A multi-criteria framework for Supplier Quality Development

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Abstract

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Supplier Development (SD) includes efforts undertaken by firms to improve their suppliers' capabilities and performance. It has emerged as one of the leading business practices in the past few years. Development of supplier's quality is an important part of these programs. Supplier Quality Development Programs (SQDPs) are strategic quality development activities for increasing quality, reliability and efficiency of suppliers. Evaluation and selection of appropriate SQDPs to improve quality of supply chain is target of most companies, but results of these evaluations cannot be validated without ensuring credibility of a set of criteria. These criteria are factors that ensure success of SQD activities and used for ranking these efforts.

In this thesis, we propose a multi-criteria framework for Supplier Quality Development integrating DMAIC principles. In the Define phase, we identify criteria for SQD using systematic review of literature and industrial practices. In the Measure phase, we conduct a survey study with supply chain quality experts to measure the importance of SQD criteria. In the Analyze phase, we classify the SQD criteria into three groups using Kano's model by analyzing them from the perspective of fulfilling basic needs, performance needs, and delighters/exciters. To examine the relationship between various SQD criteria, we apply Interpretive Structural Modeling (ISM) technique. In the improve phase, we apply the selected criteria to evaluate various

Supplier Quality Development Programs using Multi-Criteria Analysis (MCA) technique called TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) and select the best one. In the control phase, we suggest audits for ensuring the criteria used for evaluation are up-to-date with the latest practices.

The strength of the proposed work is a comprehensive investigation of SQD criteria using knowledge from quality experts, literature review and industrial practice and suggestion of a practical multi-criteria analysis framework for evaluation and selection of appropriate SQDPs.

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I dedicate this work to

Souls of my parents that motivated me to grow as a knowledge Wayfarer

And the first and last love, my wife Parva

And my lovely children Panteha and Parnian

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List of Acronyms

SD -Supplier Development

SQDPs- Supplier Quality Development Practices

CTQC -Critical To Quality Criteria

MCA-Multi-Criteria Analysis

DEA -Data Envelopment Analysis

AHP -Analytic Hierarchy Process

TOPSIS -Technique For Order of Preference by Similarity to Ideal method

DMAIC-Define-Measure-Analysis-Improve-Control

JIT -Just-In-Time

LM-Lean Manufacturing

QC-Quality Control

SPC -Statistical Process Control

SBP-Soft Best Position

HBP-Hard Best Position

QC-Quality control

COPQ -Cost of poor quality

COQ - Cost of Quality

TPM -Total productive maintenance

APQP -Advance product quality planning

HOS -Honeywell Operating System

STEP-Supplier track to exceptional performance

PPAP -Production Part Approval Process

BPR-Business process Reengineering

PSW-Part Submission Warranty

ACE -Achieving Competitive Excellence

FMEA -Failure Mode and Effects Analysis

CP -Control Plan

IPDT -Integrated Product Development Teams

QCPC -Quality Control Charting

STEP-Supplier Total Evaluation Process

RFT -Rolling Month Right First Time

BOS -Business Operating System PPM -Part per million

OSD -On Site Development

QOS -Quality Of Service

FEAHP -Fuzzy Extended Analytic Hierarchy Process

MOPLP -Multi-Objective Possibility Linear Programming

PDCA- Cycle: Plan, Do, Check, Act

SCOR Model-Supply Chain Reference model

SQE -Supplier Quality Evaluation

SRM- Supplier Relationship Management

SEF -Supplier Evaluation Framework

SQC -Supplier Quality Certification /Qualification

CBA -Cost Benefit Analysis

CAPA -Corrective Action and Preventive action

GMP -Good Manufacturing Practice

SQPMS -Supplier Quality Performance Measurement System

SPM-Supplier Performance Monitoring

QPM -Quality Performance Measurement

SEM -Supplier Evaluation Model

QFD -Quality function deployment

EFQM-European Foundation for Quality Management

QMS-Quality Management System

Chapter 1

Introduction

1.1 Background

One of the critical requirements for effective Supply Chain Management (SCM) is creation of a synchronized flow of materials and information from suppliers to their customers (Krajewski and Ritzman, 2004).However, finding suppliers already organized to meet a buyer's requirements for quality, delivery, flexibility and cost reductions is likely to be a challenge. One effective way that buying firms can meet this challenge is by developing their suppliers in ways that improve suppliers' capabilities. (Hartley and Choi, 1996; Krause *et al*., 1998)

Supplier development (SD) activity involves efforts undertaken by firms to improve their suppliers' capabilities and performance. Quality is one of the most important and inevitable aspects of supplier development and improvement of supplier's quality process and products is a critical need for all companies. (Talluri *et al.*, 2010; Arumugam *et al.*, 2011) Without ensuring the quality level of a supplier's delivery of goods or services, supplier development efforts will not be successful and activities like involving suppliers in product development will be problematic. (Gitlow *et al.*, 1983)

World-class companies are making significant investments in systems and processes to improve supplier's quality performance. For this reason participation in supplier quality development practices (SQDPs) is steadily increasing. SQDPs include several activities like: supplier quality evaluation, supplier certification and qualification,

implementing quality tools and training, measuring and tracking cost of poor quality, engaging supplier in quality system (Eosani, 2010). Evaluation and selection of appropriate SQDPs are important means for companies to avoid wasting time and money in useless and ineffective practices. For selection of proper SQDPs to develop quality of suppliers, various criteria must be met. (Watson, 1993) Criteria enable managers to perform gap analyses and identify areas that need improvement. Collection of critical criteria can be used in a multi-criteria analysis framework to evaluate, select and rank superior SQDPs that helps companies to obtain desirable results from implementation of SQDPs and satisfaction of their customers (partners). Suppliers are potential customers of buyers for SQDPs. Level of satisfaction of supplier's quality needs from SQD programs determine effectiveness of these programs. Multi-criteria analysis and related techniques are frequently used for evaluation and selection in supply chain (Lung 2008, Ho *et al.;* Shih *et al., 2*009, Zaeri *et al.;* Buy *et al.;* Tabrizi *et al.*, 2010).

1.2 Problem definition

Shortage of knowledge related to SQD practices and criteria for designing optimal and appropriate SQD programs is a strategic problem for supplier quality developing efforts. Krause *et al.* (1997) indicated that in order to avoid pitfalls in supplier development it is helpful to have an overall process map of the supplier's development initiative to ensure that the right suppliers are being targeted for development. According to Robert *et al.* (2000) significant problems in SQDPs often arise from lack of metrics for success and monitoring project status. Thus, to avoid these pitfalls, metrics and timelines that provide a basis for follow-up and joint problem solving

must be established to ensure project's completion. According to Forker *et al. (2*001*)* difference between perceptions of buyer and suppliers for SQDPs is one of the barriers in successful implementation. These differences arise due to a disparity in understanding the preference, intention, and process of a SD program. According to Erasmus (2006) one of the major problems in SQDPs is the inability of suppliers to meet buyers' expectations.

The aim of this thesis is to provide a multi-criteria decision making framework for SQD. In particular, we will be addressing the following problems:

1. Synthesizing literature review and industrial practices on SQD.
2. Identification of critical criteria for evaluating SQDPs, investigating their importance, and relationships with each other.
3. Development of a multi-criteria modeling framework to evaluate SQDPs.

1.3 Thesis Outline

The rest of the thesis is organized as follows:

In chapter 2, we review academic literature and industrial practices on SQD. In chapter 3, we provide our multi-criteria solution framework for evaluating SQDPs. Chapter 4 presents the application results. Finally, we present the conclusions and future works in Chapter 5.

Chapter 2

Literature Review

2.1 Structure of Literature Review

Figure 2.1 shows the structure of our literature review. Two main sources were used-review of academic literature and Industrial practices. The academic source will cover the SQD steps, methodologies used, and SQD criteria. The industrial source will be used to review SQD practices used by industries and report on best practices.

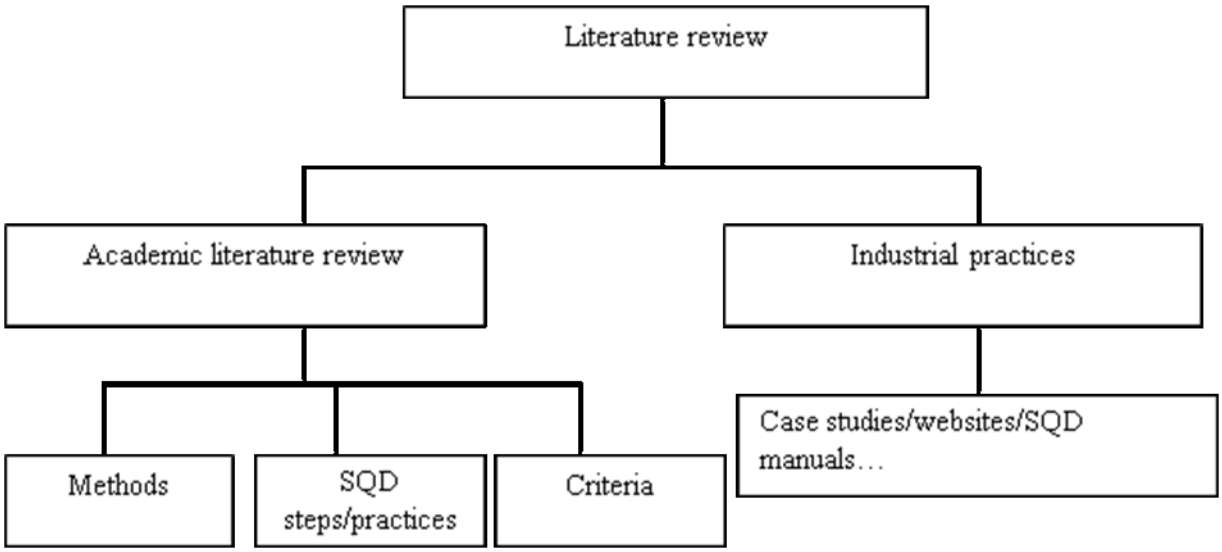

Fig. 2.1 Structure of literature review

We reviewed two groups of research in academic literature review. Subject of first group was quality practices in supplier development efforts and the second group was related to Supplier Quality (SQ). Topics related to SQD in first group were:

- SD models
- Critical elements/success factors

- Impact of SD on the other supply chain elements
- Green SD
- SD under risk
- SD Implementation
- SD Evaluation
- Best practices of world class companies in SD

Topics related to SQD in second group were:

- Improvement of SQ
- Impact of SQ on other components of supply chain
- Quality management practices
- Best practices of SQ
- SQ Critical Factors
- SQ Evaluation

According to this literature review, 19% of papers emphasized on the supplier quality evaluation as the first practice in quality measurement step. Other practices related to this step are: Measure and tracking cost of poor quality (11%), Certification and qualification (8%), Supplier performance measurement (8%). Practices for quality development step mentioned in the articles are: Implementing Quality tools (16%), Supplier relationships. (16%), Quality training (10%) Committing resources to suppliers (7%), Rewarding suppliers (5%). (Figure 2.2)

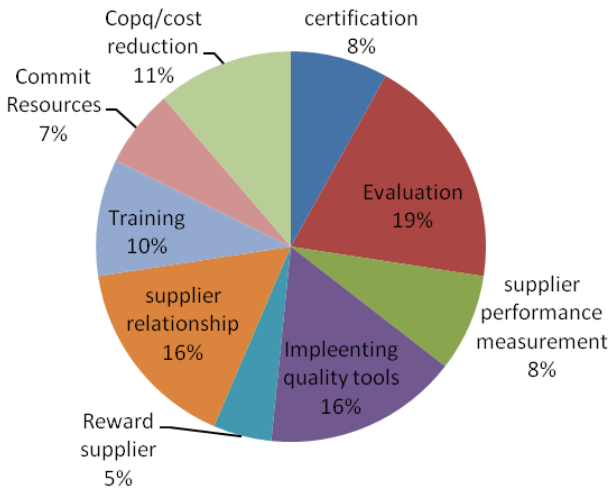

Fig. 2.2 Percentages of SQD steps mentioned in the literature review

2.2 SQD steps

SD activities can be defined as practices for improving current performance and capabilities of suppliers to meet the buyer's expectations. (Krause and Lisa, 1996) These practices are efforts of companies for improving the design, production, cost and quality. SQD programs are portions of SD activities to implement and improve Supplier Quality Systems

According to literature review, SQD steps can be classified in two categories (Figure 2.3):

1. Quality development

2. Quality measurement

Quality development activities are related to driving continuous improvement in the suppliers' production processes, quality systems and supply chain to achieve measurable improvement in quality.

