Eng.& Tech.Journal, Vol.27, No.4, 2009

Quality Control of Cost Estimation Process in Construction Organizations

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Received on: 8/5/2007
Accepted on:6/11/2008

Abstract

Quality has been emerged in the 1980s as the top strategic issue in industry. Statistical process control (SPC) is an important element of total quality management (TQM).Though SPC techniques were originally developed for manufacturing, they have been successfully applied to certain administrative and service functions. The objective of this research is to demonstrate the applicability of SPC techniques for quality control and improvement in engineering organizations involved in construction (implementing projects). One of the most important processes to be controlled in construction projects (cost estimation process) has been focused on. The technique of controlling such a process has been defined depending on reviewing the subject in the previous studies. Adopting individual measurement charts is reached as the technique used to control this process statistically. Practical data, represented as a list of projects implemented in 2002 by the State Company for Transportation Projects together with their estimated and actual costs, have been obtained and considered for this purpose (through applying individual measurement charts as a suitable technique for controlling processes statistically) showing the applicability of SPC techniques in engineering construction organizations which undertake projects along long period of time.

ضبط جودة عملية تخمين الكلفة في المنظمات الإنشائية

الخلاصة

لقد برزت الجودة في الثمانين من القرن الماضي على أنها المسألة الإستراتيجية الكبرى في الصناعة. وتعد السيطرة الإحصائية على العمليات عنصرا هاما من عناصر إدارة الجودة الشاملة. وبالرغم من أن أساليب السيطرة الإحصائية على العمليات طورت لأغراض التصنيع، فإنها قد طبقت بنجاح في مجالات إدارية وخدمية. وان الهدف من هذا البحث بيان إمكانية تطبيق هذه الأساليب لضبط وتحسين الجودة في المنظمات الهندسية المعنية بالإنشاء(تنفيذ المشاريع). ولقد جرى التركيز على واحدة من العمليات الأهم من حيث ضرورة ضبطها في المشاريع الإنشائية، ألا وهي عملية تخمين الكلفة. حيث تم تعريف أسلوب ضبط مثل هذه العملية من خلال مراجعة الموضوع في دراسات سابقة. وباعتماد طريقة القياس المنفرد فقد تم التوصل إلى مخططات (لوحات) لتكون الأسلوب المستخدم لضبط هذه العملية إحصائيا. وبعد الحصول على بيانات تطبيقية تمثلت بقائمة من المشاريع المنفذة (مع كلفها التخمينية والفعلية) عام 2002 من قبل إحدى المنظمات الهندسية (الشركة العامة لمشاريع النقل والمواصلات) واعتمادها لهذا الغرض من خلال تطبيق أسلوب القياس المنفرد كأسلوب مناسب للسيطرة الإحصائية على العمليات، تبين إمكانية تطبيق هذا الأسلوب لضبط العمليات في المنظمات الهندسية المعنية بالإنشاء وتنفيذ المشاريع على فترة زمنية طويلة.

Introduction

Project processes are categorized into: (1) project management processes, and (2) project product- related processes. The fist group represents processes such as cost- related processes, time - related processes, resource- related processes

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https://doi.org/10.30684/etj.27.4.6
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…etc. The second represents processes which are concerned solely with the project product such as design, production and verification. The first group is handled in the International Standard ISO 10006; the second is covered in ISO 9004-1.

Cost related processes (which belong to project management processes) aim to forecast and manage project costs and

ensure that the project is completed within budget constraints. These processes are[1]:(1)cost estimation- developing cost estimates for the project,(2)budgeting- using results from cost estimates to produce project budget, and(3)cost control- controlling cost and deviations from the project budget.

This paper addresses cost estimation process to show the applicability of controlling it in construction organizations (on the organization level) by using control chart technique. Reasons of deviation have not been searched because the data taken (costs of projects) are historical and the projects completed before the last war (2003), and, more importantly, the aim here is devoted to show the applicability of using a quality control tool on the organization level.

Cost Estimation

Cost estimation involves developing an approximate estimate of the costs of the resources needed to complete project activities. When a project is performed under contract, care should be taken to distinguish cost estimating from pricing. Cost estimation involves developing an assessment of the likely quantitative results- how much will it cost the performing organization to provide the product or service involved .Pricing is a business decision- how much will the performing organization charge for the product or service, that uses the cost estimate as but one consideration of many[2].

The source of cost data necessary for estimating cost can be divided into: (1) price books, (2) monthly cost data, (3) building cost information service, and (4) priced bills of quantities [3]. The nature of cost information available to quantity surveyor is different according to the source type he adopts. Whereas the third type is possibly the most extensive and comprehensive construction cost information service in the world for it provides a valuable service to its users on a reciprocal basis, the other types should be as recent as possible when adopted.

