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THE DEVELOPMENT OF A SURVEY INSTRUMENT FOR MEASURING A RELATIONSHIP BETWEEN STATISTICAL PROCESS CONTROL SUCCESS FACTORS AND PERFORMANCE

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ABSTRACT

The present study highlights the instrument development to measure the relationship between statistical process control success factors construct and performance construct. From an extensive review of literature of statistical process control implementation, eleven dimensions of statistical process control success factors and three dimensions of performance were identified. In this paper, a survey instrument to measure SPC success factors construct associated with quality and firm performance was proposed. The reliability and validity of this survey instrument were tested using data from 122 respondents. It was concluded that instrument developed in this paper has satisfactory psychometric properties, reliable and valid. Hence the researcher can use this survey instrument to build the model to find the relationship between statistical process control success factors construct and performance construct. Industrial practitioners can use this survey instrument to identify and predict the success of their SPC implementation projects through managing of these associated factors.

Keywords: *Statistical process control success factors, quality and firm performance, survey instrument, psychometric properties, exploratory factor analysis.*

1.0 INTRODUCTION

Six Sigma, Lean Sigma and Total Quality Management are the current improvement methodologies many manufacturing companies and organizations are embarking on to improve productivity and quality for corporate survival. One of the technique that is being applied for improvement is Statistical Process Control (SPC). SPC refers to a collection of statistical tools and techniques used to collect and analyze the data to reduce variability in manufacturing products and

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processes. Numerous benefits can be associated with a successful implementation of SPC such as reduced scrap, rework, improved knowledge of processes, improved customer satisfaction and improved corporate competitive advantage [1], [3]. Although many companies reported success in their SPC implementation, there are also examples of companies which are less successful and suffered failures in implementation [5], [6]. As reported by Bird and Dale (1994), more than seventy five percent of suppliers of Ford had encountered difficulties in introducing SPC program. On the other hand, there are also common factors that are associated with the successful implementation of SPC. Most empirical studies on SPC implementation so far focused mainly on identifying factors for effective or successful implementation, which can be called "factor studies" [4, 5, 17, 18, 20, 26, 30, 34, 35, 42 - 46, 50]. These studies attempt to identify the factors for successful implementation and it lacks of explaination on the cause-and-effect analysis. These studies are also based on case studies and anecdotal in nature to assess the impact of SPC implementation. However, their investigations lack the rigor and scientific methodology in empirically identifying and measuring SPC success factors associated with quality and firm performance. Another shortcoming of their studies is the lack of empirically tested study to find a relationship between SPC success factors and quality and firm performance. Therefore, this study will attempt to build the survey instrument to identify and measure SPC success factors associated with quality and firm performance that is valid and reliable.

2.0 LITERATURE REVIEW

2.1 SPC Success Factors Dimensions

Numerous studies in SPC have reported that the factors that are affecting the successful implementation of SPC are complex and abundant. Numerous researchers have identified a variety of factors that can be considered critical to the success of SPC implementation. The success of SPC implementation is a matter of managing these so called success factors that are causally linked to quality performance [8, 41]. This implies that if the quality manager has a full control over these factors, the chance of successful SPC implementation is higher. Antony et. al. [4] summarized five previous studies in identifying 12 critical factors of SPC implementation in UKs small and medium size enterprises. Another five studies that discussed the SPC success factors were found and summarized in Table 1 [7, 20, 30, 41, 25]. Table 1 shows the success factors dimension found from the literature. The number in the column Total Citation represents the total number references citing a particular factor.

Based on Table 1, the authors have rearranged the factors based on the number that has been cited the most in the ten literatures. The factors are as follows: 1. Management commitment (10) 2. Teamwork (9) 3. Training (9) 4. Control charts (9) 5. Identification of critical quality characteristics (7) 6. Process prioritization and definition (7) 7. Measurement systems analysis (5) 8. Pilot study (5) 9. Use of SPC facilitators (5) 10. Cultural change (3) 11. Use of SPC software (2) 12. Documentation and process update (1). The authors suggest that the last two factors be integrated in the first 10 factors and are believed that these first 10 factors would represent the convergent opinions from both academicians and practitioners.