Quality development includes following activities (practices):

- Supplier quality Training

- Implementation of Quality tools and Continuous Improvement
- Reward and recognition of supplier's achievements in quality improvement
- Supplier relationships
- Committing resources to suppliers

Quality measurement includes measuring opportunities to improve supplier performance and proactively assessing supplier production and quality capabilities, minimizing potential risks and ensuring effective implementation of company quality expectations. Quality measurement step includes following activities (practices):

- Supplier quality evaluation
- Supplier quality certification /qualification
- Supplier quality performance measurement
- Measuring and tracking cost of poor supplier quality

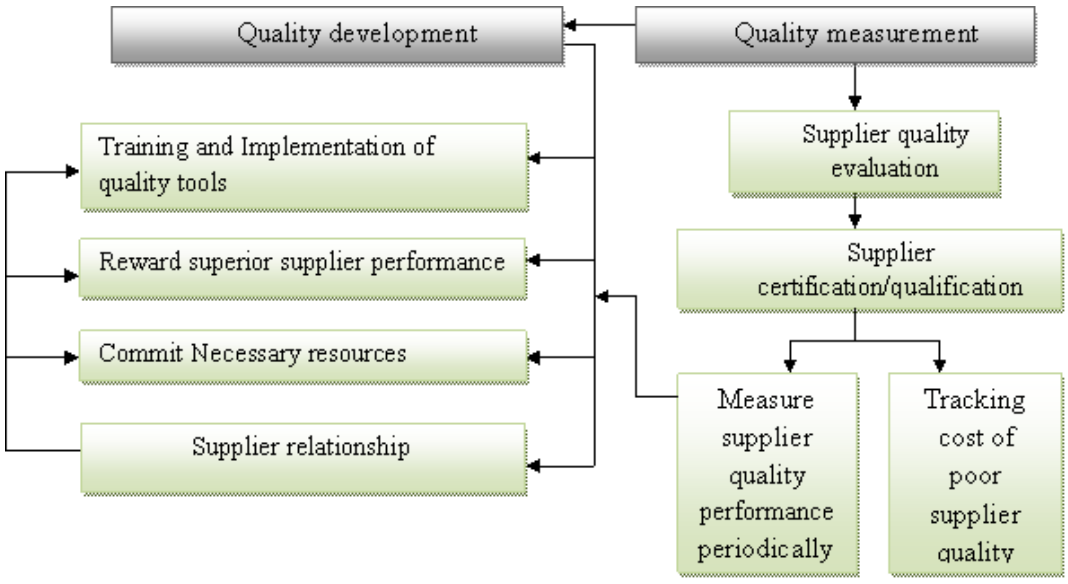

Fig.2.3 Steps and practices of SQD

2.3 Supplier Quality measurement

2.3.1 Supplier Quality Evaluation (SQE)

The first practice in quality measurement step starts with Supplier Quality Evaluation (SQE). It is a comprehensive assessment to evaluate a supplier's quality system against the customers' complaints, internal and external product specification and reviewing safety programs, the performance of suppliers, and the satisfaction of customers. Selecting an appropriate supplier for long-term partnership is one of the most important decisions of the purchasing department. In measuring and assessing the suppliers' quality systems, purchasing managers are increasingly turning to establish quality auditing and measurement systems. Two audit frameworks often applied are the ISO 9000 criteria and the Malcolm Baldrige.

Juran (1997) mentioned SQE as an important step of supplier quality assurance process. Ishikawa (1997) mentioned SQE as assessing capability of suppliers to meet purchase requirements. According to Fernandez (1996), successful supplier quality systems must have a method for evaluation of the suppliers' quality systems. Daniel *et al. (*1997) suggest supplier selection based on quality and reliability considerations to help suppliers in achieving quality levels. Trent and Monczka (1999) defined a group of supplier quality development practices connected to collaborative relationships between buyer and supplier for developing world-class quality supplier programs. Selection of suppliers based on quality is one of these practices. According to Behrens *et al.* (2006), the second stage for developing suppliers is audit and evaluation of the internal standards in order to make sure that supplier's inputs meet the current expectations of the buying company. Shrimali (2009) proposed seven steps for SQE

which includes:

1. Identifying critical commodities
2. Identifying critical suppliers
3. Forming a cross functional team
4. Meeting with supplier top management
5. Identifying key project. Metrics for this project may include the percent of cost saving to be shared, the percent of quality improvement to be achieved or the percent of delivery time reduction etc.
6. Defining details of agreement
7. Monitoring status and strategies

Eosani (2010) proposed assessment of potential suppliers and supplier selection for SQD According to Shokri (2010) SQE improves supplier's operations.

2.3.2 Supplier Quality Certification /Qualification (SQC)

Supplier Quality Certification helps identify candidates for strategic relationships, facilitate communication with potential suppliers, and ensures new suppliers meet firm-wide quality, management, and safety standards. It creates baselines for evaluating supplier risk levels, and ensures material conformance to specific requirements such as ISO 9000 or TS-16949 or other specific standards. It promotes broad participation and qualification of suppliers and creates selection criteria for several processes including design control, inspections, equipment testing, handling, storing, packaging, and delivery. Comprehensive supplier qualification processes and tools enable organizations to monitor supplier performance history. A firm's certification program typically is used as a means of measuring and qualifying

suppliers (Monczka and Trecha, 1999). Supplier certification programs have been offered up as a way for companies to effect or enhance competitive advantage.

Certification programs involve a thorough examination of all dimensions of a supplier's performance, increasing the likelihood that the supplier will consistently meet required specifications of product performance. Central to the certification ideal is the buying company's desire for reliable supplier performance in delivering products or services that consistently achieve or exceed product specifications (quality), with the idea that such consistency will translate to bottom-line operational and financial success. Expected benefits of Supplier Certification Programs (SCP) include lower component cost, improved delivery performance, lower total levels of inventory, and improved responsiveness of the supply chain (Dillman, 2000).The time required to certify a single supplier varies between three months and three years, with more complex and consequential certification efforts requiring more time (Lockhart and Ettkin, 1993).

Certification of qualified suppliers is seventh step of Juran model (1997). Ishikawa (1997) mentioned SQC as also the seventh step of his SQ model and described it to formally recognize supplier that achieve preferred status. According to Daniel *et al.* (1997) Supplier certification is one of the supplier quality activities to help suppliers achieve quality levels. Trent and Monczka (1999) proposed supplier certification under ISO 9000. Noori (2004) propose SQC with quality standards such as ISO 9000 as effective tool for developing suppliers. Rodriguez *et al.* (2005) indicated SQC implementation in moderate SQD activities. Bedey (2008) mentioned certifying supplier processes and methods as one of seven phases for SQD.Eosani (2010)

proposed Supplier approval and qualification/certification as one steps of developing suppliers.

2.3.3 Supplier Quality Performance Measurement (SQPM)

The target of a successful Supplier Quality Performance Measurement (SQPM) is to grow and nourish suppliers who consistently deliver quality product, on time, in full, with proper documentation, and are easy to work with on a daily basis. It is a tool that helps manufacturer and suppliers collaboratively work on issues that impact their businesses, and eliminate costly mistakes. The process starts with observation and measurement of supplier system followed by assessing its effectiveness, diagnosis of the problem, recommendation of corrective actions, and suggestions on how to eliminate any problems through a program of remediation that might include training or process changes.

According to Simpson *et al.* (2002) and Narasimhan *et al.* (2002) Supplier performance measurement is an important step in Supplier quality Development because it serves as a baseline for planning actions and improvement suppliers. It consists of measurement of quality, cost, delivery, health and safety, and environmental aspects of the supplier performance. Noori (2004) proposed establishment of performance targets for suppliers in SQD practices. Eosani (2010) and Littlefield (2012) mentioned site inspection**,** supplier risk scorecards, ranking of the supplier's relative performance as important SQPM practices in SQD activities. According to Metric Stream site (market leader in Enterprise-wide quality Solutions for global corporations), supplier audits and supplier scorecards are necessary in SQPM activities.

2.3.4 Measuring and tracking Cost of Poor Quality for suppliers (COPQ)

COPQ consists of those costs which are a result of producing defective material. This cost includes the cost involved in fulfilling the gap between the desired and actual product/service quality. It also includes the cost of lost opportunity due to the loss of resources used in rectifying the defect. This cost includes all the labour costs, rework costs, disposition costs, and material costs that have been added to the unit up to the point of rejection. The majority portion of these costs is hidden. The Cost of Poor Quality of individual suppliers participating within a supply chain has a cumulative effect on the COPQ of the end product. As a result, companies are working very proactively with their suppliers to reduce their COPQ. Most organizations do not track and measure the cost of poor supplier quality (COPQ) attributed to their suppliers. Such COPQ may add up to over 10% of the organization's revenue. Some companies only track supplier COPQ by measuring scrap and increase in MRB (Material Review Board) inventory. Quality Management Systems (QMS) or manufacturing systems can track the above costs incurred due to supplier quality issues.

Talluri *et al.* (2010), Arumugam *et al*. (2011), Eosani (2010) and Metric system (2012) also emphasize the role of measuring & tracking cost of poor supplier quality in SQD practices

2.4 Supplier Quality Development (SQD)

2.4.1 Supplier Relationship (SR)

Supplier Relationship is an all-inclusive approach to managing the affairs and interactions with the organizations that supply company with goods and services. This

includes communications, business practices, negotiations, methodologies and software that are used to establish and maintain a relationship with suppliers. Benefits include lower costs, higher quality, better forecasting and less tension between the two entities resulting in a win-win relationship. Following practices include SR:

- Sharing cost and quality information
- Engaging supplier in quality systems
- Supplier involvement in the product development
- Long-term relationships
- Face to face communications
- Cross functional teams

Haun *et al. (*1990) emphasized on the long-term relationships and mutual benefits for facilitating SQD activities. According to Juran (1997), joint quality planning, and cooperation during relationship period is important for implementation of supplier quality. Communication of the program objective and methodology, engaging advanced quality planning and ongoing quality improvement relationship based on a free exchange of information are mentioned in Ishikawa's model (1997). According to Fernandez (1996), sharing of long term goals with supplier is necessary for SQD. Trent and Monczka (1999) defined a group of supplier quality development practices connected to collaborative relationships between buyer and supplier in world-class quality supplier programs. They mentioned long-term relationships with a reduced number of suppliers, visiting supplier's plants, intensive communications and information sharing, supplier involvement in the buyer's new product development

process as practices of supplier relationships in SQD. Rodriguez *et al.* (2005) proposed visiting suppliers' plants to assess their processes, involving suppliers in the new product design process, sharing of cost and quality information as practices of supplier relationship. According to Bedey (2008) involving suppliers early in product and process development are practices of supplier relationship in SQD. Shrimali (2009) proposed seven steps for developing suppliers that includes forming a cross functional team and meeting with supplier top management. Eosani (2010) emphasized on engaging suppliers in quality systems. Shokri (2010) proposed establishing effective communication between parties in supplier development practices. Metric Stream (2012) mentioned closed-loop, integrated quality management system and engaging Suppliers in quality systems as critical items of supplier quality.

