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STATISTICAL PROCESS CONTROL SUCCESS FACTORS AND PERFORMANCE: AN EXPLORATORY ANALYSIS

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1.1 INTRODUCTION

Since the introduction of ISO/TS 16949 Quality Management Systems and the deadline of automotive manufacturing companies to switch from QS-9000 to ISO/TS 16949 by December, 2006, the use and correct application of quality planning tools such as Statistical Process Control (SPC), Failure Mode and Effect Analysis (FMEA) and Measurement Systems Analysis (MSA) have become widespread. Among all these three tools, SPC specifically look deeply into company's own manufacturing processes for continuous quality improvement and reducing process variability. SPC was first introduced by Shewhart back in 1930s and the Japanese companies have been very successful in applying its tools and techniques in solving quality related problems such as reducing scrap, reducing customer complaints and reducing process variability. Despite the successful application of these tools by Japanese companies, there are other organizations that are not successful or still struggling in implementing SPC. Brannstrom-Stenberg and Deleryd (1999) reported that organizations whose top management had voluntarily implemented SPC would reap greater benefits. Reid (2005) argued that SPC implementation efforts have not been successful and sustaining not because of its underlying methodology, but, with its organization and deployment effort of SPC integrated improvement activities. This statement is further supported by Gruska and Kymal (2006) who said that contributing causes of unsuccessful SPC have nothing to do with the underlying methodology, but with the organizational aspect and deployment. Robinson et. al. (2000) reported that many companies that used SPC are not satisfied with the results of SPC program without management involvement. SPC research can be divided into two major categories: technical and methodological aspects and organizational and implementation aspects. Between the two, the organizational and implementation aspect of SPC is almost being neglected and there is lack of attention given by the SPC researchers. Most empirical studies on SPC implementation aspects so far are focused mainly on identifying factors for effective implementation, which are called "success factors" (Antony et. al., 2000; Rungtusanatham et. al. , 1999; Harris and Yit, 1994; Donell and Singhal, 1996; Rungtunasanatham et. al., 1997; Deleryd et. al., 1999a, Deleryd et. al., 1999b, Runganasamy et. al., 2002; Does et. al., 1997; Antony and Taner, 2003) that is, only trying to explore and identify the factors. This is a typical type in exploratory study stage, which is to determine the "success factors". Relatively, less progress has been made in bringing existing theoretical research/practices together in explaining the relationship empirically between success factors and performance that is called explanatory study.

The primary objective of this study is to address the following research questions based on exploratory and explanatory type of study;

(1) To determine the success factors in SPC implementation (exploratory study);
(2) To determine the key components related to quality and

firm performance (exploratory study);
(3) To propose the relationship between success factors associated with quality and firm performance (explanatory study)

1.2 A REVIEW OF STATISTICAL PROCESS CONTROL SUCCESS FACTORS (EXPLORATORY STUDY)

One key and often mentioned reason for lack of success and failed SPC implementation program is lack of proper implementation. The implementation aspects are not only cover the technical side of SPC, but, it must also focus on management aspects as well. Gordon et. al. (1994) argued that managers must be able to identify the technological and management factors that are linked to the success of a quality improvement program. Xie and Goh (1999) identified three main aspects as a holistic approach for effective SPC initiatives: The management side, the human side and operational side of SPC. Mason and Antony (2001) identified four essential areas that will make SPC program successful: management issues, engineering skills, statistical skills and teamwork skills. A review of literature revealed that most studies are focused mainly on identifying factors that affect the success of SPC program. This study attempts to fill the gap by examining the relationship between the implementation factors and quality and firm performance. By identifying the significant critical factors that influence the quality and firm performance, this study will enable the SPC practitioners to focus on limited resources to the SPC initiatives for the maximum benefits.

1.2.1 Critical Success Factors Approach

Critical Success Factors (CSF), also known as key success factors, were first proposed by Daniel (1961) and popularized by Rockart (1979) in the study of the information systems. The CSF approach has been widely adopted and used in a variety of field of study to determine key factors which are essential to the success of any program or technique. In SPC study, Rungasamy et. al. (2002) was among the pioneer to use the word to identify CSF for SPC implementation in UK small and medium enterprises.

A brief exploratory study of SPC success factors by different studies is presented in Table 1.1. The factors for other statistical based problem solving methodology such as process capability study are also included in this study (Deleryd et. al., 1999).

