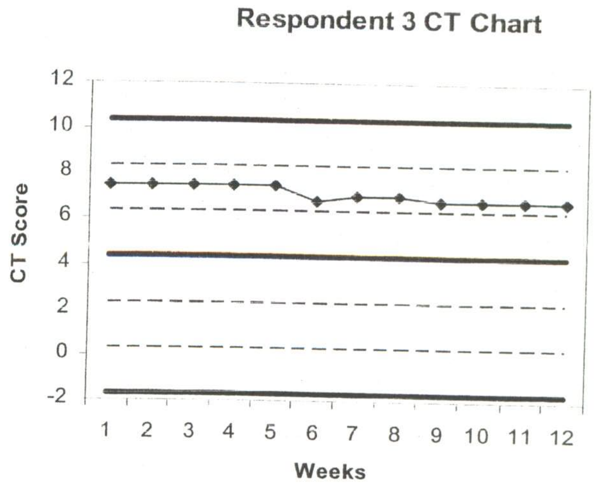

Figure 4. SPC chart respondent 3.

three were borderline CTs. This would follow along with the theory that many people who believe they are not CTs do actually measure as CT. This further explains why this problem needs to be identified and addressed from organizations as a whole.

Although all respondents show some form of CT, there are some respondents who had more profound out-of-control patterns on the control charts than others. It appears that there is not a large change from week to week for some of the respondents. It appears that if respondents' scores were tracked on a 4 to 5-week basis (monthly), there may be a larger trend. After informal discussions with respondents, during the process events such as performance reviews, company layoff news, and personal life events may have affected the score on a certain week. Furthermore, the country's current economy, an economy with recessionlike indicators, may have an impact on burnout. This affect on burnout can definitely impact respondents' CT scores.

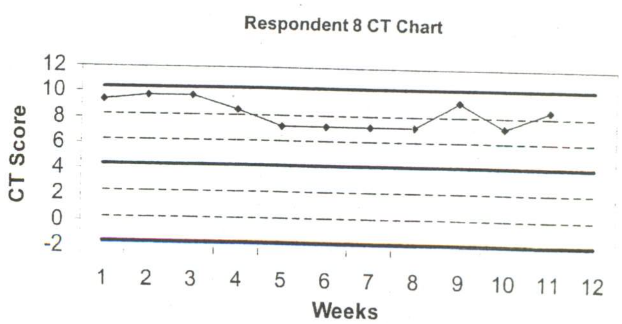

Figure 5. SPC chart respondent 8.

CONCLUSIONS

In this research, we demonstrated a quantitative measurement technique for knowledge workers in several ways. First, we described a method for measuring an index that measures when knowledge workers have reduced mental focus that affects their work productivity. Next, we used QC to truly identify that the problem is out of control. The benefits are that companies can use these techniques to identify low-output engineers and knowledge workers. Furthermore, companies can save money on nonproductive behaviors that may lead to company turnover and reduced work output.

There are other potential applications using the QC component of this SECtCS methodology. One opportunity is to measure the group means of project teams or different engineering departments and compare it with other projects or the engineering population as a whole. This would require using a more traditional X-bar chart, but could provide valuable company insight to their engineering team's production. Also, the SECtCS methodology provides for a recharting of the indexes after a company intervention has taken place. This allows the company to evaluate the solutions they may have implemented to address the problems. The challenge that may occur with this research is that management and personnel may not be willing to address the problems that this methodology may identify and take action.

The SECtCS methodology can potentially go into any organization and indicate which common causes are relevant for that organization and then evaluate the knowledge workers who work there. The true benefit is that after personnel or teams are measured, the scores can be used to determine if a department, group, project, or organization as a whole has an out-of-control CT group. On identification, some type of intervention can take place for these engineers, which will allow the company to become more profitable. Also, they can cut their losses on personnel or departments that are not providing the productivity that is necessary for the group, project, or organization to remain profitable.

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Dr. Erick C. Jones is an assistant professor at the University of Nebraska–Lincoln. Areas of specialization and teaching include total quality management, manufacturing systems, logistics, and engineering management. Erick has worked for United Parcel Service (UPS), Academy Sports and Outdoors, Tompkins Associates, and Arthur Anderson, LLP. He worked as an industrial engineer (IE), IE manager, IE director, and business consultant on various projects. His consulting areas ranges from ERP system implementations to supply chain logistics planning and organizational strategy.

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