2.4.2 Reward Superior (RS) supplier performance and improvement

Reward is always a tempting offer to motivate suppliers to improve their quality levels. One example of rewards is to share the benefits resulting from supplier initiated improvements. Objectives of the supplier award are to:

- Raise awareness of the key role suppliers play in corporate success reward and reinforce strong supplier management
- Illustrate that company's values and listening to suppliers help achieve goals and increase commitment

According to Trent and Monczka (1999), supplier reward and recognition of quality improvements are motivations for suppliers in SQD activities. Rodriguez *et al.* (2005) and Bedey (2008) emphasized on role of reward and recognition of supplier's

achievements in supplier quality improvement practices. Shokri (2010) proposed award certification to improve supplier's operations.

2.4.3 Training and Implementation of Quality Tools (TIQ)

Training and implementation of quality tools is the most common approach for supplier development and improvement. A purchaser may provide training and implementation of problem solving in statistical process control, quality improvement techniques, just-in-time delivery or any other crucial performance area. In order to adequately assess and aid suppliers in improving quality, purchasers need to train suppliers and implement quality and problem solving tool for them. In many organizations, purchasing may request the assistance of quality and engineering departments in assisting with the supplier quality problem solving and training. Purchasing companies emphasize four areas of supplier quality problem solving and training with their suppliers:

1. Implementation and training total quality management and quality improvement tools
2. Statistical quality control techniques
3. Focusing on integrating quality into the design of products and processes to reduce variability
4. Problem solving techniques (Monczka and Handfield, 1998)

Haun *et al.* (1990) proposed implementation and training of statistical process control (SPC) and quality circles (QC) as necessary quality tools for SQD activities. According to Carter *et al.* (1994), implementation of process analysis techniques such

as SPC helps improve quality of suppliers. Fernandez (1996) proposes an excellent continuous improvement tool, trained evaluators, and CI professionals important for implementation of SQD. Trent and Monczka (1999) emphasized on training in supplier quality activities. According to Gonzah *et al.* (2000), co-operative supplier development practices, purchasers and suppliers should join forces to develop potential process improvements and new production and supply techniques of quality management like Just-In-Time (JIT), Lean Manufacturing (LM). According to Noori (2004), the most effective tools used in Canadian companies for developing suppliers are JIT and lean manufacturing. According to Rodriguez *et al.* (2005) training suppliers and measures training effectiveness are advanced level of SQD. Erasmus (2006) mentioned training of lean manufacturing, health & safety, environment, and 6 Sigma as important parts of supplier quality development. Behrens *et al.* (2006) proposed joint teams and training as stages of developing suppliers. Shokri (2010) proposed providing training to suppliers improves supplier's operations.

2.4.4 Commit Resources (CR)

Currently, many companies realize the value of this issue and have begun to assign more resources to improve supplier quality performance.

According to Fernandez (1996), successful supplier quality systems must prepare resources for supplier development. Bedey (2008) mentioned committing the necessary resources for supplier development as one of important phases and activities for SQD. Shokri (2010) proposed technical assistance activities to improve supplier's operations.

Table 2.1 summarizes the above presented literature review.

Practice	Detail	Reference
Supplier Quality Evaluation (SQE)	Evaluation of alternative suppliers	Juran, Ishikawa (1997) Fernandez (1996) Daniel *et al.* (1997) Trent and Monczka (1999) Behrens *et al.* (2006) Shrimali (2009) Eosani,Shokri (2010)
	Selection of the most appropriate suppliers	
	Identify key suppliers	
	Assess the capability of suppliers to meet purchase requirements	
	A method for evaluation of suppliers	
	Supplier selection based on quality and reliability considerations	
	Selection of suppliers based on quality	
	Audit and evaluate supplier	
	Identify critical suppliers	
	Identify key project	
	Assessing potential suppliers	
Supplier Quality Certification (SQC)	Certification of qualified suppliers	Juran and Daniel *et al.* (1997) Trent and Monczka (1999) Noori (2004) Rodriguez *et al.* (2005) Bedey (2008) Eosani (2010)
	Supplier certification	
	Supplier quality certification under ISO 9000	
	Quality standards such as ISO 9000	
	Supplier Certification	
	Certify supplier processes and methods	
	Supplier approval and qualification/certification	
Training and Implementation of Quality Tools (TIQ)	Trained evaluators and CI professionals	Haun *et al.* (1990) Fernandez (1996) Trent and Monczka (1999) Erasmus (2006) Rodriguez *et al.* (2005) Behrens *et al.* (2006) Shokri (2010) Carter *et al.* (1994) Fernandez (1996) Gonzah *et al.* (2000) Noori (2004)
	Supplier training	
	Training of Lean manufacturing, Health & SafetyEnvironment,6 Sigma	
	Training suppliers and measures training effectiveness	
	Joint team and develop training	
	Providing training	
	Implementation of process analysis techniques likes SPC	
	Continuous Improvement Tool	
	Just-In-Time (JIT), Lean Manufacturing	
	JIT and lean manufacturing	

Practice	Detail	Reference
Reward Suppliers(RS)	Supplier reward and recognition of quality improvements	Trent and Monczka (1999) Rodriguez *et al.* (2005) Bedey (2008) Shokri (2010)
	Reward and recognition of supplier's achievements in quality improvement	
	Reward superior supplier performance and improvement	
	Award certification	
Supplier Quality Performance Measurment (SQPM)	Supplier performance measurement	Simpson *et al.* Narasimhan *et al.* (2002) Noori (2004) Rodriguez *et al.* (2005) Bedey (2008) Eosani (2010)
	Establishment of performance targets for suppliers	
	Evaluating supplier performance and providing feedback to suppliers	
	Measuring supplier quality performance	
	Site inspection	
Supplier Quality Performance Measurement (SQPM)	Supplier scorecard	Littlefield (2012)
	Ranking the supplier's relative performance	Metric Stream(2012)
	Supplier risk scorecards and supplier portals	
	Supplier Audits	
	Supplier Scorecards	
Supplier Relationships (SR)	Sharing long term goals with supplier	Fernandez (1996)
	Long-term relationships with a reduced number of suppliers	Trent and Monczka (1999)
	Visiting supplier's plants	
	Intensive communications and information sharing	
	Supplier involvement in the buyer's new product development process	
	Visiting suppliers' plants to assess their processes	Rodriguez *et al.* (2005)
	Involving suppliers in the new product design process	
	Sharing cost and quality information	
	Involving suppliers early in product and process development	Bedey(2008)
	Form a cross functional team	Shrimali (2009)
	Meet with supplier top management	
	Product development	Talluri *et al.* (2010), Arumugam et al. (2011)
	Engaging suppliers in quality systems	Eosani (2010)

Practice	Detail	Reference
	Establishing effective communication between parties	Shokri (2010)
	Closed-loop, integrated quality management system	Metric Stream (2012)
	Engaging Suppliers in quality systems	
	Long-term relationships Mutual benefits Conduction of joint quality planning Cooperation during relationship period Communicates the program objective Engaging advanced quality planning Ongoing quality improvement relationship based on a free exchange of information	Haun *et al.* (1990) Juran,Ishikawa (1997)
Commit Resourcing (CR)	Resources for supplier development	Fernandez (1996)
	Commit the necessary resources to supplier development	Bedey, (2008)
	Technical assistance activities to improve supplier's operations	Shokri (2010)
Cost Of Poor Quality (COPQ)	Measuring & tracking cost of poor supplier quality for suppliers	Talluri *et al.*(2010) Arumugam *et al.* (2011) Eosani (2010) Metric system(2012)

Table 2.1 SQD practices based on the literature review

2.5 Method wise classification of supplier quality development research

Following methods used in research related to:

- Empirical study with Interview and survey including case studies (best practices)
- Multi-criteria methods and techniques
- Six sigma methodology
- Other models

2.5.1 Empirical study with interview and survey including case studies (best practices

Carter and Ellram (1994) investigated practices for improving SQ with empirical data from suppliers of machined parts for various industries. The authors viewed supplier quality improvement as two dimensional that includes modification of product and implementation of process analyses techniques like SPC. These activities are significant and need resources allocation and implication from both buyer and supplier. Fletcher (1992) provided a range of reportedly successful supplier quality management practices of leading companies. Forker (1996) examined the results of a survey of 348 aerospace component manufacturers to provide new insights into factors that affect supplier quality performance. Gonza *et al.* (2000) used empirical observations for the Spanish auto components industry in implementing supplier quality and reliability practices. They pointed out that suppliers more advanced in the use of quality practices are achieving better operational performance in terms of quality, reliability, cost, flexibility and design. Nwankwo *et al.* (2002) studied the expert systems, a branch of artificial intelligence that is capable of helping organizations to co-ordinate and connect potentially diverse sources of input resources in supplier quality management. Two principal approaches were followed in the research process. The first involved a series of unstructured and informal one-to-one interviews with professionals in marketing (especially, the purchasing and supply functions) whereas the second approach involved the distribution, through the postal system, of questionnaires to 500 UK organizations randomly selected. Rodriguez (2004) analyzed and classified quality management practices in purchasing and

assessed the relationships of these practices with measurements of a firm Purchasing Operational Performance (POP), internal customer satisfaction and business performance. The results reported in this study are based on a field survey consisting of responses gathered from 306 purchasing managers within the Spanish manufacturing industry. Noori (2004) designed a detailed questionnaire to investigate the extent to which continuous collaborative improvement (CCI) activities are being implemented in the supply chains of Canadian industries. Eklund (2006) provided case studies for supplier quality development in developing countries. Osani (2010) prepared a detailed questionnaire for monitoring the quality and compliance of API suppliers. Srinivasan (2011) examined the relationship between buyer–supplier partnership quality and supply chain performance in the presence of supply and demand side risks and environmental uncertainty. They proposed a positive relationship between partnership quality and supply chain performance. Empirical evidence, based on the survey data of 127 US firms supported their results.

2.5.2 Multi-criteria methods and techniques

Pun (2006) identified critical assessment criteria and factors for Managing Supplier Quality (MSQ) through literature review, a mail survey of manufacturers in Hong Kong and the Analytic Hierarchy Process methodology. Awasthi *et al*. (2011) provided a hybrid approach based on Hierarchical cluster analysis (HCA) and Data Envelopment Analysis (DEA) for supplier quality development. Fuzzy set theory is used for modeling parameters in HCA and DEA. Zu *et al.* (2011) examined two approaches that buying firms can utilize to manage supplier quality and investigated the ways in which factors inherent in supply chain relationships affect the use of these

approaches in supply chain quality management. They proposed a conceptual framework that relates the underlying factors of a supply chain relationship to the use of quality management approaches. Two types of approaches, outcome-based and behavior-based, are discussed in terms of their focuses, purposes, and methods. Propositions are developed about the effects of these factors on the decisions buying firms make about supply chain quality management. Salem (2012) investigated the most important criteria for evaluating the quality of suppliers based on a review of the literature and observation in practice. The research proposes a three-stage model for performing supplier quality evaluation using Cluster Analysis, AHP and VIKOR method.

2.5.3 Six sigma methodology

Wang *et al.* (2004) investigated how quality management can be employed in SCM to improve the performance of various issues in the whole supply network. They developed an application guideline for the assessment, improvement, and control of quality in SCM using Six-Sigma improvement methodology. Based on their results, improvements in the quality of all supply chain processes lead to cost reductions as well as service enhancements.

2.5.4 Other models

Christian (2004) provided a methodology for "integrating supplier and manufacturer capabilities and applying different strategies for quality improvement". Sculli and Yeung (2006) investigated the impact of supplier quality management (SQM) on the quality performance of manufacturing companies. Path analysis is used to build a

model that demonstrates how SQM contributes to quality performance and also the constructive effect of supply quality on organizational quality performance.

2.6 SQD criteria

According to the Oxford dictionary a criterion is: "a principle or standard by which something may be judged or decided".