Approximate Estimate

Generally**,** there are several methods that can be used for the preparation of cost plans and approximate estimates. These methods are summarized as follows [3]:

- **Unit method**: this method is very accurate when applied to projects such as schools to set a cost limit. It is based on the cost per place, and is based upon the fact that a close relationship exists between the cost of a building and the number of functional units it accommodates.
- **Cube method:** this method is now rarely used in practice due to the inaccuracies which can occur. It is a traditional method in which costs per cubic meter from completed projects are used to calculate the costs of future projects.
- **Superficial area method:** this is a popular method because it relates cost to an easily-understood quantity. Accuracy is claimed to be within ±5 per cent. The cost per square meter of gross internal floor area is readily available and easily calculated from completed projects.
- **Storey enclosure method:** this method is based upon amalgamation of the areas for walls, floors and roofs. It is relatively a new method and is claimed to be more accurate than by using the single-quantity method.

- **Approximate quantities:** in this method, the project is measured very broadly and rates are applied to their all-in quantities. The estimate takes longer to prepare and more information is needed.
- **Parametric cost analysis:** this method uses a combination of gross internal floor area and the building's perimeter. It is claimed that accuracy is better than that obtained from using the gross internal floor area alone.
- **Cost planning methods:** these methods are approximate estimating techniques coupled with cost analysis data. They are the only techniques that can be used to check the costs of the design as it develops. They should ensure that the tender sum comes within the forecasted cost.
- **Cost models:** these are a new generation method of forecasting and determining the cost of proposed projects. They are statistical methods and can only really be attempted if computer assisted.

Cost Estimation through Project Phases

Cost estimation is probably the most crucial function to the success of construction organizations. Cost estimating needs to be done in different manners at different stages of project as illustrated in Figure 1. Thus, estimate types fall in to two methods: the parametric and detailed method.

Parametric Cost Estimating

At the early stages where project budgets are to be decided and detailed information is not available, a parametric cost estimating techniques are most applicable. Parametric estimating (either preliminary or elemental) is made without working drawings or detailed specifications [5]. The estimator, who often works on behalf of the owner or the designer, may have to make such an estimate from rough design sketches, without dimensions or details and from an outline specification. The preliminary cost estimate, as such, can serve several purposes, including feasibility analysis, budgeting, preparing owners funding, and a baseline for evaluating contractor's bids.

The preliminary estimate can price the whole project as a function of some project parameters such as the floor-area method, storey-enclosure method, cubic method and approximate quantities.

In the elemental estimate, on the other hand, the project is first divided into convenient functional elements that are separately priced to improve accuracy. As such the elemental estimate can reveal the costs distribution of the project components to enable a cost comparison of each element in different projects [4].

The start is from stored cost data related to some existing projects that most closely resemble the one at hand and then modifying these costs by means of variation factors to suit the environment of the new project. Therefore it is essential to keep detailed historical cost records related to past projects or use one of the published references.

Detailed Cost Estimating

Detailed estimating can be performed when items are identified and a take off of their quantities is possible. A detailed estimate requires analysis of the method of construction to be used, the quantity of work, the production rates of resources, and the factors that affect each sub item. The key to the quantity takeoff is a structured work breakdown structure (WBS).

The various cost categories associated with a project looking at a contractor's point of view are as follows:

- **Direct costs**: these costs are the costs attributed to the production activities of a project. They are estimated based on detailed analysis of the contract, the site conditions, resource productivity data, and the method of construction being used for every activity. Direct costs can be ranged from 70 to 90% of the total cost [5]. Direct costs for a project include the direct costs for materials, labor and equipment which can be related specifically to an activity. The direct costs for a project are the sum of all of the activity direct costs [4]. Estimating activity cost is obtained by multiplying its duration by cost per unit of time which is daily cost of crew plus cost of material.

- **Indirect costs**: Indirect Costs are the necessary costs of doing business which cannot be related to a particular activity and in some cases cannot be related to a specific project. It tends to increase as project duration increases. Indirect costs can be classified into two subsets: project overhead and general overhead.

Project overhead includes those items of cost that can be related to a particular project but cannot be assigned to a specific activity. Such items include site supervision, site utilities, site trailers, project insurance and scheduling costs [5]. Project overhead can be ranged from 5 to 30% of total cost [4].

General overhead includes those items that are a part of the cost of doing business but cannot be related to a specific project. These are including items such as head office expenses, taxes. The current projects share of these costs can be estimated to be proportional to the projects value as compared to the total yearly volume of the contractor's organization. General overhead can be ranged from 0 to 15% of total cost.

At last it is the markup. This bid component represents the contractor's added fees (percentage of direct plus indirect costs) that cover profit and risk contingency. Markup can be ranged from 0 to 20% of total cost [4].

Statistical Process Control

Walter Shewhart established the foundation of statistical process control in 1931. He distinguished the causes for variation in a quality characteristic into two types: assignable causes and chance causes. Variations in the product of a manufacturing process which are unavoidable and cannot be removed (i.e., random variations) are said to be due to non-assignable causes (state of statistical control); otherwise they are due to assignable causes(out of statistical control) such as needing resetting, replacing , retraining, redesigning, etc.[6].

Nolan and Provost [7] in 1990 defined "special causes and common causes" terms popularized by Deming [8] in 1986 as follows:

- **Common causes-** those causes that are inherently part of the process hour after hour, day after day, and affect every one working in the process.
- **Special causes-**those causes that are not part of the process all of the time or do not affect every one, but arise because of special circumstances.