Table 1: Success Factors Dimension from Literatures

Success Factors	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	Total Citation
Management commitment	X	X	X	X	X	X	X	X	X	X	10
Teamwork	X	X	X		X	X	X	X	X	X	9
Identification of critical quality characteristics	X	X		X	X	X			X	X	7
Control charts	X	X	X	X	X	X	X		X	X	9
Documentation and update of knowledge process		X									1
Measurement system analysis	X	X	X			X				X	5
Process prioritization and definition	X	X		X	X	X			X	X	7
Cultural change	X			X	X						3
SPC Training & Education	X	X	X	X	X		X	X	X	X	9
Use of Pilot Study	X		X			X			X	X	5
Use of SPC Software	X									X	2
Use of SPC Facilitators	X	X	X	X						X	5

R1: [4], R2: [43], R3: [51], R4: [52], R5: [53], R6: [20], R7: [30], R8: [7], R9: [41] and R10 : [25]

The authors have also employed a method used by Rungtusanatham et. al. [42] of interviewing four subject matter experts (SME) from SPC practitioners and consultants to obtain their views and opinions on the so called SPC success factors. The criteria for selecting the SME is also based on Rungtusnatham. The SME were used to provide the combination of identifying and measuring SPC success factors from both the academic and SPC practitioners and to provide high degree of content validity. In addition, the selection of SME will also provide an insight on SPC success factors related to Malaysian manufacturing industries. Based on the interview conducted on the SME, seven set of SPC success factors that are relevant to Malaysian manufacturing industries were proposed. Those factors are as follows: Management commitment, Systems/Methods procedures, Culture, Recognition, Deployment, Training and Team work. All the seven factors proposed by the SME are similar with the 10 factors derived from the literature except Deployment. Hence, deployment dimension is added to the existing 10 factors proposed derived from the literature.

In the study conducted by [18, 19] on process capability implementation at nine Swedish organizations, they suggested in order to achieve successful process capability implementation, it must include critical factors, deployment and results. They identified factors such as management support, show potential of process capability study, conscious data gathering, educational efforts, cross-functional teams, routine of process capability study, awareness and willing to change, pilot projects and use of computer can lead to successful implementation. Although this research is focused on SPC implementation, the authors feel that some of the factors are really very relevant to any statistical based quality improvement methods such as SPC. Therefore, 11 factors were proposed as SPC success factors dimension in our study. Table 2 shows the initial set of 11 factors with its respective items. There were a total of 40 items that measured the 11 SPC success factors dimension. Table 2 shows the list of these 40 items and its respective source of literatures. For example, top management commitment dimension is consists of five items, namely, a1, a2, a3, a4 and a5. The description of each item is also shown in Table 2.

Table 2: Initial 40 items for measuring SPC success factors dimension

SPC SUCCESS FACTORS	
1. Top management commitment (Sources: [4, 7, 22, 25, 27, 43])	
a1.	Top management regulary spearheads quality improvement effort
a2.	Top management provides visible support for the use of SPC
a3.	Top management provides adequate resources to facilitate SPC efforts
a4.	Quality issues are reviewed in organization's management meetings
a5.	Top management has objectives for quality performance
2. Teamwork (Sources: [4, 22, 25, 43])	
b1.	Cross functional teams meet regularly to discuss quality improvement effort
b2.	Teams are recognized for superior quality improvement
b3.	Supervisors encourage problem solving activity through teamwork
3. SPC training and education (Sources: 4, 22, 43])	
c1.	Basic SPC training is given to related production workers before doing the charting
c2.	Quality related training is given to managers and supervisors in your organization
c3.	Real life examples from production floor is importance for effective training

c4.	Knowledge gained of SPC tools must be applied immediately after training
c5.	Refresher classes in the application of SPC tools regularly conducted
4. Control charts (Sources: [4, 43])	
d1.	Proper control charts are being used to monitor the stability of the process
d2.	Control charts are being used to satisfy the customer demands
d3.	Whenever the process is out-of-control, special causes are identified and removed
d4.	The computer software is required to construct control charts
5. Identification of process/product parameter (Sources: [4, 43])	
e1.	Selection of key process/product parameter is critical for the study
e2.	The impact of selecting those parameter to the process is well known
e3.	The customer has asked to monitor or control this parameter
6. Process prioritization and identification (Sources: [4, 22])	
f1.	Selection of key processes from a larger number of processes is being done
f2.	Management assists in choosing process that has caused problems
f3.	Process flow chart and cause and effect diagram helps in defining the process
7. Measurement systems analysis (Sources: [4, 22, 25])	
g1.	Adequate measurement system analysis (MSA) is in place
g2.	Only calibrated measurement devices are being used to take measurement
g3.	Gage repeatability and reproducibility (GR&R) is performed before conducting SPC
8. Pilot project (Sources: [4, 18])	
h1	Choose right application for the pilot project
h2	Pilot project is carefully planned to produce benefits and savings
h3	Successes from pilot applications is publicize to secure management confidence
9. Use of SPC Facilitator (Sources: [4, 22, 25])	
i1.	A technical expert comes to my aid when a problem arises regarding the use SPC
i2.	Technical support for the implementation and use of SPC is obtainable in-house
i3.	A champion to oversee implementation of SPC is available
10. Cultural Change (Sources: [4, 22])	
j1.	Regular meetings are held to discuss SPC problems based on data
j2.	Problems discovered through the use of SPC is resolved based on data
j3.	Results of SPC would be discussed with other related employee
j4.	The workers resistance to change were communicated effectively by management
11. Deployment (Sources: [7, 10, 18])	
k1.	SPC is being implemented in other production departments within organization
k2.	SPC is being implemented according to a well structured action plan
k3.	SPC procedures are being applied by improvement teams such as quality control circle, kaizen group, etc.
k4.	SPC procedures are being applied by large number of relevant personnel in the daily work