Krause *et al.* (1996) emphasized on two way communication and cross functional team criteria for developing suppliers. According to Ishikawa model for supplier quality, mutual understanding and cooperation between quality control system of buyer and supplier, evaluation method of various items beforehand, exchange of necessary information criteria should be considered before the design and implementation of each supplier quality development program. Daniel *et al.* (1997) proposed cross-functional buying firm teams, long-term perspective and supplier evaluation as important criteria for supplier quality development effort. Trent *et al.* (1999) proposed measurement and evaluation systems and information systems development as criteria for supplier quality development. According to Chan (2000), evaluation and selection of potential suppliers are important criteria of supplier quality development practices. Hudson *et al.* (2001) proposed two parts for supplier quality: supplier performance measurement that acts as a basis for continuous performance improvement and continuous performance improvement. Monczka (2002) proposed the rate of quality performance improvement as criterion for evaluation of supplier quality. According to Wognum *et al.* (2002), face-to-face interaction between supplier and buyer is considered an important medium for information exchange in supplier

quality. According to Wagner (2004) a firm should first tailor its supplier evaluation criteria to the firm's requirements. It is vital to understand how supplier quality is best implemented in everyday organizational practice. Chin *et al.* (2005) suggests information sharing, supplier evaluation, and performance measurement and improvement are criteria for managing supplier quality. Carr *et al.* (2007) proposed traditional communication methods, information sharing within a firm and information sharing between firms as significant factors for improving suppliers' performance through the supplier quality practices. Blindenbacj (2009) and Hrimali (2010) propose improving communication between buyers and suppliers in order to make the SQD successful. Arumugam *et al.* (2011) proposed information sharing and communication methods as key factors of supplier quality development practices. According to Srinivasan *et al.* (2011) a good partnership quality between the buyer and its supplier, based on mutual trust and joint problem solving are important factors in supplier quality. Mortensen (2011) investigated the importance of considering suppliers' interest and motivation when implementing supplier quality practices. Customer attractiveness is presented as one approach that takes supplier view and motivation into consideration. The results indicate that supplier performance is influenced by perceived customer attractiveness. According to Wagner (2011) the length of the buyer–supplier relationship is important for obtaining acceptable outcomes from supplier quality practices. The results show that supplier quality practices are more effective in mature as opposed to initial and declining life-cycles phases. Wenli *et al.* (2012) proposed supplier evaluation and supplier strategic objectives as significant

factors in supplier quality. Buyers that have closer collaborative relationships with suppliers may strengthen their competitive advantage. Summarization of these criteria Is provided in Table 2.2.

Critical criteria	Reference
Performance : • Measurement and evaluation systems • Evaluation method • Evaluation related to quality and reliability of suppliers • Tailor supplier evaluation criteria with regard to the firm's requirements • Performance measurement	Fernandez (1995) Krause *et al.* (1997) Trent and Monczka (1999) Helen Chan (2000) Wagner (2004) Chin *et al.* (2005)
Development: • Continuous performance improvement • Rate of quality performance improvement • Effect of supplier's motivation on Performance • For suppliers in quality development practices • Two way communication • Mutual understanding • Cooperation between quality control systems • Face-to-face interaction • Effective communications • Traditional communication methods • Advance technology for information sharing • Information sharing within and between firms • Exchange information necessary to carry out better quality control • Long-term relationship and commitment	Fernandez (1995) Krause et *al*. (1997) Trent *et al.* (1999) Hudson *et al.* (2001) Trent and Monczka (2002) Wognum *et al.* (2002) Chin *et al.* (2005) Behrens (2006) Carr *et al.* (2007) Blindenbacj *et al*. (2009) Shrimali (2010) Mortensen (2011) Wenli *et al.* (2012)

Table 2.2 Criteria for SQD steps

2.7 Industrial practices in SQD

A review of the literature proposes that manufacturing industry, and in particular automotive and aerospace (Quayle, 2000) have used SQD towards collaboration with more suppliers. Some have invested resources to develop supplier capabilities in line with their own strategic requirements and organizations are taking a practical approach in getting involved with their suppliers, people, plant, manufacturing and administrative process (Hartley and Choi, 1996). Almost 70% of procurement organizations in these industries are expected to have SD and SQD in position by 2013 (Minahan, 2005).

Honda has been the world's largest motorcycle manufacturer since 1959 as well as the world's largest manufacturer of internal combustion engines measured by volume, producing more than 14 million internal combustion engines each year. One of the successful experiences in developing quality of suppliers happened in Honda. Dramatic improvement was seen in product quality since Honda began to develop suppliers in North America. In 1985, quality level was 7000 defects per million; and in 1995, quality level improved to only 100 defects per million (Barlow, 1995) At first, a team of seven Honda engineers from the Purchasing Department identified a group of 8 supplier companies and started implementing changes. It starts with cleaning the shop floor (3S and 5S) and changing the factory layout. This activity came to be known as SBP (‘Soft Best Position’) and HBP (“hard best position) which can be distinguished as follows:

1. Soft BP is achieved through changes which can be made without spending money (e.g. 3S), while Hard BP is achieved by making new capital investment
2. Soft BP results in kaizen (small improvements), while Hard BP results in kaikaku (larger jumps in performance improvement) (Source : Sako M. ,2002)

Toyota employed 300,734 people worldwide and was the third-largest automobile manufacturer in 2011 by production behind General Motors and Group. In Toyota every year, each supplier company hosts a study over a two months period. The study session begins by setting concrete performance targets in terms of shop floor indicators, such as productivity, cost reduction, and inventory turns. The senior supplier quality development engineer in charge visits a supplier company under study around three times during the two months period and generally makes severely critical observations, whilst more junior supplier quality development engineers visit the company at other occasions to give more detailed guidance. Toyota's SQD engineer also provides necessary individual assistance to suppliers. For instance, the purchasing department may request assistance for a supplier with a pre-production problem in fixing its component quality. More concrete individual guidance is given to suppliers that aspire to obtain the Toyota quality control (QC) Award. (Marksberry, 2012)

Nissan is a Japanese multinational automaker headquartered in Japan. It was a core member of the Nissan Group, but has become more independent after it is restructuring under Carlos Ghosn (CEO).Nissan was the sixth largest automaker in the world behind General Motors, Volkswagen AG, Toyota, Hyundai Motor Group, and Ford in 2011. Nissan has two category of supplier quality development activity,

namely component-based assistance and factory-wide assistance. The former involves the teaching of various techniques to improve cost, quality, delivery and development. The latter, factory-wide assistance, is known as Capability Enhancement Activity, and incorporates synchronized production, total productive maintenance (TPM), and Gemba Kanri. It consisted of a three year program to implement synchronized production. The aim in the first year was to improve the use of direct labour, in the second year to improve indirect labor, and in the third year to cut overheads. Typically, a supplier specifies a model factory which is diagnosed and improved with intensive help from Nissan engineers; 3-4 engineers visiting the factory 4 times a month and it is known for a Nissan engineer to be resident at the supplier for 3 month. Nissan's Capability Enhancement Activity places great emphasis on evaluation and diagnosis. The thinking here is that without concrete evaluation measures, Nissan cannot provide effective assistance, nor would suppliers feel convinced of the need to make improvements. Since the mid-1990s, Nissan has developed a whole series of measures for suppliers concerning:

1. Their financial performance
2. Data on quality, cost and delivery
3. Evaluation of systems governing components, factories, and companies (Source: Sako M., 2002)

The ABC Group Inc. founded in 1974 is a Canadian-based Certified Women's Business Enterprise (WBE) and is a world leader in vertically integrated plastic processing, supporting a global organization with locations in North America, South America, Europe, and Asia. Supplier quality expectations of ABC from suppliers is

Robust Quality Management System which promotes defect free products through prevention, monitoring and continual improvement .Requirements of SQD in ABC group are:

- On-site audit of the facility by ABC Supplier Quality Assurance (SQA) or plant personnel.
- Principles of Lean Manufacturing" and utilization of "5S – Visual Factory" methods in its operations.
- Excellence in adhering to fundamental process basics in areas of Safety and environment, quality, human, delivery and total Cost
- Continuous improvement throughout operation
- Take necessary corrective actions to promptly remedy any identified noncompliance

Supplier selection in ABC group is an evaluation process and conducted to ensure all suppliers continue to meet ABC's expectation for quality, delivery, responsiveness, ability to stay current with technology and cost. It includes following requirements:

Supplier's Selection in ABC group is An evaluation process and conducted to ensure all Supplier's continue to meet ABC's expectation for quality, delivery, responsiveness, ability to stay current with technology and cost. It includes following requirements:

- Suppliers must implement a visual business operating system (BOS) that involves all employees in driving continuous improvement activities

- Adaptation with Lean Manufacturing principles
- Third party registration to ISO 9001:2008 (or TS-16949:2009)
- Suppliers encouraged to be ISO 14001 certified

Supplier Development Program includes:

- ✓ Request for corrective action
- ✓ Scheduled progress report meetings
- ✓ Audits by ABC plant or Corporate SQA and on-site support of quality systems
- ✓ Support in quality systems
- ✓ Lean manufacturing
- ✓ Six-sigma
- ✓ Team-oriented problems solving.

- Supplier's performance evaluation consists of Supplier's performance measurement through means of a scorecard in each of the following areas:
  - ✓ Part per million (PPM)
  - ✓ Corrective Action Reports
  - ✓ Delivery – on-time, Line interruptions, Logistics issues and Documentation issues, PPAP(Production part approval process)

(Source: ABC group website, annual reports, supplier quality portal and manual)

Bell Helicopters was founded in 1935 as Bell Aircraft Corporation. Bell has delivered more than 35,000 aircraft to customers around the world. The key logistics supply and service centers are maintained in Europe, Canada, and Singapore as well as in the

United States. The portal of suppliers is located in Sell2Bell.site that contains information, such as training materials, quick reference cards, and other helpful documents. SQD of Bell helicopter consists of following practices:

1. Continuous Improvement that includes:
    - Waste Elimination primarily through Lean principles and tools
    - Reduction of variation through traditional DMAIC tools
    - Growth and Innovation using the tools and principles of DFSS (Design for Six Sigma)
2. Supplier Facility Audit and Surveys includes:
    - Audits of supplier capability and compliance with Bell helicopters Product Assurance requirements
    - Suppliers certify to applicable NADCAP processes or ISO/IAQS-9000 EN/AS/JISQ 9100 system(s) for the control of quality of products or services
    - Assess the quality systems of sub-tier suppliers and subcontractors
    - Inspection results
    - Material certifications
    - Control of nonconforming material
    - Supplier participation in mistake-proof applications and statistical process control methods
    - Systematic problem solving techniques for determining the root cause
3. Other practices:
    - Quality Management / Inspection System

- Nonconforming Material Control
- Corrective Action, Program Self Audit
- Product Development Process and manufacturing controls
- Certification of suppliers with First Article Inspection consists of following processes:
    - ✓ Application of the final inspection acceptance stamp
    - ✓ Identifying both the supplier and the individual inspector on finished parts
    - ✓ Statistical Process Control (SPC)
    - ✓ Training per basic requirements of International Organization for Standardization (ISO) 9000 and/or International Aerospace Quality Standard (IAQS) 9000
    - ✓ A calibration program
- Cost reduction: Bell Helicopter's annual cost reduction requirements are 6% or more per year incremental. It is a system to identify, record, and monitor costs on a regular basis for all products
- Textron Six Sigma (TSS): a comprehensive and proven set of tools and techniques applied in a consistent, systemic fashion to enable to better solve problems and optimize processes in all functional areas

(Source: Bell Helicopter website, annual reports and supplier quality portal and manual)