When a process has only common causes affecting the outcomes, it is called a stable process and is said to be in a state of statistical control. A stable process does not necessarily mean that the product produced or service provided is meeting specification or is satisfactory. It only means that the cause system for variation remains constant over time and the outcome is predictable. In an unstable process the magnitude of variation from one period to the next is unpredictable [8].

Quality Control Charts

In order to detect when a special cause of variation is creeping in and causing a process to go out of statistical control, samples of the product are taken at regular intervals and tested. The choice of the sample size will depend on the nature of the production process, the product and the testing technique; the larger the sample size the more reliable the information it gives but the longer it takes to test the items. A simple, effective and widely used device for analyzing and interpreting the data obtained from samples is the quality control chart.

Shewhart developed the control chart as a tool to separate special causes from common causes. It consists of three statistically based lines: the center line(CL), an upper control limit(UCL) and a lower control limit(LCL) (Figure 2).

Data for the sample statistic (or quality characteristic) are divided into subgroups. The subgroups should be selected in a way that makes each subgroup as homogenous as possible and gives the maximum opportunity for variation from one subgroup to another. Often, especially for variable control charts, the sub grouping is based on the order in which the product is produced.

In general, 3-sigma limits are used for the UCL and LCL. As a general model, the three sigma limits can be expressed as [10]:

$$UCL_y = E(y) + 3s_y \quad \ldots\ldots\ (1)$$
$$CL_y = E(y) \quad \ldots\ldots\ (2)$$
$$LCL_y = E(y) - 3s_y \quad \ldots\ldots\ (3)$$

Where

y = random variable or control statistic to be plotted on the control chart,

E(y) = expected value of the statistical variable, and

s_y = standard deviation of the variable y.

Variable Control Chart

The average chart(X) is used to study the process mean, and the range(R) or standard deviation(S) chart is used to study the process dispersion. While either the S or R charts could be used to study the process dispersion, the R chart is often used because of the ease of computations [11]. The distribution underlying these charts is the normal distribution. Even though the distribution of the R and S charts is not normal, the formulas derived for these charts are based on sampling from a normal distribution. The subgroup sizes usually vary from 2 to 5[9].

Quality Control Chart for Sample Means

A control chart for monitoring the mean quality of a product, that is, quality control chart for sample means, is shown in Figure 3. On this chart the values of sample means, x, are plotted against their corresponding serial number, i [6].

Table 1 shows equations for computing the control limits [10]. The values of the constants A , A2 , A3 , d2 , D1 , D2 , D3 , D4 , C4 , B3 , B4, B5 ,and B6, and their derivations can be found in most statistical quality control books.

Quality Control Chart for Sample Ranges

Although a control chart for sample variances is possible, the calculation of the sample variances can be time consuming. An easier and quicker means of monitoring a process variance is to use a quality control chart for sample ranges. That is, the easily obtained sample ranges are used to check the variance of the quality of the product. A quality control chart for sample ranges is shown in Figure 4.

Table 1 shows equations for computing the control limits.

Charts for Individual Measurement

This type of control charts is used when it is impractical or difficult to obtain some measurements during a short period of time. The mean(x) is used to estimate the average of process characteristic. For standard deviation, it can be computed by two ways :(1) the moving range between consecutive observations (MR), and (2) the general standard deviation for the sample. The first way (using moving range) is considered the more widely used in quality control. In this way, consecutive pairs of observations are used typically to calculate the moving ranges. This is done for (n) observations and (n-1) moving ranges. Then, the average moving range is calculated as follows [11]:

$$\overline{MR} = \frac{\sum_{i=2}^{n} MRi}{(n-1)} \quad \ldots\ldots. (4)$$

The control limits of the X chart are:

$$\overline{X} = \frac{\sum_{i=1}^{n} Xi}{n} \quad \ldots\ldots\ldots (5)$$

$$UCL = \overline{X} + \frac{3}{d2} \times MR \quad \ldots (6)$$

$$LCL = \overline{X} - \frac{3}{d2} \times MR \quad \ldots. (7)$$

In this case, (n) has special value (2), so d=1.128, and control limits will be:

Control Limits = $\overline{X}$ ±2.66MR … (8)

Process Control Techniques in Engineering Organizations

The applicability of process control technique for some quality measures is discussed here briefly. Some examples from the literature where statistical process control (SPC) techniques have been applied in engineering organizations are presented.

Control Charts for Change Order Percentages

Nigro [12] has provided data on change order percentages for all major military construction projects. It is estimated that approximately 50 percent of all change orders are due to interdisciplinary coordination errors and omissions. The rest are due to unforeseen site conditions and changes in owner requirements. The REDICHECK system, for interdisciplinary coordination checking, was introduced. The introduction of REDICHECK, a quality improvement action, led to a significant decrease in change order percentages. The system resulted in the process operating at a more acceptable level and with less variation.

Control Charts for Analysis of employee performance

Deming refers to rating systems of employee performance as lotteries. He notes that "apparent differences between people arise almost entirely from the action of the system that they work in, not from the people themselves." Deming considers the number of changes for each of 11 engineers in a division over the course of development of a project. After drawing C chart, he recognizes that all of the 11 engineers are within the limit and, hence, they form a system [8].

