Using of Cause-Selecting Control Charts to Model and Improve Service Performance of a Utilities Company

Rai’d A. Jemayyle and Nasser H. Ruhhal *

ABSTRACT

Cause-selecting control chart is a managerial tool that monitors industrial performance indicators of cascaded operational processes. It is used whenever statistical analysis indicates a cross correlation between the service performance indicators of cascaded stages of processes. The aim of this study is to use the CSC charts that are basically a regression based charts used in conjunction with traditional control charts for monitoring service performance indicators in cascaded service operations. This tool was implemented in one of the major electric power service providers in Jordan that provided the statistical data and information. The output results were verified along with the validity of the adopted methodology. Also, the capability of this tool to detect the potential problems in order to analyze the causes of each problem and find the proposing remedies had been proved. Addition result of this study demonstrated the building of service utility's model which is useful for similar electric power service providers.

The main conclusion of this study is that the networks and the electric meters installation departments are the prime-movers that have the main influence on the electric power company's revenues.

Keywords: Statistical Process Control (SPC), Cause-Selecting Control Chart, Cascaded Processes.

1.  INTRODUCTION

In service context, monitoring the quality of service performance in a frequent way is one of the manager's high priorities to examine the service outcome data in order to sustain competitive realities in a changing market. Managers of service companies need useful tools to monitor their operations and processes, as much as managers of manufacturing processes do. For example, Statistical Process Control (SPC) techniques have been essential tools for manufacturing managers for long time.

Shewhart quality control charts are powerful visual tools of statistical quality control, which have been used to monitor industrial processes, specially the manufacturing processes. Shewhart X-chart is considered a simple tool for construction and interpretation in comparison to other more complex statistical techniques therefore, it is attractive to convert limited operational processes data into graphical representation of the performance state of a service system (Sulek et al., 1995).

The opportunities to apply SPC techniques and Shewhart control charts of service processes had been discussed by Wood (1994) who demonstrated that even applying control charts mathematics are trivial but surprisingly it is a practical powerful tool to non-manufacturing processes specially the internal customers of the utilities companies whom receiving internal services rather than products.

Montgomery (2005) expressed that a fairly widespread but erroneous notion that Shewhart X-chart is not applicable to non-manufacturing environment because of the "product is different". The solution to this crucial conflict is to make measurements on the product that is reflective of quality and function of performance, and then the nature of service product has no effect on the applicability of control charts. One of the basic common confusions that retard the application of Shewhart X-chart to non-manufacturing product is more imagination may be required to select the proper variable or variables for measurement.

The dependency between sub-processes imposes a difficulty in control charts interpretations therefore, multivariate control charts such as Hotling T² could be a
solution. Hotling $T^2$ has a disadvantage because it is difficult to determine which of sub-processes component is out-of-control, thus CSC chart was proposed as another alternative (Yang, 2006).

Statistical process control techniques focus mostly on single-stage models. They cannot consider disseminating information throughout the multiple stages of the process, and hence may be ineffective in monitoring multistage processes (Shui et al., 2005).

Sulek et al. (2006) argues that if the stages in a multi-stage service are not independent, then SPC requires a control chart technique to adjust the dependency between successive stages. CSC Chart is a regression based chart proposed first by Zhang (1985), Wade and Woodall (1993) reviewed the basic principles of the CSC chart for the two-step process and suggested modifications. In literature the amount of researches documenting the using of CSC chart in manufacturing sector is very limited and rare in service sector. The service sector has not completely exploited the power of CSC charts.

Yang and Yang (2006) demonstrated the approach to control two dependent manufacturing processes with correlated observations; the research concluded that the correlation between two dependent manufacturing processes has a significant effect on the performance of control charts.

Monitoring manufacturing process using CSC charts including the error due to the effect of imprecise measurements was addresses by Yang and Yang (2005), CSC chart was constructed and the effect of error had been developed. Usually CSC charts are implemented without taking into account the effect of associated error, Shui et al. (2005) focused on studying the model including error and the effect of parameter estimation on the performance of CSC charts. The study found that the estimation errors affect the performance of CSC chart in a way that is different to conventional charts.