Table 1.1 Exploratory study of SPC factors and results

Study	SPC Factors and Results	Sample	Analysis
Gordon	Management commitment	Questionnaire from	Multiple
et. al. (1994)	SPC training	159 managers	Regression
	Teamwork	at 31 manufacturing	t-test
	Job security	companies	
	Results		
	Improved quality		
	Increased worker		
	Participation		
Rungtusanatham	Managerial action	Questionnaire from	Exploratory
et. al. (1997)	Control chart usage	104 operators	Factor
	Critical measurement	at 2 manufacturing	Analysis
	Measurement and technology	plants	
	Operator visibility		
	Verification control charting		
	Control chart information		
	Sampling strategy		
	Training		
	Technical support		
	Quality improvement team		
	Final inspection		

	Process knowledge Audit Results Improved quality Reduced costs		
Xie and Goh (1999)	Management commitment Continuous improvement Training Teamworking Resistance to change Incentive SPC tools Problem solving process Prioritizing process Corrective action Results Improved quality	None	None
Deleryd et. al. (1999) Process Capability Study	Management support Kickoff Educational Structured Approach Continuous support Communication Results Hard Aspects Improved capability Defection rates Improved delivery Soft Aspects Improved working Environment Better products Few problems	Case study of 9 9 Swedish companies	Polar Chart

Antony et. al. (2000)	Management commitment Training Teamwork Process prioritization Selection process variable Define measurement systems Control charts Cultural change Pilot study Use of computer and software Results Understanding process Reduction of costs Better communication Improved capability	Manufacturing and service	None
Rungasamy et. al. (2002)	Management commitment Teamwork Identification critical quality Control charts Update process knowledge Measurement systems Process prioritization Cultural change Training Pilot study SPC software SPC Facilitator Results Reduced business costs Customer satisfaction Customer requirement Certification Internal control	Questionnaire from 33 quality managers at small and medium size enterprises in UK	Reliability Mean factor scores

Grigg et. al. (2004)	Quality training Presence dedicated manager Top management commitment Regular use quality circles Existing quality systems Results Continuous improvement	Questionnaire from 72 responses at UK Food organizations	Kruskal-Wallis Hypothesis
Phynthamilkumaran and Zailani (2008)	Management commitment Teamwork Statistical/Engineering skills Education Role of quality department Communication	Questionnaire from 103 responses at 8 multi-national manufacturing companies in Penang/ Kulim Region	Regression Exploratory Factor Analysis

Gordon et. al. (1994) was among the first researcher to study the SPC implementation issues. They identified specific management factors or activities associated with successful implementation of SPC such as higher management commitment, the structure of SPC training, the involvement of workers in decision making process and job security issues.

Rungtusanatham et. al. (1997) described the process and outcome of developing a measurement instrument that operationalise the 14 dimensions underlying the SPC implementation/practice construct. The results of their study provided some evidence and insights into how the SPC implementation/practice construct might be measured in organizational setting. Rungtusnatham's 14 dimensions included managerial action, control chart usage, critical measurement, measurement technology, operator visibility, verification of control charting, control chart information, sampling strategy, training, technical support, quality improvement team, absence of final inspection, update process knowledge and audit and revision. The missing components identified in their 14 dimensions are culture issue, pilot project and use of computer.

Xie and Goh (1999) identified three main aspects, namely, management aspects, human aspects and operational aspects to be very crucial for the successful implementation of SPC. Bird and Dale (1994) identified three key factors, namely, capable measurement systems, training and management commitment for effective SPC implementation. In their empirical investigation of defining and operationalising the questions of "what does the implementation and practice of SPC entail[within organizations]?".

Deleryd et. al. (1999a; 1999b) conducted process capability implementation at nine Swedish organizations. 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 felt that some of the factors are really very much relevant to any statistical based quality improvement methods such as SPC. They also suggested process capability successful implementation model or approach includes factors, deployment and results.

The most comprehensive and detail studies of identifying SPC critical success factors for SPC implementation was done by Antony et. al. (2001), Antony et. al. (2000), Rungasamy et. al. (2002) and Antony and Taner (2003). Antony identified and discussed the key ingredients for the successful implementation of SPC in both manufacturing and service organizations. They identified 10 key ingredients which are as follows: management commitment and support, process prioritisation and definition, selection of appropriate characteristics, define system devices, selection of control charts, training and education, team work, cultural change and use of computer and software packages. In their continuing study on the deployment of SPC, Antony and

Taner (2003) reviewed and compared four existing SPC implementation frameworks and proposed their conceptual framework for the successful introduction and application of SPC program in organization.