Control Charts for Percent of Commitment Met

A commitment is defined as a pledge or promise to provide a deliverable product to or accomplish a project milestone for the client by specified date. But when does the management decide that a significant number of commitments are not being met? The best way to make this decision would have been by using a control chart procedure. Armentrout [13] has described a commitment system established at Tennessee Valley Authority's Office of Engineering.

SPC Applicability on Cost Estimation in Construction Organizations

Cost estimation is one of the primary functions of an engineering organization. An accurate estimate is required for proper budgeting and planning. The accuracy of the estimate depends on the experience of the estimator, how well the project requirements are defined, the extent to which the design is completed, and the availability of cost data from equipment suppliers and subcontractors.

The following section addresses cost estimation process in a construction organization to analyze data for variation in cost estimates for construction of 24 projects undertaken by that organization. The applicability of SPC techniques on cost estimation in construction organizations has been investigated to show how well cost estimation is controlled in that organization.

Control Chart for Cost Estimates: Practical Application

The use of control charts is adopted here to analyze data for variation in cost estimates for construction of 24 projects, undertaken by the State Company for Transportation Projects (SCTP). The data (Table 2) were obtained through several visits and interviews to the Headquarter and projects listed were undertaken and completed just before the events of the last war(2003). The company looked for getting all projects costs under control. Thus, statistical control by using control charts is suggested and implemented in this paper to achieve this objective.

The type of control chart suitable for the data obtained and the process of estimation is "charts for individual measurements"; that is by using moving range and individual charts. The quality statistic (column 5 in Table 3- control chart calculations) is the percent variation, which is the difference between actual cost and estimated cost expressed as a percent of original estimated cost.

Moving Range is calculated as

$$\overline{(\mathrm{M}R)} = \frac{\sum_{i=2}^{n} \mathrm{M}Ri}{(n-1)} = 23.225$$

$$\overline{\mathrm{X}} = \frac{\sum_{i=1}^{n} Xi}{n} = 4.24$$

Screening moving ranges is required now for outliers.

$$\mathrm{UCL} = \mathrm{D}_4 * \overline{\mathrm{M}R}$$

$$\mathrm{LCL} = \mathrm{D}_1 * \overline{\mathrm{M}R}$$

D_4 and D_1 are obtained from standard tables for control charts. Since n=2 (Values of estimated and actual cost), $D_{4=}0.00$ and $D_{1=}3.27$.

UCL= 3.27 * 23.225 = 75.86
LCL= 0.00
Figure 5 illustrates moving range control chart using SPSS program.

The two 176.41s (projects 9 and 10) are taken out of the calculations. Thus, the control limits are:
UCL= 28.20
LCL=0.00

Figure 6 shows moving range control chart after the first screening.

The two 44.25s are taken out of the calculations. Thus, the control limits are: UCL= 15.96 and LCL=0.00.

Figure 7 shows moving range control chart after the second screening.
The two moving ranges 24.98 and 25.00 (project 12 and 13) are taken out of the calculations. Thus, the control limits are: UCL= 8.24 and LCL=0.00.

Figure 8 shows moving range control chart after the third screening.

Thus, moving range after calculation is (42.83/17) = 2.52
This value of MR will be considered in the calculation of control limits of the center line (individual measurement control chart).
UCL= 4.24 + 2.66 (2.52) =10.94
LCL= 4.24 - 2.66 (2.52) =-2.46

Projects outside limits are 3, 7, 9, 12, 15 and 20 (special causes). These projects should be excluded from the calculation of the chart's limits.

$\overline{X}$ = -0.2558

UCL =-0.26 + 2.66 (2.52) = 6.44

LCL =-0.26 - 2.66 (2.52) = -6.96

Figure 9 shows the individual control chart for data from 24 projects undertaken by SCTP. All the projects, except 3, 7, 9, 12, 15, and 20 fall within the control limits which are 6.44 and -6.96. The engineers in charge of these projects should determine the special causes associated with these projects and make them out of control. After that they are required to take action.

Conclusions

The conclusions reached from this research are:

1. The application of SPC in Iraqi construction engineering organizations is extremely disregarded.
2. Change in culture of the organization is required before SPC technique can be effectively used. Management commitment and training are very important in bringing about the cultural change.
3. Control chart technique can be used not only in industry but also in engineering organizations. This study has been dedicated to apply this technique in a construction engineering organization (on the organization level); it has been found that this technique is a very efficient tool to separate special causes from common causes of variance.
4. It is possible to include further quality measures like cost and schedule measures beside the traditional ones (defect measures) to control quality in engineering organizations.
5. Five projects (from 24) undertaken by SCTP have been discovered out of the control limits, which are approximately ±6.5 percent. The engineers in charge of those projects are advised to take action, and the management to make improvements to the estimation system, considering that as a policy, by reducing the limits to ±5.0 percent to eliminate or reduce the effect of the common causes.
6. It is recommended to adopt SPC in all engineering, design and construction companies in Iraq to control and improve their processes.