This study applied to one of the main Jordanian electric power companies and examined the validity of CSC charts as statistical tool. It is divided into five parts. Part one is an introduction to the importance of this study. Part two provides a theoretical background of the core methodology to design and construct CSC chart. Part three is an actual real implementation of CSC chart to an electric distribution power company. We use the information that was provided by the electric utility's company to monitor and analyze outputs for further discussion. Finally the conclusions are summarized.

### 2. THEORETICAL BACKGROUND

In cascaded processes, the traditional Shewhart $X$-chart used to monitor the service utilities performance at the first stage while the CSC chart implemented at the following stage. The first stage variables compose the input of second stage variables which means that the relationship between different critical decisions of performance indicators and metrics should be specified. The general scenario of a multistage process assumes that any quality characteristic undergoing a parameter shift at the current stage may affect some or all of the quality characteristics at the subsequent stages, but none of the quality characteristics at the preceding stages (Shu and Tsung, 2003).

A regression model is usually used to model the cascade service processes, although CSC charts does not require a linear relationship between the variables. More complicated relationship could be handled which is one of CSC charts advantages (Wade and Woodall, 1993). The standardized residuals from the linear regression model are plotted on the CSC chart. The service utilities managers have the capability to interpret whether the process is in-control or out-of-control depending on the decision rules shown in Table (1).

<table>
<thead>
<tr>
<th>Case</th>
<th>Stage (1) X-Chart</th>
<th>Stage (2) Z-Chart</th>
<th>Managerial Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No signal</td>
<td>No signal</td>
<td>Both stages in-control</td>
</tr>
<tr>
<td>2</td>
<td>Signal</td>
<td>No signal</td>
<td>Stage 1 out-of-control</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Stage 2 in-control</td>
</tr>
<tr>
<td>3</td>
<td>No signal</td>
<td>Signal</td>
<td>Stage 1 in-control</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Stage 2 out-of-control</td>
</tr>
<tr>
<td>4</td>
<td>Signal</td>
<td>Signal</td>
<td>Both stage out-of-control</td>
</tr>
</tbody>
</table>

Source: (Wade and Woodall, 1993).

The four decision rules shown describe the managerial interpretation of the service process measurement, where "no signal" refers that the control chart indicates that the process is in-control, While "Signal" refers that the process out-of-control. The decision rules are straight forward and the process measurements outcome interpreted.
\[ UCL_x = \bar{X} + 3 \left( \frac{MR}{1.128} \right) \]
\[ CL_x = \bar{X} \]
\[ LCL_x = \bar{X} - 3 \left( \frac{MR}{1.128} \right) \]

where, \( \bar{MR} \): is the average two periods moving rang.

Since the quality metric output of the first stage affects the quality output of the second stage then the following procedures summarize the steps of building CSC chart. First phase in construction of the CSC chart is to build a relationship between the two variables. One of the most common statistical techniques that is very useful to explore the relationship between two or more variables is the regression analysis (Montgomery and Runger, 2003) Simple linear regression model for \( n \) observations is:

\[ y_i = \beta_0 + \beta_1 x_i + e_i \]  

(2)

where, \( x_i \): is the quality metric measured at preceding stage.
\( y_i \): is the quality metric measured at current stage.
\( \beta_0 \) and \( \beta_1 \) are the intercept and slope of the line respectively, they are called the regression coefficients.
\( e_i \): is the random error term.

Practically, the regression coefficients are unknown and the criterion for estimating them is the least squares method. Second phase is to compute the cause-selecting values that are represented by the residual \( Z_i \).

\[ Z_i = y_i - \hat{y}_i \text{ and} \]
\[ \hat{y}_i = \hat{\beta}_0 + \hat{\beta}_1 x_i \]  

(3)

where, \( Z_i \): Are the cause-selecting values or the residual values.
\( y_i \): is the quality metric measured at current stage.
\( \hat{y}_i \): is the estimate of \( y_i \).