Grigg (2004) described and categorized the success of SPC implementation will depend upon a number of factors, both external and internal to organizations. He defined the external factors as the factors that organizations could obtain from various outside sources such as available advice and information, external bench marking, network participation, customer support and competitive pressure experienced by the supplier. He then defined the internal factors that are essential to SPC success which include technical/quality manager, quality systems, management commitment, training, teams, self-assessment against an excellence model, facility size, technology level and process/product relevance.

Phtynthhamilkumaran and Zailani (2008) studied the factors influencing the success of SPC projects in the Malaysian firms in the northern region. Most of their factors are adopted based on the study done by Mason and Antony (2000), but included additional factors such as role of quality department, communication and culture.

Based on Table 1.1, the authors have summarized the success factors are as follows: 1. Top management commitment 2. Teamwork 3. SPC Training and Education 4. Control charts 5. Identification of process/product characteristics 6. Process prioritization and identification 7. Measurement systems analysis 8. Pilot project 9. Use of SPC facilitators 10. Cultural change 11. Deployment. Most of these factors are adopted and adapted based on the study by Antony et. al. (2001), Antony et. al. (2000), Rungasamy et. al. (2002) and Deleryd et. al. (1999). All the 11 factors represent the 40 items in researcher's part 2 questionnaire.

1.2.2 Quality and Firm Performance Construct

The long term benefits 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 as shown in Table 1.1 (Results). Various definition of definition of SPC successful implementation based on literature and interviews conducted by four subject matter experts (SME) have been defined and derived (Antony et. al.,2000; Rungtusanatham et. al., 1999; Donell and Singhal, 1996; Rungtusanatham et. al., 1997; Deleryd et. al., 1999a, 1999b; Rungasamy et. al., 2002). 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 will also try to identify and categorize which factors will have a causal impact directly on the soft aspects and/or hard aspects independently or both simultaneously. Studies by Cheng and Dawson (1998) and Brannstrom-Stenberg and Deleryd (1999) revealed that SPC being introduced into 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 research, the two motivational studies are similar to what we classified as soft and the hard aspects of quality performance.

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. 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. Dow et. al. (1999) 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. However, because of confidentiality and availability of such precise data and highly industry specific, it will have a drawback for the company from responding to the surveys and it will affect low response rate.

3. Firm Performance

   Quality performance is positively related to firm performance (Kaynak, 2003). The measurement indicators to measure the firm performance are including sales growth, unit costs, profit growth and market share (Kaynak, 2003; Adam, 2000).

In summary, all the 3 factors which represent soft aspects, hard aspects and firm performance are manifested by 12 items in researcher's part 3 questionnaire.

1.3 RESEARCH DESIGN

1.3.1. Questionnaire Design

The research instrument will use the five-point Likert scale, representing a range of perception from strongly disagree (strongly disagree = 1) to strongly agree (strongly agree = 5). The use of 5-point Likert scale in this type of quality management practices has been supported by many researchers (Prajogo and Brown, 2004; Flynn et. al., 1994; Sousa and Voss, 2002). The initial version of the questionnaire will be pilot tested to check for the following issues:

1. The representativeness, reliability and validity of the items
2. The degree of the difficulty and understanding of the items by respondent
3. The total time taken to complete the whole questioner

This questionnaire 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 questionnaire was modified. The questionnaire was sent and reviewed by the eight quality experts from both the academic and industry to check for the above three criteria. The questionnaire was modified based on comments from these nine experts. Pilot study was conducted by sending the questionnaire to manufacturing industry to pre-test the instrument and to confirm the relevancy of the questions and to provide clear meanings and jargons used in the industry.

1.3.2 Sampling Design

For this research, the sample was selected randomly from the automotive related manufacturing firms listed in the Directory of Standard Industrial Research Institute of Malaysia (SIRIM) TS 16949 Certified and the database of Perusahaan Automobile of National (Proton). Many Asian firms are reluctant to participate in research survey without developing personal relationship with the researchers as noted by Carr et. al. (2000). Based on the previous survey study on quality management research in Malaysia manufacturing industry conducted by Ahmed and Hassan (2003) the response rate was about 11 percent. In order to increase the response rate, we sent four questionnaires per organization to quality related managers and engineers within the company. Questionnaires were sent to the managers and engineers of 50 companies, resulting of 122 useable questionnaires or respondents. Sample size is an important consideration in the discussion of internal consistency and construction of satisfactory psychometrics properties. Specter (1992) recommended that in order to conduct items analysis for dimensioning factor, it will require a sample size of about 100 to 200 respondents. Therefore, based on these guidelines, our target sample of 122 respondents exceeds the minimum of 100 respondents.