2.2 Quality and Firm Performance dimension

The causal effect of successful SPC implementations have been reported in various publications such as increased communication among all departments, improved customer satisfactions, reduced costs, reduced process variability and improved product and process quality. Various definition of so called successful SPC implementation based on literature and interviews conducted by four subject matter experts(SME) have been defined and derived [4, 17, 18, 19, 42, 43, 44]. Based on professional judgemental process of grouping similar characteristics, the SPC successful implementation has been divided into two aspects: Soft aspects and hard aspects.

In addition, this study also attempts to identify and categorize factors which have a causal impact directly on the soft aspects and/or hard aspects independently or both simultaneously. Studies by [9, 12, 13, 40] revealed that SPC being introduced into an organizations could be attributed by two categories of motivational factors, namely, to improve manufacturing and process quality and to satisfy the customer demands. In this study, the two motivational studies are similar to what the authors classified as soft and the hard aspects of quality performance.

2.2.1 Soft Aspects

"Soft" aspects of successful implementation is related to human factors such as improved customer satisfaction, improved understanding of the process for people at different level of organization and uses perceptual data for measurement.

2.2.2 Hard Aspects

"Hard" aspects are concerned with internal measure of quality performance such as reduction in scrap rate, improved yield, reduced process variability, cost improvement and uses objective measure. [21] defined quality performance measures comprising four items, namely, percentage of defects, the cost of warranty, the total cost of quality and the defect rate relative to competitors. Based on interviews conducted with the panel of SMEs, the definition of quality improvement consists of increasing yield, defect reduction, cost improvements, less rework and scrap, and reduce variability.

2.2.3 Firm Performance

Quality performance is positively related to firm performance [32]. The measurement indicators to measure the firm performance are include sales growth, unit costs, profit growth and market share [2, 32]. Table 3 lists initial 12 items that measure quality and firm performance.

Table 3: Initial 12 items for measuring quality and firm performance dimension

QUALITY AND FIRM PERFORMANCE	
1. Quality Performance (Soft Aspects) (Sources: [18, 21, 25])	
sf1.	Customer satisfaction has increased over the past three years
sf2.	Our company has experience improvement in meeting industry and qualiy assurance regulations

sf3.	Our company image has improved nationally and internationally for business
sf4.	Our plant good manufacturing practice has improved over the past three years
2. Quality Performance (Hard Aspects) (Sources: [18, 21, 25])	
hd1.	Cost of scrap and rework has decreased over the past three years
hd2.	Process variability has decreased over the past three years
hd3.	The product cycle time has decreased over the past three years
hd4.	The product delivery has improved over the past three years
3. Firm Performance (Sources: [2, 10, 32])	
fm1.	Our plant's sales have grown over the past three years
fm2.	Our product unit cost of manufacturing has decreased over the past three years
fm3.	Our plant's profit has grown over the past three years
fm4.	Our market share has grown over the past three years

3.0 METHODOLOGY

This section explains the development of a survey instrument and is divided into three parts: i. Instrument development, ii. Pilot testing, iii. Sample. These parts are discussed in the following subsections.

3.1 Instrument Development

The purpose of survey instrument is to provide a valid and reliable means of data collection to identify and measure SPC success factors associated with quality and firm performance. The survey instrument developed in this study consists of four major parts. The first part of survey instrument attempts to solicit information about the description and the extent of the SPC implementation. [27] defined SPC implementation as when after the decision has been made to use SPC in department and management has committed resources to train managers or executives in applying SPC techniques. They also defined the extent of SPC implementation by providing the checklist of statistical techniques being used in manufacturing process [25, 49] added another criteria for a fully developed SPC implementation citing the minimum length of implementation between 1.5 to 2 years. The respondents were asked to rate the "extent of implementation" of SPC techniques by using 5-point Likert (1 = No implementation, 2 = Little implementation, 3 = Some implementation, 4 = extensive implementation, 5 = complete implementation, NA = Not applicable).