The CSC chart is a standard Shewhart chart for the cause-selecting values, therefore the cause-selecting values that represented by \( Z_i \) are the values that would be plotted on CSC chart to examine whether the performance processes is in-control or not. Third phase is to set up the CSC chart limits similar to a standard Shewhart control chart as follows: The center line of CSC chart is the average of residual values \( Z_i \) this value equal zero by definition of the regression residuals. The upper and lower control limits (UCL and LCL) are:

\[ UCL = \bar{Z} + 3 \left( \frac{MR}{1.128} \right) \]
\[ CL = 0 \]
\[ LCL = \bar{Z} - 3 \left( \frac{MR}{1.128} \right) \]

(4)

where, \( \bar{Z} \): is the average of residual values.

**IMPLEMENTATION TO THE ELECTRIC UTILITIES COMPANY**

Energy and particularly electrical power energy became the main engine of the modern life and the electric utilities companies all over the world have vital contribution for the prosperity of local communities through providing this essential service.

The electrical energy sector faces great challenges in this current period of competitive global market and electrical deregulation policies. This study implemented CSC chart to an electric power company in Jordan as a general case study to test to which extent this new service tool is applicable for other similar electric power companies. This electric power company has a plan of continuous improvement and modernization to be able to meet the continuous increasing demand for electric energy.

The organizational framework structure of the company is generally similar to others electric utilities companies, Therefore the model illustrated in Figure 1 is a two cascaded stages model that imitate the company’s administrative hierarchical organizational structure which includes all major departments. This model had been built through studying the organizational framework structure and deep understanding to the operational processes interrelationships. The model consists of two cascaded stages. The first stage is composed of the main technical departments that affect the total electric power utility's company’s performance outcome and a second stage that translates the service departments' efforts into revenues collections. Both stages are backed up with several other operational departments that have no big influence on the total revenues collection but have essential influence on the two cascaded stages model and facilitate the total work. The Back stage consist of others departments that are vital and indispensable for the whole cascaded stages processes.
It is obvious that each of the six departments that have been chosen has its own effect on the second stage. While each of first category’s departments respond to new subscribers’ demand for electricity to maximize the revenues, the second category’s departments protect the revenues by keeping electric meters from fraud through electric meters test and inspection department and minimizing the electric outage through electric maintenance and SCADA departments therefore, the second stage department is function of all first stage departments.

Thus, the first stage consists of six metrics to measure service performance in each of first stage departments and one metric for second stage as demonstrated in Table (2).

The reason beyond choosing each of the adopted department’s metric is based upon Sulek et al. (2006) recommendations that productivity, efficiency and effectiveness are three of the most widely used performance indicators in service operations.
Since productivity metric reflect an operating characteristic of the process and could provide managers with useful information that reflect the department practices, it was found that productivity is the most suitable metric to be used. Each department's labor productivity that measures the ratio of output value such as the department tasks to the input value such as labor hours is the most suitable metric that link each of departments practice to the company's profitability.

Data collection is one of the most difficult tasks for the researcher, because most of the private sector services companies don't permit sharing others there own data. Service performance measuring of thirty four consecutive months from the year 2004 to the end of year 2006 had been collected for each of the first and second stages departments. The Interrelationship between first stage SPI data and second stage will be analyzed to specify the strongest correlation between the two stages. Table (3) shows the correlation matrix of multiple SPI.

From Table 3 it is obvious that there is strong significant negative correlation (-0.899, p-value = 0.000) between the SPI of the high voltage and low voltage networks department and electricity sales collection department, and another strong significant positive correlation (0.927, p-value = 0.000), (0.838, p-value = 0.000) between electric meters installation department and electric meters test and inspection department with second stage department respectively. Another moderate positive correlation (0.59, p-value = 0.000) exists between the service performance indicator of main substation and substations department and the second stage. These results indicate a strong dependency between the cascaded stages departments that need to be examined.