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Table 1 Equations for Computing Control Charts for Variables [10]

Method	X chart	R chart	S chart
m and s Known or assumed	**CL= m** **UCL= m + A s** **UCL= m - A s**	**CL= Ro = d_2 s** **UCL=D_2 s** **UCL= D_1 s**	**CL= So = C_4 s** **UCL=B_6 s** **UCL= B_5 s**
m and s estimated from X and R	**CL= X** **UCL=X+ A_2R** **UCL=X- A_2R**	**CL= R** **UCL=D_4R** **UCL=D_3R**	
m and s estimated from X and S	**CL= X** **UCL=X+ A_3S** **UCL=X- A_3S**		**CL= S** **UCL= B_4S** **UCL= B_3 S**

Note: X = Average of the average values of Xs in each subgroup
S = Average of the standard deviations in each subgroup
R = Average of the ranges in each subgroup

Table 2 Estimated and Actual Costs of SCTP Projects

Project No	Project Name	Estimated Cost*10^6	Actual Cost*10^6
1	Al.Khulany Park	199	199
2	Guards Building	9	9
3	Land Transport Park	127.53	71.1
4	Culverts Project	15	15
5	Alfao Park	68.5	69.5
6	Safwan Park	42.23	42.23
7	Container Squares	450	430
8	Developing Al.Karkh Park	694.84	694.84
9	Land Station in Al.Dijail	36.92	102.05
10	Ajnadin Park	6.69	6.69
11	Fence in Beji Railway	65.5	65.49
12	Hitteen Park 1	40	30
13	Nabi Midian Culverts	19.7	19.7
14	Additional Square in Ajnadin	150	150
15	Hitteen Park 2	470.98	454.47
16	Box Culverts	12.62	13
17	Al.Hashimeia Culverts	46.72	46
18	Al.Hindeia Park	37	37
19	Park of Al.Hindeia Resedential Quarter	83.75	87
20	Hitteen Park 3	470.98	454.17
21	Elongation of Al.Hamza Culverts	33.22	33
22	Al.Hilla Park	75	75
23	5-Parkes in Misan	323.35	323.35
24	Water Supply Tanks in Al.Hilla	9	9

Source: State Company for Transportation Projects (2002)

Table 3 Control Chart calculations

Project No.	Project Name	Percent Variation From Estimated Cost, Xi	Moving Range MRi
1	Al.Khulany Park	0.00	
2	Guards Building	0.00	0.00
3	Land Transport Park	-44.25	44.25
4	Culverts Project	0.00	44.25
5	Alfao Park	1.46	1.46
6	Safwan Park	0.00	1.46
7	Container Squares	-4.44	4.44
8	Developing Al.Karkh Park	0.00	4.44
9	Land Station in Al.Dijail	176.41	176.41
10	Ajnadin Park	0.00	176.41
11	Fence in Beji Railway	-0.02	0.02
12	Hitteen Park 1	-25.00	24.98
13	Nabi Midian Culverts	0.00	25.00
14	Additional Square in Ajnadin	0.00	0.00
15	Hitteen Park 2	-3.51	3.51
16	Box Culverts	3.01	6.52
17	Al.Hashimeia Culverts	-1.54	4.55
18	Al.Hindeia Park	0.00	1.54
19	Park of Al.Hindeia Resedential Quarter	3.88	3.88
20	Hitteen Park 3	-3.57	7.45
21	Elongation of Al.Hamza Culverts	-0.66	2.91
22	Al.Hilla Park	0.00	0.66
23	5-Parkes in Misan	0.00	0.00
24	Water Supply Tanks in Al.Hilla	0.00	0.00
		$\overline{X} = 4.24$	$\overline{MR} = 23.225$

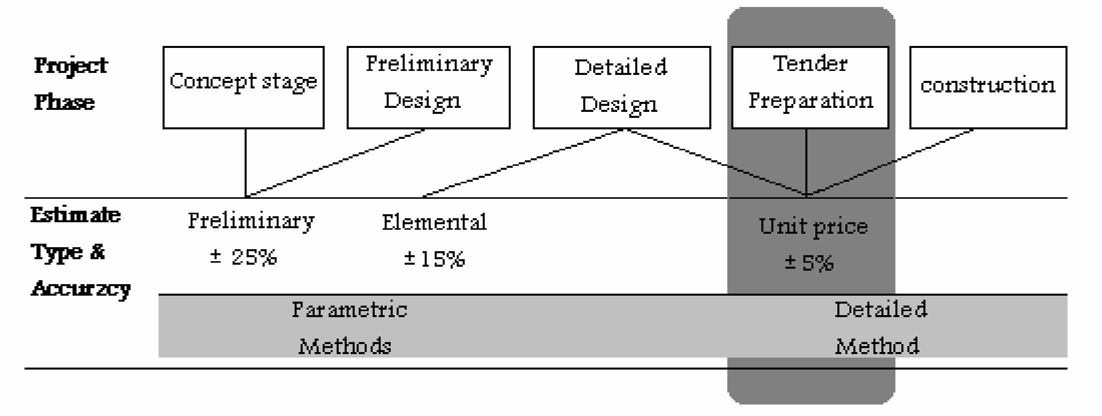

Figure (1) Estimate types through project phases [4]