Honeywell is a Fortune 100 company that invents and manufactures technologies to address tough challenges linked to global macro trends such as safety, security, and

energy. Category of products and services includes: Aerospace, Automation and Control Solutions, Performance Materials and Technologies, Transportation Systems. Suppliers in Honeywell are certified to ISO 9001 and have a goal of achieving conformance to the TS 16949 standard. Supplier selection and assessment process is the first activity in supplier quality to ensure the quality of the supplied material meets the requirements. New suppliers are selected according to quality, delivery time, price, service and readiness criteria to join a continuous quality improvement program (zero defects goal, Environmental aspects).Supplier performance is monitored based on product quality, customer requirements including field returns, delivery performance quality. For SQD, Honeywell manages plans and implements monitoring, measurement, analysis, and improvement processes, which ensure conformity and continuous improvement, as well as conformity of products and services to requirements. Six Sigma plus Honeywell Operating System (HOS) tools, and the review and monitoring of targets are used to drive improvement of processes, products and the environment. Advance product quality planning (APQP) with appropriate usage of statistical tools is included in the control plan for suppliers. For measurement & monitoring suppliers, Honeywell uses Customer Satisfaction and Internal Audit. Continuous improvement activities are implemented based on the following elements:

- Quality environmental policies, Quality & environmental objectives
- Audit results, analysis of data
- Corrective and preventive action
- Management review
- DMAIC cycle used by Six Sigma projects and gemba Walks by management

Another practice for supplier quality development is Supplier track to exceptional performance (STEP).It consists of:

- Quality Certifications
- Parts requiring Qualification
- Production Part Approval Process (PPAP)
- Part Submission Warranty (PSW)
- Submission Evidence Requirements
- Significant Production Run, Process Capability
- Measure System Analysis

Supplier Scorecard includes elements such as:

- Delivery Scoring (On Time to Request)
- Lead Time Scoring (LT) Productivity Savings Scoring (PP)

Supplier quality certification consists of ISO approval and ISO plus. They refer to certifications in Telecommunications industry: TL9000, Automotive industry: QS9000, TS16949 and special standards of Aerospace industry.

(Source: Honeywell website, annual reports , supplier quality portal and manual)

Bombardier is a global transportation company with 76 production and engineering sites in 25 countries, and a worldwide network of service centers. It has two industry-leading businesses: Aerospace and Rail transportation. SQD activities in bombardier include:

- Continuous Improvement (CI) Loop

- Supplier Performance Monitoring On-Time Delivery (OTD), On-Quality Delivery (OQD)
- Supplier Performance Improvement: Lean events used to improve processes by streamlining the process steps
- Eliminate waste
- Improve product flow
- Six Sigma methodologies for Improvement plans and Supplier continual improvement
- Other standard activities for aerospace supplier quality development are:
    - ✓ Product audits
    - ✓ Manufacturing Process Audits
    - ✓ QMS Audit and Risk Analysis
    - ✓ Rate Readiness Review and Corrective Action

One of the recent activities for developing quality of suppliers is MACH initiative. MACH (Aero Montréal's Supply Chain Working Group initiative) is designed to optimize the performance of Québec's aerospace supply chain and increase its global competitiveness. MACH begins with a pilot project that will involve about 20 Québec suppliers who will benefit from services offered by the initiatives. The initiatives will progressively make services, tools and methodologies available to participating companies to evaluate and improve their performance and market position and further develop business opportunities. The program will include services such as a MACH based on action priorities tailored training programs. Mechanisms for performance

measurement and benchmarking at the national and international levels. (Source: Bombardier website, annual reports, supplier quality portal and manual)

Pratt & Whitney is committed to being the world-class provider of dependable engines, propulsion systems, parts and services that meet customer expectations quality, compliance to requirements and continuous improvement. Supplier quality Development is an essential element of Pratt & Whitney strategy for developing a world class integrated supply chain. Important activity of Pratt & Whitney in supplier quality development is training of Suppliers and on-line Lean self-assessments. Supplier training includes courses which provide a strong base for building a quality culture within organization. Another tool is on-line Lean self-assessment tool for useful way to help determine current level of Lean implementation and provide opportunities for improvement. Pratt & Whitney has a Supplier Gold Award. This Award targets on-time delivery and best in class business results on supplier performance. Supplier Gold is a program that facilitates and accelerates superior performance and Recognizes supplier excellence in four performance levels:

1. Zero escapes
2. 100% to requirements for the last 12 months
3. Market Feedback score >= 6.4
4. Lean Assessment score >=350

Pratt & Whitney has several problem solving kits for suppliers includes:

- Quality clinic set-up
- Quality clinic process charts

- Relentless root cause analysis
- Mistake proofing
- Market feedback analysis: It uses tools for supplier quality production improvement like 5S, set-up reduction, TPM, standard work, process certification and value stream management and production preparation process.
- Suppliers certified to one of the following international quality management standards:
    - ✓ ISO 9001 Quality Management Systems – Requirements
    - ✓ ISO/TS16949 Quality Management Systems – Automotive Requirements
    - ✓ AS9100 Quality Management Systems – Aerospace – Requirements

Quality System Assessment in Pratt & Whitney consists of both the Q+ Self-Assessment and Survey criteria intended to assess a supplier‘s quality system, process control capability, as well as assist the supplier to identify strengths, weaknesses, and areas requiring improvement. Q+ Self-Assessment is implemented to determine the supplier‘s readiness for a site survey. Q+ Survey is an on-site survey consists of various quality system and process control categories. Other production part & process qualification requirements are:

- Part approval check sheet
- Process Flow Diagram
- Failure Mode and Effects Analysis (FMEA)
- Control Plan (CP), Process Audit
- Change management

- Traceability & quality records supplier gold program

Pratt and Whitney utilized Integrated Product Development Teams (IPDT). IPDT consists of project, design, process, and manufacturing engineers. IPDT select the supplier early in the preliminary design stage of the effort to gain design and manufacturing insight from the external production source. Representatives of key suppliers worked hands to hands with Pratt and Whitney's engineers on site. Critical success factors included understanding supplier's capabilities and type of support area of supply base.

Performance enhancement at Pratt and Whitney is called the Achieving Competitive Excellence institutive (ACE). ACE was being implemented in both the internal and external supply bases. It consisted of a structured development framework for implementation of lean manufacturing principals. Principals such as:

- 5S, creation of a visual factory
- Total preventive maintenance (TPM)
- Poke-yoke (Mistake proofing)
- Quality control charting (QCPC)
- Process improvement
- Process control
- Inventory control.
- Set up reduction

Pratt and Whitney used teams to train and assist suppliers in lean manufacturing, SPC, Kaizen, Quality control process charting and TPM (Total Productive Maintenance)

techniques. The team were deployed to the suppliers and worked hand in hand with suppliers to train them. (Source: Pratt and Whitney website, annual reports, supplier quality portal and manual)

Rolls-Royce is a world-leading provider of power systems and services for use on land, at sea and in the air. It has established a strong position in global markets - civil aerospace, defense aerospace, marine and energy and nuclear. The Rolls-Royce Global Supplier Portal (GSP) is the new web portal that has replaced the supplier manager-online web site. Suppliers are able to view their Supplier Scorecard that details their performance to Rolls-Royce. Supplier quality development in Rolls-Royce includes:

- Rolls-Royce Supplier Awards program: The awards recognize the contribution and commitment of the supply base to continuous improvement with a focus on performance
- Supplier selection and approval: Criteria for supplier selection are deliver mutual business benefit, minimize the environmental impact of business operations, encourage the highest standards of ethical behavior, promote sustainability and transparency
- The Supplier Total Evaluation Process (STEP) is another SQDP for approving candidate suppliers. STEP assessments include health, safety and environmental factors

An example of supplier group working is the best practice sharing program. This is a program facilitated by Rolls-Royce Supplier Development where groups of non-competing suppliers work with each other on shop floor improvement activities and sharing best practice techniques.

Key functions of supplier quality and development in Rolls-Royce are Supplier approval and maintenance:

- Numerous assessments are designed to help suppliers achieve class leading performance, qualify suppliers or supply material to meet ASME code requirements
- Supplier development: Develop and improve supplier performance or capability highlighted by the supplier evaluation process. Assess non-conformances and root cause analyze. Members of these activities are black belts and green belts
- Supplier quality ME-P: a team of engineers to ensure suppliers have manufacturing capability and assist improvements

(Source: Rolls-Royce website, annual reports, supplier quality portal and manual)

Allied signal an American aerospace, automotive and engineering company created through the 1985 merger of Allied Corp. and Signal Companies. It was subsequently purchased by Honeywell for $15 billion in 1999, and thereafter adopted the Honeywell name and identity. It provided site assistance and training to suppliers with regard to process improvement Quality, SPC, six sigma, and inventory. Allied signal had established "crack improvement teams known as on site development (OSD) teams that lived at a supplier for 13 weeks and helped supplier work through quality, inventory cycle time and lean manufacturing.(Source: Fletcher k.L.P.H. ,1992)

Lockheed Martin is an American global aerospace, defence, security, and advanced Technology Company with worldwide interests. It was formed by the merger of Lockheed Corporation with Martin Marietta in March 1995. It focuses on quality

techniques such as SPC and inspection methods. They work in conjunction with suppliers to review processes and certify the suppliers. (Gostic, 1998)

Rockwell Automation is a global provider of industrial automation, power, control and information solutions. Rockwell uses following practices in supplier quality: Creation and maintenance of a supplier performance history. Analysis and evaluation of history, Education and support, Motivation through reward and recognition. Rockwell Supplier certification program eliminates receiving inspection on supplier's material for good suppliers. It Institutes a supplier involvement council and representatives to provide guidance in supplier communities. Rockwell at regular intervals reduces red lines and prepares incentives for suppliers to motivate them for improving their quality and cost. Rockwell certified suppliers have an excellent quality and delivery history with incentive program. (Source: Fletcher K.L.P.H., 1992)

GM Company commonly known as GM (General Motors) is an American multinational automotive corporation headquartered in Detroit, Michigan, and among the world's largest automakers by vehicle unit sales.GM has a supplier performance indicator reporting system and summarizes and communicates to suppliers' key performance indicators in areas product, quality, delivery and responsiveness. (Source: Fletcher K.L.P.H., 1992)

Auto Alliance is a Ford Motor Company assembly plant located at Michigan. The plant currently produces the Ford Mustang coupe. A joint venture of Ford and Mazda, it uses QOS (quality of service) and APQP (Advanced product quality planning) to

enhance the performance of suppliers and awards Preferred suppliers to encourage suppliers to continually improve their performance. (Source: Fletcher K.L.P.H., 1992)

Expectations of **Amway,** an American multinational direct-selling company that uses multi-level marketing to sell a variety of products, primarily in the health, beauty, and home care markets from suppliers can be classified in two groups:

1. Communication requirements: good communication, sharing best practices, sharing data for reduced testing inspection consideration, focus attention on audits and follow up actions, Focus on continued quality improvement, effective and timely processes to implement corrective actions and quality improvements
2. Metrics Requirements: Maintain a rolling month right first time (RFT), Quality rating average of or higher per the performance metric section of this manual. If the (RFT) quality rating average is below 99%, suppliers may be asked to provide short and long-term improvement plans to improve their performance

New suppliers become qualified and approved with the following 3 elements:

1. Technology and Risk screening
2. Capability assessment
3. Performance evaluation.

Following activities are implemented in supplier quality development:

- Non-Conforming Products and Materials: it includes Corrective Action and Preventive Action (CAPA)

- Performance Measurement/Supplier Scorecard: The Supplier Scorecard measures supplier performance using key supply chain metrics
- RFT (Right First Time): The RFT metric measures a supplier's ability to meet agreed-upon specifications and requirements

(Source: Amway website, annual reports, supplier quality portal and manual)

Motorola is an American multinational telecommunications company. It highlighted two factors for implementation of successful SQDPs: Responsibility for program implementation shared in the organization, cross functional team for implementation of quality activities. Motorola established a university for training of suppliers. Motorola moved personnel from incoming inspection to working with suppliers.