The correlation indicates that three main departments (high voltage and low voltage networks department, electric meters installation department and electric meters test and inspection department) have the potential to be the main influence on the electric power company's revenues. A multiple linear regression analysis is used to build the mathematical model of electric utility's company that analyzes the statistical relationship between the SPI of first stage and second stage.

Stepwise backward elimination regression method was used to find the best subset predictors between the nominated SPI to build the model. Finding the best regression model that screening the nominated variables which lead for best subset of regressor variables subjected to different criterions. Usually the recommendation is to choose a combination between the minimum MS_E, Cp and PRESS multiple iteration tests were examined among the nominated regressors to specify the best possible regression model. Since Mallows statistic satisfies the two conditions that $C_p = 2.4 \approx 1 + \text{number of candidate regressors} = 3$ which is the minimum closest values of $C_p$ as an unbiased estimator and with $PRESS = 18.0503$ which is the minimum prediction error of square among other PRESS values, then the best found from all possible service performance regressors are CL / LH and NMI / LH.

Table 2. The SPI Metrics of an Electric Power Distribution Company

<table>
<thead>
<tr>
<th>Model Departments</th>
<th>Performance Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Substation and Substations Department</td>
<td>Number of Substations Installed / Labor Hour</td>
</tr>
<tr>
<td>High Voltage and Low Voltage Networks Department</td>
<td>High Voltage and Low Voltage Lines Length in (Km) / Labor Hour</td>
</tr>
<tr>
<td>Electric Meters Installation Department</td>
<td>Number of Electric Meters Installed / Labor Hour</td>
</tr>
<tr>
<td>Electric Meters Test and Inspection Department</td>
<td>Number of Electric Meters Tested and Inspected / Labor Hour</td>
</tr>
<tr>
<td>Electric Maintenance Department</td>
<td>Number of Electric Maintenance Tasks / Labor Hour</td>
</tr>
<tr>
<td>(SCADA) Department</td>
<td>Number of Outages / Labor Hour</td>
</tr>
<tr>
<td>Electricity Sales Collection Department</td>
<td>Electricity Sold in Million of JD</td>
</tr>
</tbody>
</table>
Since the adjusted coefficient of multiple determination $R^2$-adj penalizes for adding terms to the model, it is preferred for comparing and evaluating competing regression models, therefore $R^2$-adj $= 94.06\%$ still has one of the highest values and confirmed the previous choice of candidate regressors. Thus the previous results suggest that both high voltage and low voltage networks department and electric meters installation department of first stage do significantly affect the second stage electricity sales collection department. Therefore multiple linear regression analysis of the two service regressors is examined.

Summary of the two service performance electric company's performance indicators of multiple regression analysis results shown in Table (4) and the final regression mathematical model is:

$$ES = 14.3 - 1615 (CL / LH) + 55.9 (NMI / LH) \quad (5)$$

The regression result of the model with $R^2$-adj $= 94.1\%$ was significant at the p-value $= 0.000$.

An ANOVA analysis was used for testing the significance of the multiple regression models, it is shown in Table (5). Since (F $= 262.39$) $> (F_{0.05, 2, 31} = 19.46$) and p-value $= 0.000$ there is strong evidence to reject the null hypothesis and to verify the validation of the model.

The results show that the residuals plot were randomly distributed without any specific patterns or trend, in addition they satisfies the rule that if the errors are normally distributed, approximately 95 % of the standardized residuals should fall in the interval between -2 and 2 (Montgomery and Runger, 2003).

The conclusion is that the best approximately model found so far fitted and passed all of the adequacy check tests of regression model and assured its validation for further manipulations. CSC chart of the electric service utility's model satisfies all the assumptions to be constructed.