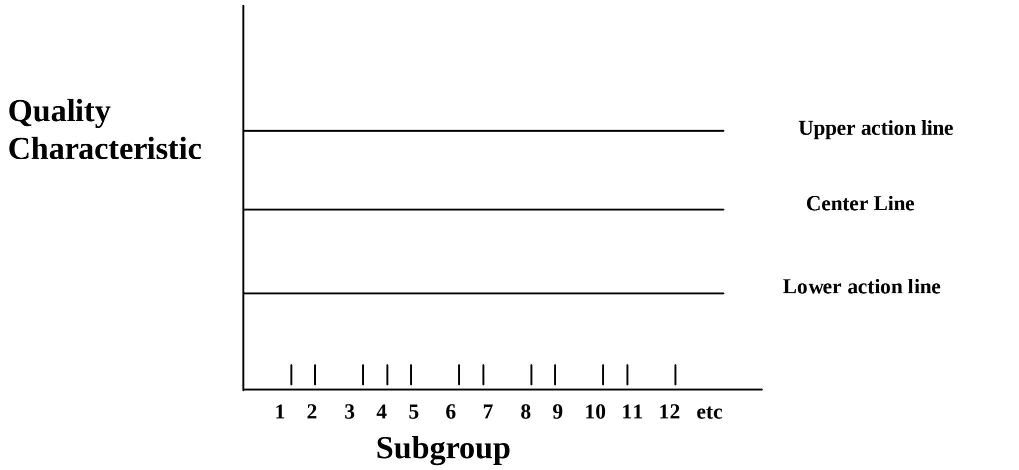

Figure (2) Control Chart [9]