Campbell soup-a well-known producer of food products-implemented a process–based supplier quality development (Process-oriented often stress: communication with suppliers, Supplier- involvement) it moved personnel from positions in incoming inspection to analyze their processes. Company rewards and publicizes supplier that reach select supplier status. (Source: Fletcher K.L.P.H., 1992)

Tennant Company is a recognized leader in designing, manufacturing and marketing solutions that help create a cleaner, safer, healthier world. Tennant maintains data for suppliers related to incoming lots, zero defects; reliability on time delivery. Company uses publicity and personal ceremonies for supplier recognition. Company implements person to person visits with suppliers, worker to worker communication with them. Tenant invites groups of suppliers to meet and discuss product development for involving suppliers in process development. (Source: Fletcher K.L.P.H., 1992)

Varian medical Systems is the world's leading manufacturer of medical devices and software for treating cancer and other medical conditions with radiotherapy, radiosurgery, proton therapy, and brachytherapy. Varian medical certifies every part to medical equipment by the subject. The company uses Historical data on defective parts. The criteria for selecting suppliers is defect rate less than two percent to twelve months When a supplier is selected, Varian conducts a process evaluation survey of supplier's plant to analyze the supplier's quality process. (Source: Fletcher K.L.P.H., 1992)

Alcoa Inc. is the world's third largest producer of aluminum. Alcoa identifies key suppliers as candidates for certification, Alcoa assigns a supplier quality associate for working with each candidates to assess and bring the supplier's process into conformance with Alcoa's quality expectations. The company uses prior self-audit for one, one and half to two years. After this period and getting a good performance history, Alcoa eliminates incoming inspection. Alcoa assigned an Alcoa employee and supplier associates for training of suppliers. (Source: Fletcher K.L.P.H., 1992)

HP (Hewlett-Packard) is an American multinational information technology corporation headquartered in Palo Alto, California, United States. It provides products, technologies, software, solutions and services to consumers, small- and medium-sized businesses and large enterprises, including customers in the government, health and education sectors. HP for supplier audit uses a quality system audit-process control for suppliers. A quality system requirement for suppliers is ISO 9001.Supplier performance expectations are: TQRDC (Technology, Quality, Responsiveness, Delivery, and Cost of ownership for financial stability). HP produces a feedback in its

TQRDC annually twice per year with key suppliers and signs a mutual agreement of objectives with suppliers (Fletcher, 1992). (Source: Fletcher K.L.P.H., 1992)

Based on the review of industrial practices, we found each company has some best practices in SQD steps. Best practices for each company highlighted in Tables 2.3 and 2.4. List of quality techniques used in SQD steps of various companies is provided in Table 2.5.

Company	SQE	SQC	RS	SR	SQPM	Training	Quality tools	CPSQ	CR
Honda							■		
Toyota			■				■		■
Nissan							■		■
Bell							■	■	
Honeywell		■							
Bombardier						■			■
Pratt & Whitney			■				■		■
Rolls-Royce	■								■
AMWAY					■				
ABC group	■								
Allied signal									■
Lockheed Martin							■		
Motorola						■			
Campbell soup				■					
Rockwell									■
Tenant				■					■
GM	■								
Varian Medical									■
HP	■				■				
Auto							■		

Company	SQE	SQC	RS	SR	SQPM	Training	Quality tools	CPSQ	CR
Alliance									
Alcoa									

Table 2.3 Best practices of SQD based on the industrial practices review

Company	Best SQD practices
Honda	• Supplier Products development, SBP ('Soft Best Position') and HBP ("hard best position).
Toyota	• Toyota's SQD engineer provides necessary individual assistance to suppliers. • Toyota quality control (QC) Award for suppliers.
Nissan	• Implementation of Gemba Kanri for suppliers • 3-4 engineers visiting the factory 4 times a month and it is known for a Nissan engineer to be resident at the supplier's site.
Bell	• Cost reduction, Textron Six Sigma (TSS).
Honeywell	• Supplier track to exceptional performance (STEP) for certification / qualification.
Bombardier	• MACH initiative training programs Mechanisms for performance measurement and benchmarking at the national and international levels.
Pratt & Whitney	• Supplier Gold Award, problem solving kits, integrated product development teams (IPDT). Achieving competitive excellence institutive (ACE).
Rolls-Royce	• The Supplier Total Evaluation process (STEP).
AMWAY	• Performance Measurement/Supplier Scorecard.
ABC group	• Supplier's Performance Evaluation.
Allied signal	• Signal on site development (OSD).
Lockheed Martin	• Quality techniques such as SPC.
Motorola	• University for training of suppliers.
Campbell soup	• Effective communication with suppliers.
Rockwell	• Supplier involvement council and representatives.
Tenant	• Person to person visits with suppliers, worker to worker communication with them.

Company	Best SQD practices
GM	• Supplier performance indicator indicators in areas product, quality, delivery and responsiveness.
Varian medical	• Process evaluation survey of supplier's plant to analyze.
HP	• Supplier performance expectations are: TQRDC (Technology, Quality, Responsiveness, Delivery, and Cost of ownership for financial stability).
Auto Alliance	• QOS (quality of service) and APQP (Advanced product quality planning).
Alcoa	• Supplier quality associate for working with each of the candidates.

Table 2.4 Best practices of SQD

Company	Quality tools
Honda	• 3S and 5S
Toyota	• Quality Control(QC)
Nissan	• Capability Enhancement Activity, and incorporates synchronized production • Total productive maintenance (TPM) • Gemba Kanri
Bell Helicopter Bell Helicopter	• Lean principles • DFSS (Design for Six Sigma) • Mistake-proof applications • Statistical Process Control (SPC) • Textron Six Sigma (TSS)
Honeywell	• Six Sigma plus Honeywell • Honeywell Operating System (HOS) tools • Advance product quality planning (APQP) • Gemba Walks by management • Production Part Approval Process (PPAP)
Bombardier	• Lean events • Six Sigma methodologies • Benchmarking at the national and international levels

Company	Quality tools
Pratt & Whitney	• On-line Lean self-assessment tool • Mistake proofing • 5s, creation of a visual factory • Total preventive maintenance (TPM) • Poke-yoke (mistake proofing) • Quality control charting (QCPC) • Process improvement • Process control • Inventory control • Set up reduction • Process Flow Diagram • Failure Mode and Effects Analysis (FMEA)
Rolls-Royce	• Non-conformance and root cause analyze • Six sigma
Amway	• Corrective action and preventive action (CAPA)
ABC group	• Lean Mfg. • Six-sigma • Team-oriented problems solving
Lockheed Martin	• SPC

Table 2.5 Quality tools used in SQD (industrial practices review)

2.8 Criteria for SQD practices

In this section based on the academic literature review and industrial practices we selected critical factors for previous mentioned practices.

2.8.1 Supplier Quality Evaluation (SQE) criteria

1 Evaluation methods

1-1 Cost Benefit Analysis

The CBA compares the losses and benefits for the selection of supplier with the not outsourcing option. For calculation of CBA a performance or decision criterion is

required. The common criteria used are the Net Present Value (NPV) and Benefit Cost Ratio.

1-2 Data Analysis (Monitoring growth using historical data)

Historical information about supplier performance can also be leveraged during the SQE process with the suppliers. The buyer may choose to directly incorporate this information into a competitive bidding process via a bid mark-up or some other means to send a clear signal to the supplier about the importance of performance. (Beil and Ross, 2009)

1-3 Expert Ratings (Buyers, Departmental Heads)

This method includes a seminar workshop for the evaluation of the suppliers by the experts (the questionnaires are mailed to them). A supplier evaluation criterion applies a rating system, and scores rated are averaged. However, the different criteria provide different interpretation for different experts; some experts emphasize the quality while others concentrate on the price. This way, the users are required to set weight for each criterion in the same standard by means of a review. In doing so, each expert evaluates the degree of importance for each criterion, estimates and, averages. The fractions are divided to estimate the determining scores mean for entire criteria. Absolute value for each criterion is determined by product of mean value and corresponding weighting factors (Eldeshteyn ,2006, Achariya, 2012)

2 Criteria to evaluate suppliers

2-1 Price

Price is the amount paid by the enterprises to buy goods from its suppliers. Suppliers offering a fair price provide the benefit of cost reduction to the buying firm, while also providing themselves with a fair profit. A mutually beneficial price allows suppliers to remain profitable and continue business. Firms that earn extremely low profit margins relative to their competitors are likely to either cut corners on quality or to exit the relationship. (Arsan, 2011)

2-2 Delivery performance

It evaluates how well a supplier succeeds in delivering goods according to schedule. Selecting suppliers with exceptional delivery ability eliminates the "waste" associated with purchasing raw materials such as inventory costs, storage expenses, and the costs of transferring materials multiple times.

2-3 Service

This criterion evaluates the after-sales service and support provided by the suppliers. Buyers and suppliers of manufactured products appear to agree that service is becoming increasingly important related to product and price issues. A manufacturer, even the best manufacturer in the world, who can't respond to customers' needs, is not going to survive. The efforts by manufacturers to be more customers focused must be matched by buying organizations ensuring that their suppliers are giving them the level of service that is required and at reasonable cost. Service, defined as all those activities provided by the seller that enhance or augment the product and have value for the buyer, thus increasing customer satisfaction and encouraging patronage and loyalty between the parties, is increasing in importance to buyers (Donaldson, 1994)

2-4 Flexibility

Measures the ability of a supplier to accommodate changes in the enterprise's production plans. Suppliers offering order flexibility provide value to firms by giving them the ability to seize opportunities or avert crises due to last minute changes. Last minute changes are sometimes unavoidable and flexibility is the key to surviving such changes.

2-5 Environment, health and safety

This criterion now is becoming a very important quality aspect in leading companies. Motorola evaluates its supplier in safety and health and environmental sustainability. Environmental sustainability includes 3 aspects: 1) Environmental Management System (EMS): Suppliers of goods will have an EMS in accordance with ISO 14001 or equivalent. 2) Material Disclosure: Motorola encourages its suppliers to provide them with environmentally preferred products.3) Ozone Depleting Substances: The evaluation also involves the raw material content data management; waste management; programs for improving environmental performance and product development.

3 Frameworks for supplier evaluation

In line with best practices of supplier evaluations, three audit frameworks often applied are the ISO 9000 criteria, the Malcolm Baldrige Award criteria, and EFQM.

4 Systems used for inputting data

This criterion evaluates system used for inputting data of supplier evaluation. Nowadays with growth of IT technology, several companies implement an internet

based mechanized system for more accessibility of suppliers, thereby saving time and having an increased accuracy of information. Supplier portals are web systems for inputting data of suppliers.

5 Items to be evaluated in evaluation system

This criterion includes following sub-criteria used for measurement and investigation of supplier evaluation.

5-1 Quality management and organization policy

It investigates following items in supplier quality system:

- Appropriate quality management policy
- Safety and environmental policy
- Continuous improvement program to ensure improvements to quality, service, productivity and Costs
- Integration of Quality objectives into business plan and measurability of them
- Objectives to ensure product requirements are satisfied
- Cost of quality is calculated and measured and objectives are established in business plan
- Effectiveness of Quality Management System
- Safety incidences and lost work accidents

5-2 Understanding of customer requirements

It includes following items:

- Technical criteria concerning the product: understanding and respect for customer requirements
- Customer requirements are deployed in the Quality Management System
- Analysis of contract deviations and methods of resolving deviations from the contract
- Method of determining production feasibility before acceptance of order
- Methods of communication with the customer regarding the product
- Logistical and service criteria concerning the product include: understanding and respect for customer requirements for handling customer applied product and Method of determining logistics feasibility and customer service requirements

5-3 Staff training and motivation

It includes existence of a process for identification of training requirements, scheduling and evaluation of effectiveness of training. Personnel are properly trained according to training requirements and on-the-job training is managed. Establishment of requirements for qualification of personnel and process for updating of qualifications exists along with individual training plans and training records. Another factor in motivating employees to achieve quality objectives that leads to continuous improvement and innovation.