The data set of thirty four consecutive months from January of the year 2004 to October of the year 2006 for the two main SPI of the regression model were used to construct CSC chart and to generate the residuals of the model. The output of CSC chart illustrated in Figure (2) which needs later on more manipulation. CSC chart does not exhibit any unnatural variations and all of the residuals are within control limits.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>SE Coefficient</th>
<th>T</th>
<th>P-Value</th>
<th>VIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>14.290</td>
<td>2.046</td>
<td>6.98</td>
<td>0.000</td>
<td>2.5</td>
</tr>
<tr>
<td>CL / LH</td>
<td>-1615.0</td>
<td>235.7</td>
<td>-6.85</td>
<td>0.000</td>
<td>2.5</td>
</tr>
<tr>
<td>NMI / LH</td>
<td>55.865</td>
<td>6.426</td>
<td>8.69</td>
<td>0.000</td>
<td>2.5</td>
</tr>
<tr>
<td>R-Sq</td>
<td>R-Sq</td>
<td>R-Sq (adj)</td>
<td>C-p</td>
<td>PRESS</td>
<td>R-Sq (Pred)</td>
</tr>
<tr>
<td>0.710863</td>
<td>94.4 %</td>
<td>94.1 %</td>
<td>2.4</td>
<td>18.0503</td>
<td>93.57</td>
</tr>
</tbody>
</table>
Table 5. ANOVA for Testing Significant of Electric Company’s Regression

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>2</td>
<td>256.19</td>
<td>132.59</td>
<td>262.39</td>
<td>0.000</td>
</tr>
<tr>
<td>Residual Error</td>
<td>31</td>
<td>15.67</td>
<td>0.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>33</td>
<td>280.85</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2: Cause-Selecting Control Chart for Residuals

Since CSC chart decouple the cascade stages together then the full information analysis require constructing Shewhart $X$-chart of first stage SPI of the regression model. The Shewhart $X$-chart of the first stage SPI for high voltage and low voltage networks department and electric meters installation department illustrated at the Figure A1 and Figure A2, respectively in Appendix A.

A final recognized remark that is beyond May of the year 2005, CSC chart and Shewhart $X$-charts behave new quality levels that require to be tested. Therefore we proposed new revised control charts for these variables. The impression found that the service processes exhibits improvement in quality level operations, which is statistically, indicates that a difference in means of the first stage SPI distributions occurred.

Montgomery (2005) expressed that the effective use of any control chart will require periodic revision of the control limits and center lines. By examining the data, we noticed that the mean shift after the data point 17. Thus the data of the 34 months was divided into two periods, the first one includes the first 17 consecutive months and the second period includes the last 17 consecutive months. To insure that the proposed shift happened then a hypothesis testing procedure on the difference in the means of two normal populations based on the two sample t-test should be done.

The pooled t-test procedures are:

$H_0: \mu_1 = \mu_2$

$H_1: \mu_1 \neq \mu_2$

Test statistic

$T_0 = \frac{\bar{X}_1 - \bar{X}_2}{S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$ (6)

The pooled estimator

$S_p^2 = \frac{(n_1 - 1) S_1^2 + (n_2 - 1) S_2^2}{n_1 + n_2 - 2}$

Using a significance level of 0.05, then we found $(t_{\alpha/2, n_1+n_2-2} = t_{0.025,32} = 2.037)$. Since $(T_0 = 7.29) > 2.037$ and p-value = 0.000, then there is strong evidence to reject the null hypothesis. That is at the 0.05 level of significance, we have strong evidence to conclude that both means of CL / LH are different between the two periods. The same conclusion is applicable to the other two means of NMI / LH because $(T_0 = 5.39) > (t_{0.025,32} = 2.037)$. The service performance enhanced and
Using of Cause-Selecting …

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...a tangible progress of SPI acquired. Therefore the CSC chart and Shewhart $X$-charts should be revised and the data needs to be reexamined.