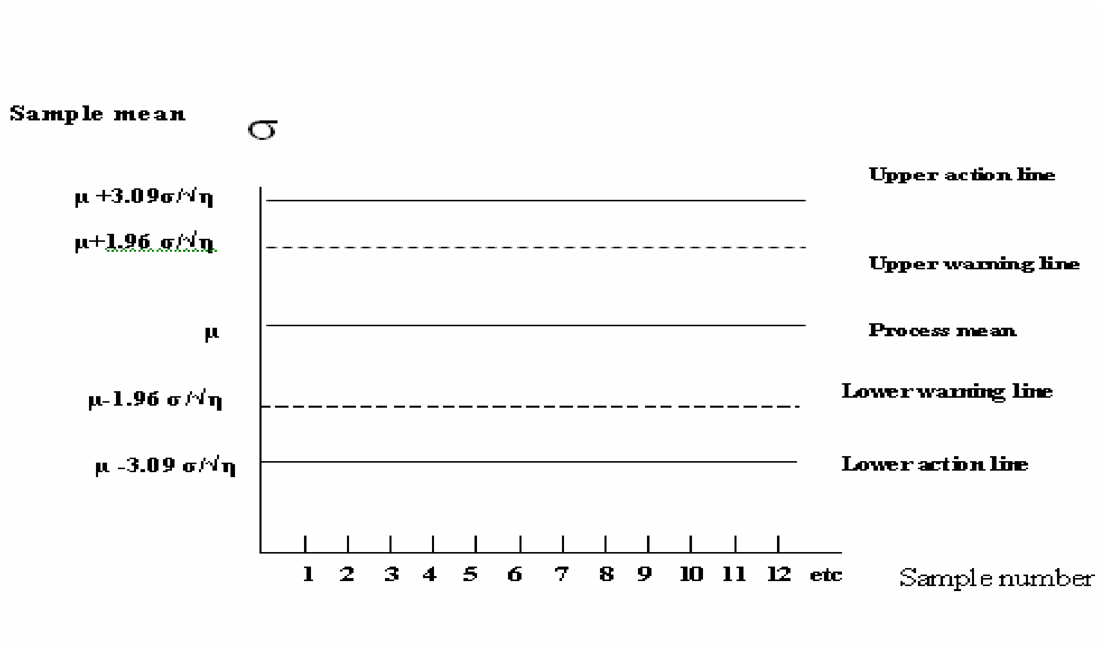

Figure (3) Quality Control Chart for Sample Means

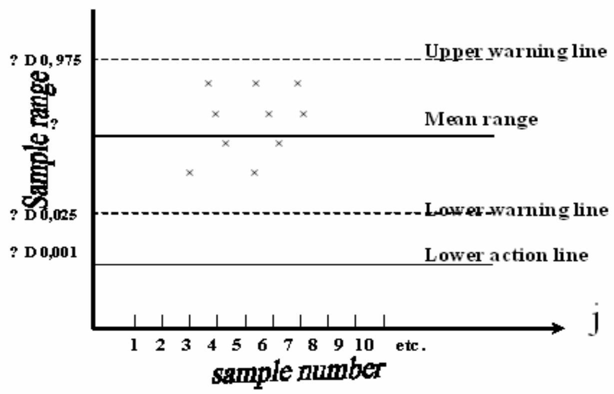

Figure (4) Quality Control Chart for Sample Ranges

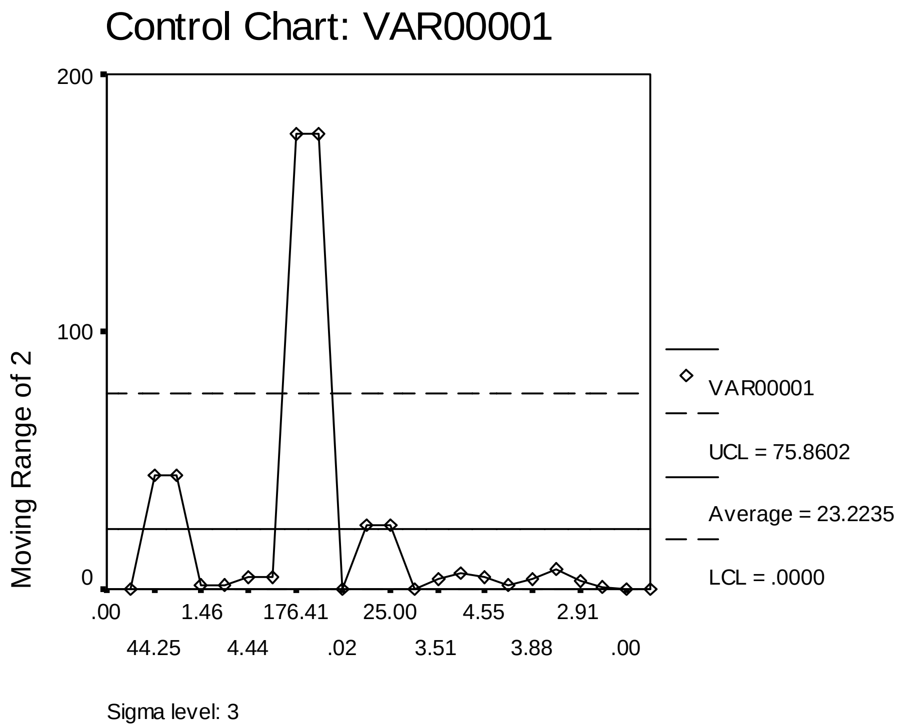

Figure (5) Moving Range Control Chart Using SPSS Program

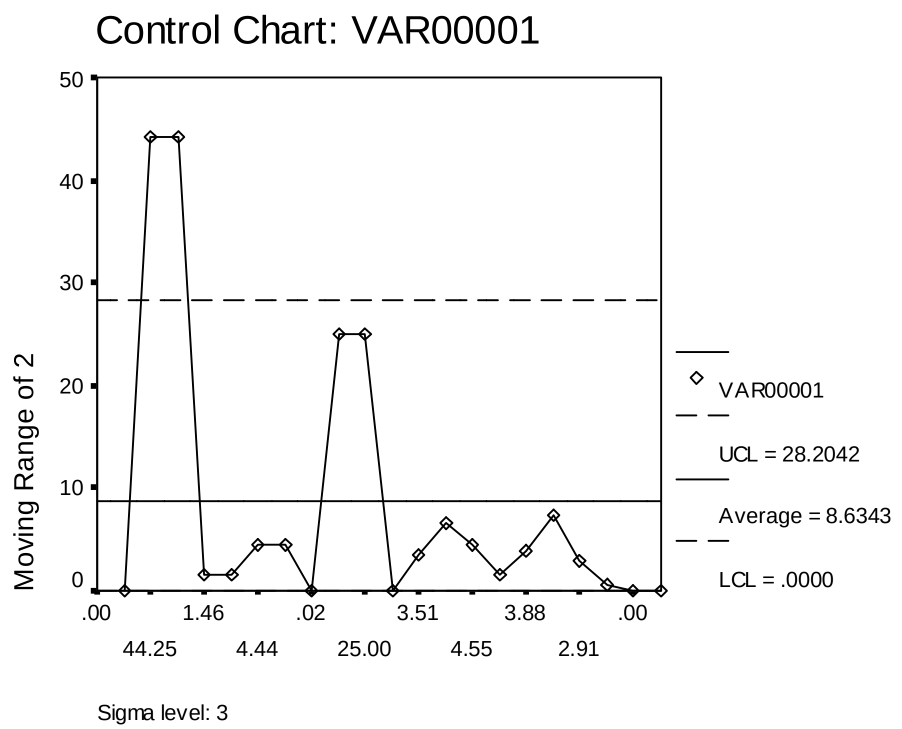