The second part of the survey instrument comprises 11 proposed SPC success factors derived from the literature and subject matter experts as shown in great details in Table 1. In this part, the respondents were asked to rate whether they could agree or disagree to some degree of declarative statements as shown in Table 2 by using 5-point Likert (1 = Strongly disagree, 2 = Disagree, 3 = Some what agree, 4 = Agree, 5 = Strongly agree. The third part of survey instrument comprises the performance outcomes of the successful implementation of SPC, namely, quality and firm performance. The quality performance consists of two parts: soft aspects and hard aspects. The details of the 12 items measuring quality and performance and its references are shown in Table 3. The last part of the survey instrument is designed to capture general information regarding the background of respondent and company, SPC program and some aspect of SPC implementation. The use of 5-point Likert scale in this type of quality management practices has been supported by many researchers [23, 47, 39, 48].

3.2 Pilot Testing of the Instrument

The initial draft of the survey instrument was presented and reviewed by the 16 members of manufacturing and industrial engineering department at departmental colloquium. Individual consultation and meeting was held based on the feedbacks and the survey instrument was modified. The survey instrument was sent and reviewed by the nine quality experts from both the academic and industry to check for the following issues:

i. The representativeness, reliability and validity of the items
ii. The degree of the difficulty and understanding of the items by respondent
iii. The total time taken to complete the whole survey instrument

The survey instrument was again modified based on comments from these nine experts. Pilot study was conducted by sending the survey instrument to 10 manufacturing industries to pre-test the instrument and to confirm the relevancy of the questions and to provide clear meanings and jargons used in the industry. The 10 returned responses were evaluated and their comments reviewed. The final survey instrument contains 40 items for SPC success factors and 12 items for quality and firm performance as shown in Table 2 and Table 3 respectively.

3.3 Sample

The authors had selected manufacturing companies within Johor area such as Senai, Tebrau, Tampoi and automotive original equipment manufacturer such as Proton, Perodua, Honda and Toyota for our exploratory study. Questionnaires were sent to the managers and engineers of these companies, resulting of 122 useable questionnaires or respondents. Sample size is also important consideration in the discussion of internal consistency and construction of satisfactory psychometrics properties. Reid, recommended that in order to conduct items analysis for dimensioning factor, it will require a sample size of about 100 to 200 respondents [47]. Therefore, based on these guidelines, our target sample of 122 respondents exceeds the minimum of 100 respondents.

4.0 RESULTS

This section explains how the data was analyzed to determine the reliability and validity of SPC success factor constructs and performance construct.

4.1 Reliability of SPC Success Factor Construct and Performance Construct

Table 4 shows the computed Cronbach's Alpha reliability coefficients for each of the six factors based on Exploratory Factor Analysis(EFA) [16, 24]. The reliability coefficient fell between 0.7 and 0.9, therefore, all the six measurement scales developed for this study were judged to be reliable since reliability coefficients of 0.7 or higher are considered satisfactory [36]. Factor loadings significantly exceeded the minimum threshold of 0.3 recommended that item values less than 0.5 do not share enough variance with other items in that scale and should be deleted from the scale, [37], [38]. Some suggested that loadings greater than 0.45 could be considered fair, those greater than 0.55 are considered good, those of 0.63 are considered very good and those of 0.71 and higher are considered excellent [15], [28], [31]. Most loadings exceeded 0.63 of each respective construct and therefore, is considered reliable construct.

Table 4: Results of EFA for SPC success factors construct

	Factor Pattern					
Items	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Factor 1 (Cronbach's Alpha = 0.919)						
i1	0.695					
i2	0.707					
i3	0.711					
j1	0.789					
j2	0.738					
j3	0.819					
j4	0.758					
Factor 2 (Cronbach's Alpha = 0.889)						
a4		0.686				
a5		0.72				
b1		0.808				
b2		0.8				
b3		0.699				
Factor 3 (Cronbach's Alpha = 0.786)						
c1			0.57			
c2			0.604			
c3			0.733			
c4			0.703			
c5			0.638			
Factor 4 (Cronbach's Alpha = 0.877)						
k1				0.579		
k2				0.654		
k3				0.636		
k4				0.772		

Factor 5 (Cronbach's Alpha =0 .84)		
a1	0.763	
a2	0.796	
a3	0.641	
Factor 6 (Cronbach's Alpha = 0.7)		
e1		0.534
e2		0.687
e3		0.771

Table 5 shows the computed Cronbach's Alpha reliability coefficients for each of the three factors for quality and firm performance. The reliability coefficient for each three factors exceeded 0.7 threshold value recommended by Kemp and Nunally, recommended that item values less than 0.5 do not share enough variance with other items in that scale and should be deleted from the scale [33, 36]. Comrey suggested loadings greater than 0.45 could be considered fair, those greater than 0.55 are considered good, those of 0.63 are considered very good and those of 0.71 and higher are considered excellent [15]. All each three factors loadings exceeded 0.63, therefore, all the scales developed for measuring quality and firm performance were judged to be highly reliable and internally consistent.