5-4 Management of product and process evolution

It measures methods for developing the product and management of developing stages. The criteria include: Multidisciplinary approach interface management, effective communication, review of product characteristics, establishing and

documenting input and output data for design and development, setting up of a prototype program and a quality plan and conformance with a customer-approved process for approving product and production process.

5-5 Quality of products received from suppliers

This item includes the supplier quality guarantee for ensuring all specifications of suppliers have conformance with quality requirement of buyer and evaluation of suppliers periodically with requirements.

5-6 Process control

Includes all characteristics and knowledge of the parameters to be controlled and potential failures.

5-7 Inspection programs and measurement quality

It consists of inspection programs for control of monitoring and measuring equipment.

5-8 Process complaints

It investigates a system or *process* for assimilating customer complaints throughout organization and established problem solving methods.

5-9 A system for corrective actions in areas those are not meeting requirements

Corrective action and preventive action (CAPA) also called corrective action / preventive actions are improvements to an organization's processes taken to eliminate causes of non-conformities or other undesirable situations.

2.8.2 Supplier Quality Criteria (SQC) Criteria

The structure of each certification system includes the following important criteria and sub criteria:

1 Measure supplier quality performances

1-1 Monitor supplier certifications and quality system

Supplier certification is an important component of a total supplier qualification/certification that assures a supplier's product is produced, packaged, and shipped under a controlled process that results in consistent conformance to company's requirements. It eliminates the need for final quality inspections by the supplier or the customer.it includes following items:

1-1-1 ISO 9001-2008 standard

The purchasing requirements in the ISO 9001 standard help to ensure that products and services that are purchased from various suppliers fully meet buyer's needs. The disruption and cost to an organization stemming from supplier problems can impact buyer's customers and bottom-line. So, having processes in place that prevent problems and provide consistency within the supply chain is a key focus of ISO Quality Management System (QMS).While suppliers' operations are not under direct control, purchasing power can give a significant influence over which suppliers do business with and how they meet company's needs. These needs then must be translated into criteria for choosing suppliers and requirements for them to meet. Without this clarity, neither companies nor their suppliers will know what is to be expected and will inevitably lead to problems down the road. The ISO 9001

requirements for purchasing (section 7.4) itemize basic processes that will put company and their suppliers on the same page.

1-1-2 QS 9000 standard

QS 9000 is the name given to the Quality System Requirements of the automotive industry which were developed by Chrysler, Ford, General Motors and major truck manufacturers and issued in late 1994.

1-1-3 ISO 14000 standard

This Environmental Management System (EMS) is a set of internationally created and recognized guidelines that allows companies to address the environmental impact of their products, services and business practices. It also provides a system for monitoring, controlling, and improving performance regarding any regulations, legislation, and codes of practice that an organization has to comply with. ISO 14000 certified suppliers ensure their partners have an acceptable level of environmental condition in their companies.

1-1-4 AS 9100 standard

AS9100 is the quality management standard specifically written for the aerospace industry. Certification of this standard for suppliers of aviation companies is mandatory. It had long been considered by some entities, such as the Federal Aviation Administration (FAA), that the ISO 9000 series of standards were inadequate in terms of ensuring quality and safety in the “high risk” aerospace industry.

1-1-5 NADCAP / PRI standard

Nadcap (formerly NADCAP, the National Aerospace and Defence Contractors Accreditation Program) is a global cooperative accreditation program for aerospace engineering, defence and related industries. NADCAP program is a part of PRI (Performance Review Institute). NADCAP provides independent certification of manufacturing processes for the industry.

1-2 Monitor safety and risk assessment:

This criterion includes following sub criteria:

1-2-1 Establish consistent safety standards

While regulating safety is a national responsibility, international standards and harmonized approaches to safety promote consistency, help to provide assurance, and facilitate international technical cooperation, commerce and trade.

1-2-2 Monitor supplier risk

Organizations which adopt and implement a comprehensive supplier risk monitoring program will have visibility into a broad spectrum of overall supplier risk factors, not just compliance.

1-2-3 Verify insurance coverage

Once appropriate insurance requirements are determined for various situations and corresponding insurance clauses developed, some organizations require suppliers to submit insurance certificates to prove their coverage. Companies must sure those certificates of insurance are not only received but they're inspected to make sure they

do provide the correct level of coverage. If something go wrong and supplier doesn't have the required insurance, company have to bear 100% of the risk.

1-3 Practices to ensure potential suppliers meet product quality requirements

Product quality is collection of features and characteristics of a product that contribute to its ability to meet given requirements. The product must work reliably and perform all of its intended functions. Product quality is the product's ability to fulfill the expectations and needs set by the end user. The product must work reliably and perform all of its functions. Following sub-criteria ensure companies those suppliers product are in accordance with quality requirements.

1-3-1 Communicate product quality requirements

Clear communication between supplier and company related to product quality requirements facilitate mutual cooperation and decrease misunderstanding about product quality requirements.

1-3-2 Collect and review supplier self-assessments

Companies use a range of assessments to understand a supplier's performance level and compliance to requirements.

1-*3-3 Confirm sample products' quality levels*

Sampling from products is a way to inspect and test conformance degree of products with required quality. Following items are tested for sample conformance:

- Conformance to specifications: Typically, as soon as a purchase order is signed with a factory, an important next step is to engage suppliers in order follow

ups. This is to ensure that suppliers are in line to produce the correct product, level of quality, special requests, shipment dates, etc.

- Process capability: Process capability is considered to be the most effective method in selecting quality products or parts (Asokan and Unnithan, 1999; Boyles, 1996; Chan *et al.*, 1991; Chen, 1990; Liu, 1993; Pearn and Chen, 1997–98; Pillet *et al.,* 1997–98; Singhal, 1990; Taam *et al.*, 1993) Process capability is the long-term performance level of the process after it has been brought under statistical control. In other words, process capability is the range over which the natural variation of the process occurs as determined by the system of common causes for each new product.
- Product reliability: Suppliers must perform product reliability testing to guarantee the product meets industry reliability standards.

2.8.3 Rewarding Supplier (RS) criteria

Following important criteria have been extracted from Literature review and industrial practices)

1 Honours outstanding suppliers with mark of excellence and targets for excellence driven quality's supplier award

Recipients will show substantial improvement in total quality and performance levels compared with unrecognized suppliers. Recognition awards help suppliers develop new business and create strong relationships with other companies.

2 Publicity and personal ceremonies

Publicity and personal ceremonies are methods for rewarding superior suppliers. Tenant prepares publicity and personal ceremonies for selected suppliers.

3 Supplier incentives

Incentives include financial and non-financial rewards for increasing motivation of suppliers. Companies normally use key performance indicators (KPIs) for incentives. These give the supplier an indication of what will be satisfactory to company in terms of performance and so they have an incentive to achieve the levels of service that their buyer company expects.

4 Eliminating incoming inspection

Companies after certifying suppliers and ensuring the quality performance can eliminate the incoming inspection for rewarding suppliers. Rockwell eliminates receiving inspection on supplier's material for good suppliers.

2.8.4 Supplier Relationship (SR) Criteria

SR consists of following sub criteria:

1 Close communication

Open communication, monitoring the progress and actions of suppliers, and closer relationships with suppliers motivates suppliers to make a greater effort to improve their internal processes, which in turn leads to better quality performance (Eisenhardt, 1989; Forker *et al*., 1997; Kaynak and Hartley, 2008; Lin *et al*.,2005; Zsidisin and Ellram, 2003).

2 Long-term relationship

For making decisions about how to manage supplier quality performance, companies need to assess the nature of their buyer-supplier relationships in order to select the appropriate management mechanism. According to definition of SQD, Supplier quality development is a long-term, planned, strategic effort to improve supplier capabilities in quality assurance and improvement Focus on strategic initiatives aiming at sustaining beneficial buyer-supplier relationships is essential for long-term supply needs.

3 Cross functional team

Firms use a great variety of teamwork practices and they develop ensembles of teamwork practices, which become institutionalised within the firm. The permanent, cross-functional supplier quality development teams are used in companies. Best practices companies use a matrix structure to establish platform groups and project for implementation of supplier quality activities.

4 Shared quality information

Experiences of world-class quality suppliers have been used to describe the set of practices associated with collaborative relationships with suppliers byTrent and Monczka (1999).These relationships can be characterized as information sharing with suppliers, and supplier involvement in the buyer's new product development process. Information sharing is essential as it provides the mechanism for coordination and integration of the processes or activities along the supply chain (Lee, 2000; Ramayah and Omar, 2010). Effective flow of product and services is dependent on information sharing among supply chain members (Lee *et al.*, 1997). Information sharing among

supply chain partners also enables firms to achieve common goals (e.g. Bowersox *et al.* 2003; Bowersox *et al.* 2000; Gustin *et al.* 1995) besides enabling the coordination of the supply chain processes. The ability of firms to gain competitive advantage and to ensure product availability in supply chain is being determined by how information is used in the supply chain (Mason-Jones and Towill, 1997; Ramayah and Omar, 2010). The importance of information quality in SCM has been discussed in many studies (e.g. Rabren, 2010; Ramayah and Omar, 2010; Li *et al.* 2006; Miller, 2005; Raghunathan ,1999; Monczka *et al.,*1998; Gustin *et al.,*1995). Exchanging quality information between customers and suppliers and enhancing supply chain performance (Mason-Jones, 1997; Monzcka *et al.* ,1998; Holmberg ,2000; Forslund and Jonsson, 2007) through information sharing is a vital component for organizational success (Miller ,2005; Li *et al.*, 2006).

5 Involve suppliers early in product and process development

This activity strives to maximize the benefit received from a supplier's engineering, design, testing, manufacturing and tooling resources. Qualified suppliers, which obtain part directly in a cross functional product development team at the buyer, can provide early insight into the production processes. Also, by relating and inviting a supplier to take part in these types of R&D projects can lead to better design solutions regarding to quality and the need of production resources (Trent *et al.* 1999) which often leads to both better quality and lower purchasing prices. This is a key step of supplier quality development even though it improves together the suppliers and the buying firm's quality.

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The target of a successful supplier quality performance measurement system (SQPM) is to grow and nourish suppliers who consistently deliver quality product, on time, in full, with proper documentation, and are easy to work with on a daily basis. It is a tool that helps manufacturer and suppliers collaboratively work on issues that impact each of their businesses, and eliminate costly mistakes.