Figure (6) Moving Range Control Chart after First Screening

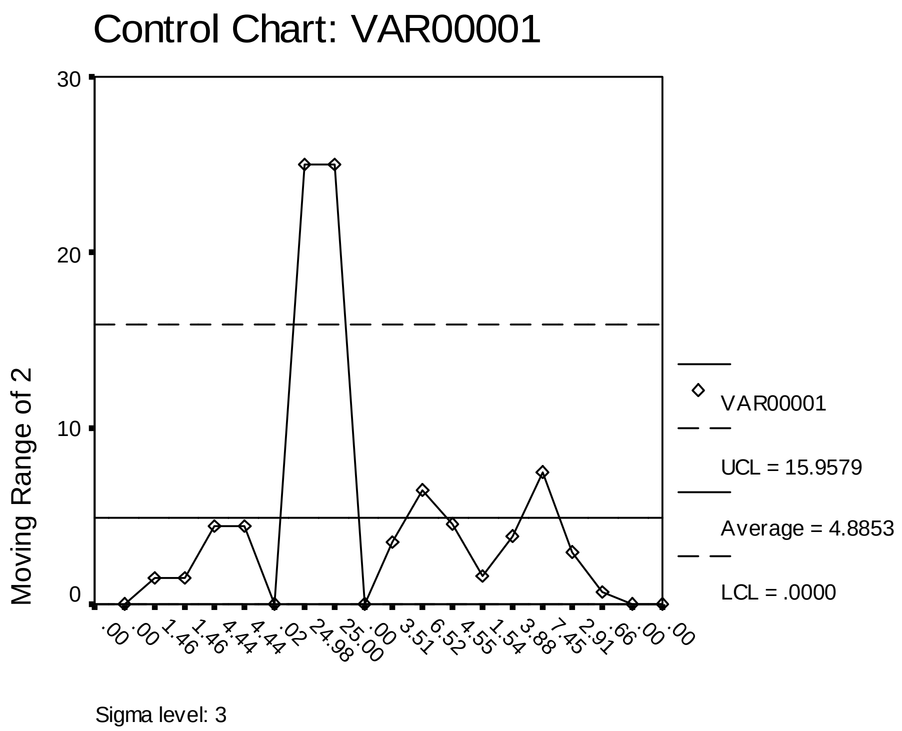

Figure (7) Moving Range Control Chart after Second Screening

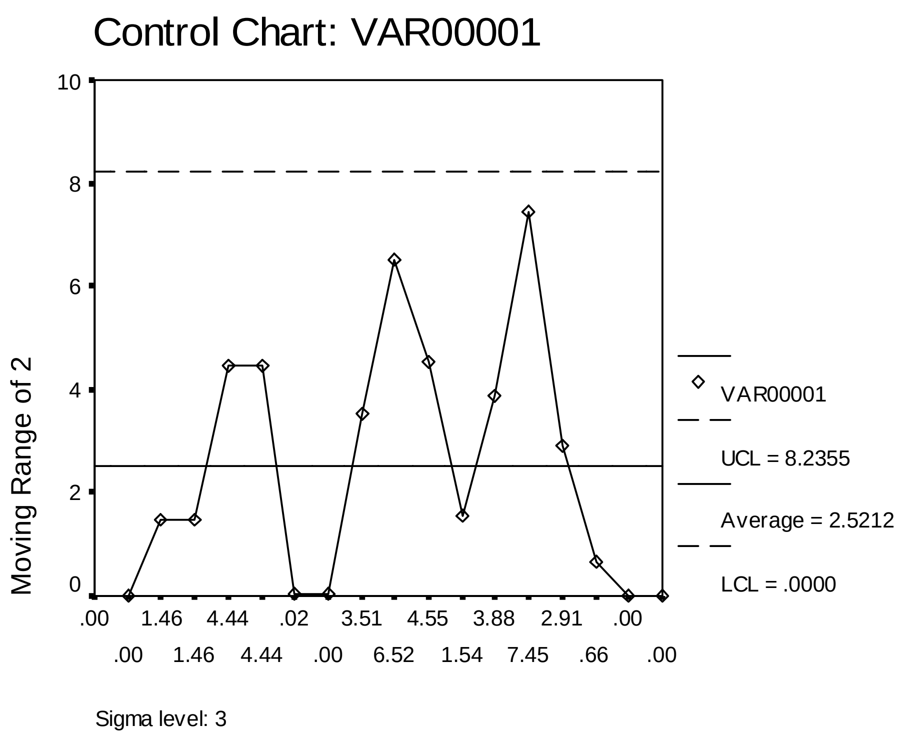

Figure (8) Moving Range Control Chart after Third Screening

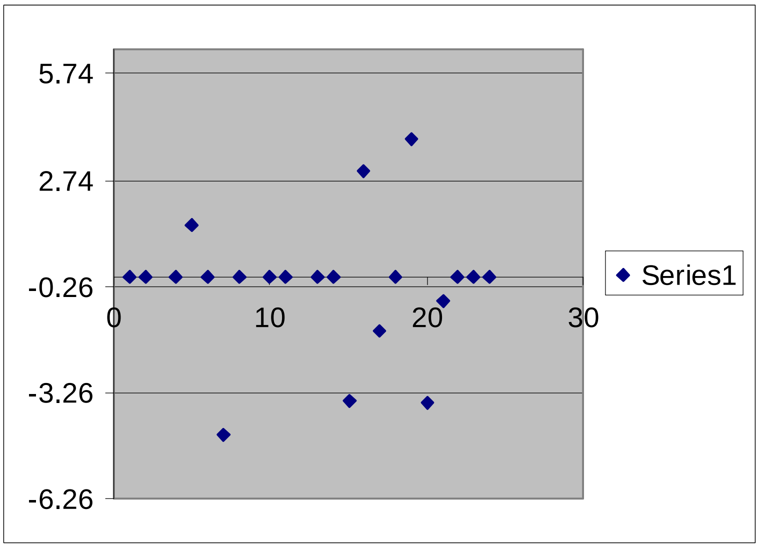

Figure (9) Control Chart for Percent variation from estimated cost