Figure (3) illustrate the revised CSC chart while Figure A3 and Figure A4 in Appendix A illustrate the revised Shewhart $X$-charts for SPI of CL / LH and NMI / LH consequently.

The assumption that supposed an existence of new operational quality level toward processes improvement was valid. The revised figures explicitly demonstrate the shift that occurred at service processes. The revised CSC chart did not alarm any signal far from control limits boarders which reflect that the second stage is robust.

While revised Shewhart $X$-chart for CL / LH alarm one signal in March of the year 2004 and when this data point revised it was found that at that date an over average productivity was achieved with minimum regular and over time due to internal regulations and absence of some technicians.

Figure A4 illustrates the revised Shewhart $X$-chart for NMI / LH. This chart delivered one alarm signal in September of the year 2004, when the information data revised it was found that these data did not show any exceptional of the staffing schedule or any increase or decrease in labor hours at that date even it is clear that that data point indicate an over average high productivity of SPI, the main logical reason for this ostensible improve that at September of the year 2004 and two months before as clear through the revised chart there was a continuous increase in the electric meters demand at that year in summer season that cause increase of SPI and then the demand declined to normal ordinary level until the beginning of May of the year 2005. The analyses of CSC chart do not show signals of unnatural variations of second stage which indicate that there are no assignable causes and the process fall within control limits.

Traditional Shewhart $X$-charts of high voltage and low voltage networks department indicate several out of control signals that might be referring to assignable causes; therefore the data of SPI were analyzed. The results revealed that the labor hours did not change drastically within the three years under study but there is a dramatic decrease in cables length, therefore according to the available information the results could be interpreted as follows.

Since the technical electric losses that related to resistance heat effect which increase directly with the increase of cables length showed tremendous increased at the national grid lines within the last three years under study, that require a quick and urgent remedy, thus the service utility's company take an action of reforming of the grid gradually. Therefore in March and April at the year 2004 the SPI exhibit over staffing but after that the same labor hours were used to replace the old cables of all sizes at low voltages and high voltages levels with less length according to new specifications and to install new insulated cables for new customers with the best possible minimum routing. Thus at the year 2006 in June, August and September it is admirable that even the ES trends increased which corresponds directly to new customers consumptions of electric energy but at the same time the new cables length decreases and the usage of grid maximized. The reconstruction policy indicates also an improvement of the technical losses which means also that the new policy achieved the goals with minimum labor hours.

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**Figure 3: Revised CSC Chart**
Even traditional Shewhart $X$-charts for SPI of electric meters installation department had several signals that lead to six out of control runs and even these signs might express negative assignable causes that represent a distortion within the existence process, the apparent circumstances are different than actual investigated facts. The discovering that within the last three years under study the number of technicians and regular labor hours and over time hours did not seriously change and the electric engineers of the intermediate management used there privileges to keep the over time schedules of staff's labor hours constant within normal average level and they used the regulations that permit to use the maximum over time ratios that leads to over staffing in January, February and March of the year 2004.

At September of the year 2005 the unexpected jump of SPI due to the necessity to fulfill the unexpected demand for new electric meters particularly at that month, with the same staff labor of regular and over time hours. The data revealed that in August and September of the year 2006 the labor hours did not change while the number of new meters installed kept increasing as a function of natural increase of population and new foreign investments which means that the productivity of technicians increased to fulfill the demand by the aid of new management systems and well organization.

Thus Out-of-Control-Action Plan (OCAP) which is a set of sequential activities plays an important role of the corrective action procedures. Figure (4) illustrate the proposed OCAP for the electric power company's main processes.

The OCAP describe the proposed sequence of actions that should be taken when one of the Table 1 decision rules scenarios occurred. The OCAP is a perfect troubleshooting problems solving tool for out-of-control points. Since the role of process engineers to react to remove the assignable causes if such out-of-control points had been detected at the first stage, Therefore a focus group of processes engineers and financial manager should be gathered to investigate the following possibilities:

1-If the technical electric losses that related to resistance heat effect show any increase on the national grid. From the technical view point as long as the cables spread the electric losses increase, therefore the revenues increase when ever the electric losses decreased, this aim could be achieved with minimum cables span related to high labor productivity, thus the processes engineers shall take a quick action to reform the grid.