Table 5: Results of EFA for quality and firm performance construct

	Factor Pattern		
Items	Factor 1	Factor 2	Factor 3
Factor 1 (Cronbach's Alpha = 0.869)			
sf1	0.77		
sf2	0.833		
sf3	0.798		
sf4	0.735		
Factor 2 (Cronbach's Alpha = 0.804)			
hd1		0.716	
hd2		0.734	
hd3		0.734	
hd4		0.741	
Factor 3 Cronbach's Alpha = 0.878)			
fm1			0.83
fm2			0.637
fm3			0.81
fm4			0.842

Hence, based on Table 4 and Table 5, the six SPC critical success factors construct (Factor 1, Factor 2, Factor 3, Factor 4, Factor 5 and Factor 6) and three quality and firm performance factors construct (Factor 1, Factor 2 and Factor 3) extracted by the EFA is highly reliable.

4.2 Validity of SPC Success Factors Construct and Performance Construct

The three most popular methods to evaluate the validity of the constructs are content validity, construct validity and criterion-related validity [11]. Table 6 shows the definition of three types of validity.

Table 6: The definition of three types of validity

Content Validity	Construct Validity	Criterion-related Validity
• The degree to which the items in the measurement scale represent all aspects of the variable being measured • Content validity is not evaluated numerically, it is judged by researcher	• The degree to which the measurement instrument measures the theoretical constructs that it was intended to measure • Construct validity can be carried out through factor analysis	• The degree to which a measurement instrument is related to independent measure of the relevant criterion • Criterion-related validity can be evaluated by computing the multiple correlation (R) and performance

4.2.1 Content Validity

Content validity refers to the degree in which the scale items represent the domain of the construct. In this study, all the measurement items were developed and constructed based on both extensive review of the literature and detailed evaluations by the 16 members of Industrial and Manufacturing Engineering department as well as 9 quality experts consists of academicians, consultants and practicing managers and engineers in SPC related field..

4.2.2 Construct Validity

Construct validity refers to an operational concept or a theoretical constructs that it was intended or was designed to measure. The construct validity of six measurement scales for SPC success factors and three measurement scales for quality and firm performance was evaluated by using Principal Component Factor Analysis with varimax rotation [29]. All factors loaded acceptably well and the results are shown in Table 4 and 5. In this study, KMO index is 0.885 and Bartlett's test of spehericity (approx. Chi-square = 2111.88; df = 351, Sig. = 0.000) for SPC success factors, while, for quality and firm performance KMO index is 0.851 and Bartlett's test of spehericity (approx. Chi-square = 843.089; df = 66, Sig. = 0.000). Therefore, the construct validity of the survey results is established.

4.2.3 Criterion Validity

Criterion validity concerns with the extent to which the model is related to an independent measure of the relevant criterion. This is also known as predictive validity or external validity. The criterion related validity of the model was determined by computing multiple correlation (R) between dependent variables of quality performance (soft aspect and hard aspect) and six independent variables of SPC success factors. The multiple correlation (R) were 0.546 and 0.40 for soft aspect and hard aspect suggested that a multiple correlation of 0.14 to a small effect size, that coefficient of 0.36 represents to effect size and that coefficients above 0.51 represents to a large effect size [14]. Thus, this indicates that six independent variables of SPC success factors have a reasonably (medium to high) degree of criterion-related validity.

Based on the results of reliability and validity study, the authors have developed a reliable, empirically tested and validated survey instrument and had also established desired psychometric properties.

5.0 CONCLUSIONS

In this study, the survey instrument was developed to measure multi-items construct for the SPC success factors and quality and firm performance. The survey instrument is designed and developed based on the factors obtained through extensive literature review and conducted interview to practitioners and consultants in SP implementation field. The results of reliability and validity analysis demonstrate that the instrument has desirable psychometrics properties, which are reliable, empirically tested and rigorously validated. Six statistical process control critical success factor construct sand three quality and firm performance constructs were identified. The next step is the researcher can use this survey instrument to develop the model to find the relationship between statistical process control success factors construct and performance construct. Industrial practitioners can use this survey instrument to evaluate their SPC implementation projects through managing of these associated factors.

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