1.4 RESULTS AND DISCUSSION

1.4.1 Purification of Items

Before conducting factor analysis, an item must be purified first in order to avoid the confounding effect during the interpretation of the conceptual factor. Two criteria for purification of the items are adopted that are items analysis and reliability. First, it is called items analysis. Nunally (1978) developed a method to evaluate the assignment of the items to scales. Hair et.al. (2005) recommended a correlation greater than ±0.3 are considered to meet the minimal level; ±0.4 are considered more important and ±0.5 or greater are considered practically significant. In this study all the 40 items for success factors and 12 items for quality and firm performance exhibited corrected item-total correlation exceeds the cut-off value of 0.3 recommended by Nunally, and Bernstein (1994); Hair et. al. (2005). Second, items are also eliminated using internal consistent reliability. The reliability of the items comprising each factor is examined using Cronbach's Alpha (α) which computes internal consistency reliability among a group of items combined to form a single scale (Nunally, 1978; Cronbach, 1951). Nunally (1978) recommended that new developed measures can be accepted with Cronbach's Alpha (α) of more than 0.6, or else, 0.7 should be the threshold and 0.8 or more is significant and reliable. Based on these recommendation, our study is setting 0.7 or higher for minimum reliability of all 52 items. All 52 items passed this reliability test. As a result, all the 52 items for success factors and quality and firm performance were retained for subsequent factor analysis.

1.4.2 Kaiser-Meyer-Olkin (KMO) Measure and Bartlett's Test

KMO measures the degree of intercorrelations among the variables and the appropriateness of factor analysis (Norusis, 1999). Hair et. al. (1998) recommended the value of 0.5 or higher for entire matrix or an individual variable to indicate the appropriateness for factor analysis. Bartlett's test of sphericity which provides the probability of correlation matrix among the variables, which indicates significant correlations among at least some of the variables (Hair et. al., 1998; Norusis, 1999). KMO measure of sampling adequacy was 0.885 and results of Bartlett's test of sphericity (Chi-square = 2111.88; df = 351;p < 0.000) indicates that success factors have a clear construct validity. For the quality and firm performance construct, the KMO was 0.851 and results of Bartlett's test of sphericity (Chi-square = 843.089; df = 66; p < 0.000) establish clear construct validity.

1.4.3 Exploratory Factor Analysis (EFA) – Principal Axis Factoring

Based on the results of KMO and Bartlett's test of sphericity suggested that the intercorrelation matrix of success factors and quality and firm performance contains enough common variance for factor analysis to be carried out. 40 items for success factors and 12 items for quality and firm performance were analyzed by using EFA applying the principal axis factoring as an extraction method and varimax criterion as rotation method. It need to be noted that EFA applying the principal component as an extraction method and varimax criterion as rotation method delivered the same factor structure for both SPC success factors and quality and firm performance. In order to conclude that the factor is uni-dimensional, Comrey (1973) suggested that factor loadings greater than 0.45 are considered fair; greater than 0.55 are considered good; greater than 0.63 are considered very good and those of 0.71 as excellent. Hair et. al. (1998) recommended that items with factor loadings greater than 0.5 are considered adequate items for that factor. The cut-off points of 0.5 to delete items that cross-load on multiple factor(s) were used (Ngai et. al. 2004). Cronbach's Alpha was calculated for the extracted six success factors and three quality and firm performance. The proposed factors are said to be internally consistent and highly reliable if the Cronbach's Alpha is greater than the cutoff points 0.7 (Nunally, 1978). Table 1.2 and 1.3 show the results of EFA which produced six-factor model with 27 items for SPC success factors and three-factor model with 12 items for quality and firm performance.

Table 1.2 Results of Exploratory Factor Analysis (SPC success factors)

Factor, constituting items (factor loading)	EV	% V	CV	CA
Factor 1	10.9	40.3	40.3	0.919
A technical expert comes to my aid (0.654)				
Technical support is obtainable in house (0.674)				
A champion to oversee SPC implementation (0.6674)				
Regular meetings to discuss SPC problems (0.768)				
Problem discovered is resolved based on data (0.723)				
Results of SPC is shared with other employee (0.801)				
Resistance to change is communicated effectively (0.723)				
Factor 2	2.7	10.1	50.4	0.889
Quality issues are reviewed in management meetings (0.618)				
Management has objectives for quality performance (0.665)				
Cross functional teams meet regularly (0.778)				
Teams are recognized for superior quality (0.756)				
Problem solving activity through teamwork (0.648)				
Factor 3	1.5	5.5	55.9	0.786
Basic SPC training is given to production worker (0.436)				
Quality related training is given to managers (0.496)				
Real life examples is importance for training (0.689)				
Knowledge gained must be applied after training (0.646)				