2-If the electric meters installation productivity meet the customer demand, specially the unexpected demand regardless of the natural increase of population that shall be meet ordinarily by the aid of new management systems and well organization.

3-If the electric power company achieving the correspondent profits. Some of the financial problems that it could be related to the company’s delay in collecting the revenues from their customers.

The role of the financial manager comes at second stage alone with his team to investigate all of the possibilities of all types of financial procedures failure that results of showing week revenues collecting when out-of-control points are detected.

3. CONCLUSIONS

The fruitful advantage of decoupling CSC charts with Shewhart $X$-charts is that it attributes the assignable causes of second stage to first stage in multi cascade stages, whatever the results they are improvement or retardation of SPI. This tool distinguishes between the causes to which stage they are belong.

The aim of control chart is not just to detect and then to eliminate the assignable causes, but to find the real root cause of the problem, therefore this require a continuous improving of the process which is an essential part to control charts usage. It is very interesting to comment that the whole regression model and control charts are subjected to shifts, deviation and modifications according to nature of the continuous processes changing and the related regulations and ambient influences. Therefore there is an urgent need for periodic revision to update the model and data even the basic physical model of the cascaded service and the interrelation between them subjected to slower changes which enhance the stability of dealing with continuous improvement of service monitoring.

The operational processes of an electric power provider company was traced and the cascaded model configured, then CSC chart that is a regression based model was successfully implemented and the idea that CSC chart as managerial quality tool that has the potential to measure the service performance was proved. CSC chart now is not restrictive to manufacturing processes, but it was proved that it is a tool that could be
used identically in multi cascaded service operations. This study provided a practical glance to an electric power company in Jordan as a general case study to similar utilities companies. Thus the advantages of the results founds could be summarized in the following points:

1. The networks and electric meters installation departments represents the prime-movers of the electric power provider and there is also such other correlated important interrelationship between electric meters installation department and electric meters test and inspection department that shall be taken into account.

2. The managers shall give more concrete consideration to the main departments that play a major role of company’s profits and revenues.

3. The managers should give more attention to the supply chain that affects the main prime-movers business departments. Thus the supply chain of all of the technical electric equipments and apparatus that facilitate the productivity of electric meters installation department should be revised to fit the installation time table.

4. All of the electric company's effort starting from electric power stations to electric maintenance and power flow monitoring etc, serve the electric meters installations goal. Because the electric meters represent the revenue boxes of the electric power companies.

5. The electric meters installation department and electric meters test and inspection department had a high correlation that indicate a special care should be always done to protect electric meters’ operation.

6. The choices of SPI are managerial philosophical wise that needs deep understanding to the aggregate supply chain interactions.
Call the financial manager and processes engineers

Remove the assignable causes

Enter comments in log describing actions and Continually improve processes

Call the processes engineers

Remove the assignable causes

Figure 4: The OCAP for the Electric Power Company's Main Processes
Appendices

Appendix A

Figure A1: Shewhart X-Chart for CL / LH

Figure A2: Shewhart X-Chart for NMI / LH

Figure A3: Revised Shewhart X-Chart for CL / LH
Figure A4: Revised Shewhart X-Chart for NMI / LH

Appendix B

LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Terminology</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
</tr>
<tr>
<td>CL</td>
<td>Cable Length in Km</td>
</tr>
<tr>
<td>Cp</td>
<td>Total Mean Square Error</td>
</tr>
<tr>
<td>CSC</td>
<td>Cause-Selecting Control Charts</td>
</tr>
<tr>
<td>DF</td>
<td>Degrees of Freedom</td>
</tr>
<tr>
<td>LCL</td>
<td>Lower Control Limits</td>
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REFERENCES