Refresher class is regularly conducted (0.588)				
Factor 4	1.4	5.3	61.2	0.877
SPC is being implemented in other department (0.545)				
SPC implementation based on structured plan (0.608)				
SPC procedures are being applied by teams (0.564)				
A large number of personnel used SPC (0.723)				
Factor 5	1.3	4.7	65.9	0.84
Top management spearheads quality effort (0.635)				
Top management provides visible support (0.783)				
Top management provides adequate resources (0.568)				
Factor 6	1.1	4.1	70	0.7
Selection of key process/product parameter (0.424)				
The impact of selecting those parameter is known (0.666)				
The customer has asked to monitor this parameter (0.544)				

Extraction Method: Principal Axis Factoring
Rotation Method: Varimax with Kaiser Normalization

EV = Eigen Value; % V = % Variance; CV = Cumm. Variance; CA = Cronbach Alpha

Majority the factor loadings exceed 0.5 recommended by Hair et. al. (1998), Eigen value rule greater than 1 suggested by Kaiser (1970). Six –factor model for SPC success factors explains 70 percent of the total variance, whereby, three-factor model for quality and firm performance explains 70.74 percent of the total variance.

1.4.4 Assessment of Reliability and Validity

Reliability refers to the consistency and stability of a score from a measurement scale and was evaluated by internal consistency analysis using Cronbach's Alpa. (Cronbach, 1971). Table 1.2 and 1.3 show the values of the respective factors and the overall Cronbach's Alpha for the six-factor model of SPC success and three-factor model of quality and firm performance. All the values of Cronbach's Alpha were above the recommended cut-off point of 0.7 (Nunally, 1978). Since the Cronbach's Alpha of all the factors extracted by EFA is above 0.7, all the multi-items scales developed for this study were judged to be reliable and internally consistent.

Table 1.3 Results of Exploratory Factor Analysis (Quality and Firm Performance)

Factor, constituting items (factor loading)	EV	%V	CV	CA
Factor 1	5.9	49.3	49.3	0.869
Customer satisfaction has improved (0.65)				
Compliance with industry and quality assurance (0.781)				
Company imaged improved (0.763)				
Part of company good manufacturing practice (0.657)				
Factor 2	1.4	11.6	60.9	0.804
Sales have grown over the past three years (0.707)				
Product unit cost has decreased over the past 3 years (0.589)				
Profit has grown over the past 3 years (0.783)				
Delivery has improved over the past 3 years (0.804)				
Factor 3	1.2	9.7	70.7	0.878
Cost of scrapped has decreased over the past 3 years (0.597)				
Process variability has decreased over the past 3 years (0.651)				
Product cycle time has decreased over the past 3 years (0.65)				
Delivery has improved over the past 3 years (0.653)				

Extraction Method: Principal Axis Factoring
Rotation Method: Varimax with Kaiser Normalization
EV = Eigen Value; %V = % Variance; CV = Cumm. Variance; CA = Cronbach Alpha

Validity refers to which a construct or a set of measures correctly represent the concept of study. Validity is differentiated from reliability in it is concerned with the how accurate the concept is defined by the measure(s), while, reliability relates to the consistency of the measure(s). Three most popular types to evaluate validity of the constructs: content validity, construct validity and criterion-related validity.

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..

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 (Hair et. al., 2005) with varimax rotation. All factors loaded acceptably well and the results are shown in Table 1.2 and 1.3. 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 result is established.

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 correlations (R) were 0.546 and 0.40 for soft aspect and hard aspect respectively. Cohen (1988) suggested that a multiple correlation of 0.14 represents to a small effect size, that coefficient of 0.36 represents to a medium effect size and those coefficients above 0.51 represents to a large effect size. 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 the EFA, reliability assessment and validity analyses showed that the survey instrument has desirable psychometric metrics properties, which are reliable, empirically tested and rigorously validated.

1.4.5 Discussion

Based on the final results of EFA in Table 1.2 and 1.3, six-factor model for success factors and three-factor model for firm and quality performance were extracted. In order to interpret or label them under particular success factors, subjective judgment based on theory should be considered.

1.4.5.1 Six-Factor Model SPC Success Factors

For the six-factor model, the following SPC success factors were labelled:

Factor 1: Roles of quality department (FC1)

The role of quality department plays a critical role to support the implementation of SPC. The role which includes supporting and establishing the systems/method in placed for the effective implementation. Examples of systems/methods procedures are appropriate tools, gage repeatability and reproducibility, use of software and hardware, select parameter and process, data