1 Quality scorecard

Supplier scorecards are one of the best techniques in using facts to rank the supplier's relative performance within the supply base and tracking improvement in supplier's quality over time. Scorecards also provide a data point into any future business negotiations. Following are the key operational metrics that leading manufacturers track in their supplier scorecard:

- PPM of Supplier Components
- # of Corrective Actions Last Quarter
- Average Response and Resolution time for Corrective actions
- # RMAs Processed per month
- MRB Inventory Levels
- # of Rework Hours due to Supplier Components
- % of Actual COPQ Recovered from Suppliers
- # of Customer Complaints on Product Quality
- Warranty Reserves
- Relative ranking of supplier

- Performance against benchmark

2 Supplier Performance Monitoring

An effective SPM process should include key internal stakeholders who interact with suppliers as well as the suppliers themselves. (See Figure 2.4)

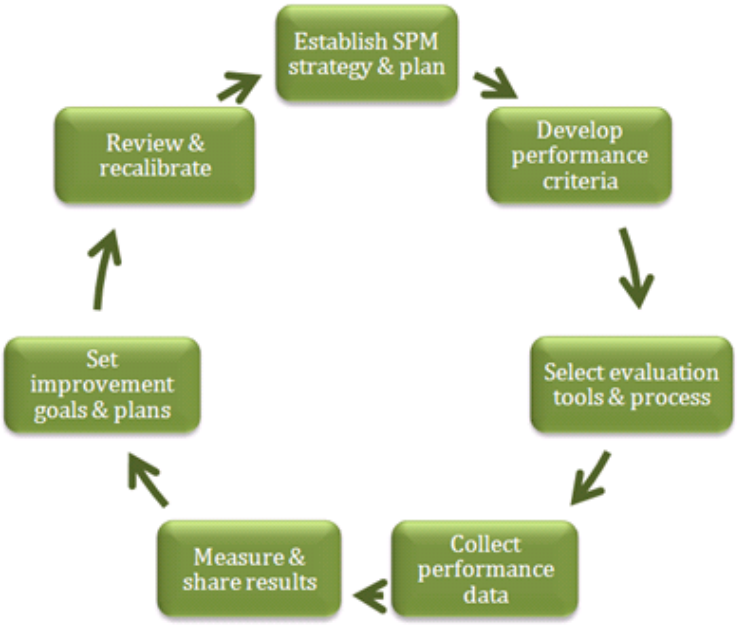

Fig 2.4 Process of Supplier Performance Monitoring (Source: Esourcing Wiki)

3 A system for emerging capability of suppliers

Supplier performance is becoming increasingly important; as customers place additional demands upon organization for faster and more reliable deliveries, better quality and lower prices. It is critical to maintain key suppliers and develop their capabilities, and identify problematic suppliers quickly to eliminate them from supply chain. Supplier capability assessments are an important tool that will enable companies to identify suppliers' base capabilities and their performance and system gaps.

2.8.6 Training and implementation of quality tools Criteria

Training and implementation of quality tools is the most common approach to supplier development and improvement. A purchaser may provide training and implementation of problem solving in statistical process control, quality improvement techniques, just-in-time delivery or any other crucial performance area. In order to adequately assess and aid suppliers in improving quality, purchasers need to train and implement quality and problem solving tool. In many organizations, purchasing may request the assistance of quality and engineering departments in assisting with the supplier quality problem solving and training. Purchasing companies emphasize four areas of supplier quality problem solving and training with their suppliers:

1. Implementation and training of Total quality management and quality improvement tools.
2. Statistical quality control techniques
3. Focusing on integrating quality into the design of products and processes to reduce variability
4. Problem solving techniques(Monczka and Handfield,1998)

Following criteria are included in training and implementation of quality tools processes:

1 A formal process defining the APQP process

The Advanced Product Quality Planning process consists of four phases and five major activities along with ongoing feedback assessment and corrective action (Figure 2.5)

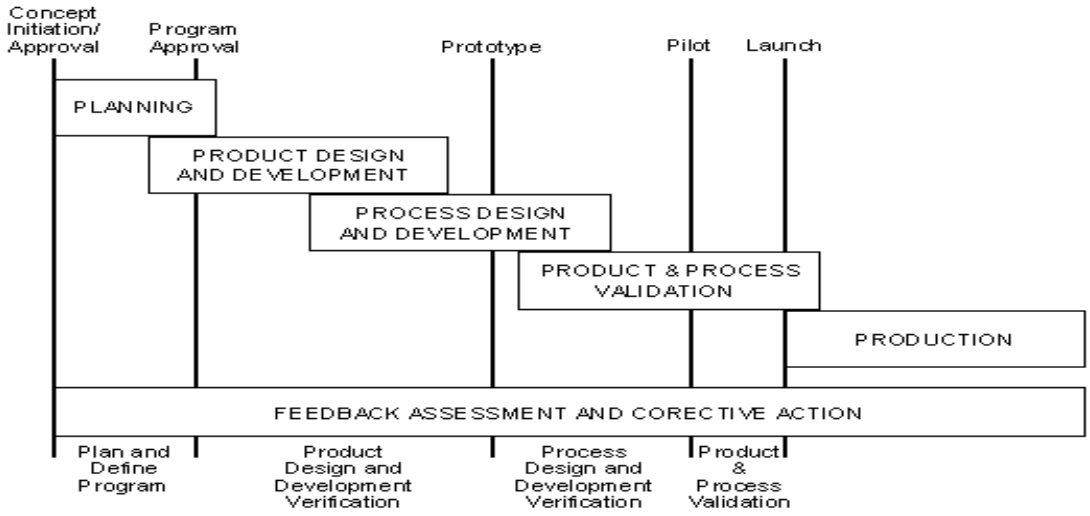

Fig. 2.5 Process of APQP, (Source: Kenneth Crow, 2001)

2 A tracking system available to monitor the stages of APQP process

A tracking system for APQP is a connected system for investigation, monitoring and documentation in all stages of APQP. This system facilitates communication between the supplier and the customer to clarify feedbacks that translate into more detailed specifications.

3 Consideration of best practices and lessons learned from similar part DFMEA, FMEA

Four broad success factors are critical to uniformity of success in the application of FMEA in any company or organization for SQD. They consist of:

1. Understanding the basics of FMEAs and Risk Assessment
2. Applying key factors for effective FMEAs
3. Providing excellent FMEA facilitation
4. Implementing a “best practice” FMEA process

The lesson learned from this case study is that an FMEA team must ensure that all high risk failure modes have effective actions regardless of whether or not a solution is envisioned by the team.

4 Utilize a team approach and structured problem solving tools and methods

Problem solving has been a key concept in the literature on buyer-supplier relationships. Many contributions have focused on creative problem solving such as product development. Most studies have taken the (inter-)organizational level as the level of analysis.

5 Continuous improvement program for suppliers

Continuous improvement is an ongoing effort to improve products, services, or processes.

These efforts can seek "incremental" improvement over time or "breakthrough" improvement all at once. (ASQ, http://www.asq.org) Quality improvement activities for suppliers without a continuous improvement cannot be succeeding. These practices ensure suppliers capability to encompass problem solving, non-conformance, complaints.

2.8.7 Measuring & tracking cost of poor supplier quality for suppliers (COPQ) Criteria

COPQ consists of those costs which are generated as a result of producing defective material. This cost includes the cost involved in fulfilling the gap between the desired and actual product/service quality. It also includes the cost of lost opportunity due to the loss of resources used in rectifying the defect. The labor cost, rework cost

disposition costs, and material costs that have been added to the unit up to the point of rejection. The majority portion of theses these cost are hidden. Following items are important activities of a COPQ system for supplier in supplier quality development practices:

1 Proactively work with suppliers to improve their quality for reducing their own COPQ

The Cost of Poor Quality of individual suppliers participating within a supply chain has a cumulative effect on the COPQ of the end product. As a result, companies are working very proactively with their suppliers to reduce their COPQ.

2 Utilize a program of improvement initiatives such as capacity improvement, scrap reduction and cost control for suppliers

Most organizations do not track and measure the cost of poor supplier quality attributed to their suppliers. Such COPQ may add up to over 10% of the organization's revenue. Some companies only track supplier COPQ by measuring scrap and increase in MRB inventory. Results have shown that materials account for less than 50% of the total COPQ.

3 Measuring & tracking cost of poor supplier quality

Quality Management Systems (QMS) or manufacturing systems can track whenever any of the above costs are incurred due to supplier quality issues. World-class manufacturers are using the entire above criterion to track actual supplier-related COPQ.

2.8.8 Commit the necessary resources to supplier quality development Criteria

Currently, many companies have realized the value of this issue and begun to assign more resources to improve supplier quality performance.

1 Quality development engineer/ representative of company in supplier's site

Honda commits to supplier quality development 40 full time engineers in the purchasing department, these Engineers work with improving the supplier's productivity and quality. Rockwel has established a supplier involvement council with four representatives to provide guidance in supplier communities.

2 Sending instructors and technical consultants to supplier's site

In Rockwell's supplier quality, on site development teams provide site assistance and training to suppliers in process improvement, quality, SPC, six sigma.

Chapter 3

Solution approach

Solution approach for supplier quality development is based on DMAIC methodology. DMAIC is an acronym for five interconnected phases in six sigma. These are Define Measure, Analyze, Improve, and Control. Conceptually the cycle is an advanced process of PDCA cycle: Plan, Do, Check, and Act. Each phase in the cyclical DMAIC process is required to ensure the best possible results. The general process includes following steps:

Define the Customer, Critical to Quality (CTQ) issues, and the Core Business Process involved. Define who customers are, what their needs are for products and services, and what their expectations are. Define project boundaries, the beginning and end of the process. Define the process to be improved by mapping the process flow.

Measure the performance of the core business process involved. Develop a data collection plan for the process. Collect data from many sources to determine types of defects and metrics. Compare to customer survey results to determine shortfall.

Analyze the data collected and process map to determine root causes of defects and opportunities for improvement. Identify gaps between current performance and determined goal. Prioritize opportunities to improve. Identify sources of variation.

Improve the target process by designing creative solutions to fix and prevent problems. Create innovate solutions using technology and discipline. Develop and deploy implementation plan.

Control the improvements to keep the process on the new course. Prevent going back to the "old way" require the development, documentation and implementation of an ongoing monitoring plan. Institutionalize the improvements through the modification of systems and structures (staffing, training, incentives) (Terry, 2010)

Although DMAIC is related to Six Sigma; it can be widespread to a superior level as an overall approach to improvement. As such, it provides a verified approach to problem solving and leads us to the application of improvement tools in a highly structured and sequenced approach. This occurs apart from of whether the specific tools originate within Six Sigma, lean or some other method. In fact, the use of DMAIC, from its original definition of the project forward, can help identify the most effective tools and techniques at each stage of the improvement process for a particular project. (Snee, 2007)

3.1 DMAIC used in supply chain research

DMAIC has been used in few researches for supplier development:

Wang *et al.* (2004) proposed the five steps of the DMAIC model to SD. When multiple dimensions are simultaneously considered in evaluating the overall competence of a supplier, the performance score of each supplier can be obtained by the PCA method. Suppliers with high performance scores are likely to sustain a high level of capabilities and are better candidates for inclusion in an optimized supplier base. Thus, improvement in the quality of all supply chain processes reduces costs and improves the level of customer service.

Haque *et al.* (2010) used six sigma – DMAIC framework for supplier selection in Pakistan Cement Limited. The target of the project was to develop a competitive supplier base out of bulk suppliers available in the market that would result in competitive advantage over competitors. Secondly, they wanted to improve their supplier selection process so that there would be low variance and exclusion of unnecessary activities that would ultimately help in achieving the cost, quality and service enhancement objectives.

Knowles (2005) proposed a conceptual model. The model integrates the Balanced Scorecard, SCOR model (Supply Chain Reference model) and Six Sigma DMAIC methodology in a two-level framework. This is a strategic-level cycle, developing focused projects to generate maximum business benefit, and an operational-level cycle, applying Six Sigma and lean tools in a DMAIC cycle to deliver supply chain improvements. The model is composed of seven distinct steps:

1-Define objectives

2-Measure and assess

3-Define project

4-Model and measure

5-Analyse

6- Improve

7- Control

These seven phases are organised in two complementary cycles, the strategic cycle (DM&C) and the operational cycle (DM&MAI).

3.2 Proposed approach

In our research we are using the analogy of five phases of DMAIC, but our approach is different from standard steps of DMAIC (Figure 3.1).

In Define phase, we identify the criteria for SQD using review of academic literature and industrial practices. In Measure phase, we measure the data related to degree of importance of each criterion using expert opinions (survey method). In the Analyse phase, we analyze the expert survey results and decide criteria importance using Kano's model. To analyze the relationships between criteria we use the ISM (Interpretive structural modeling) to define relationships and interactions of criteria. In the improve phase, we propose a multi-criteria framework based on TOPSIS for evaluation and selection of SQDPs using the weighted criteria. In control phase, we propose Audits to make sure the selected SQDPs perform as intended and to incorporate any changes (if required).

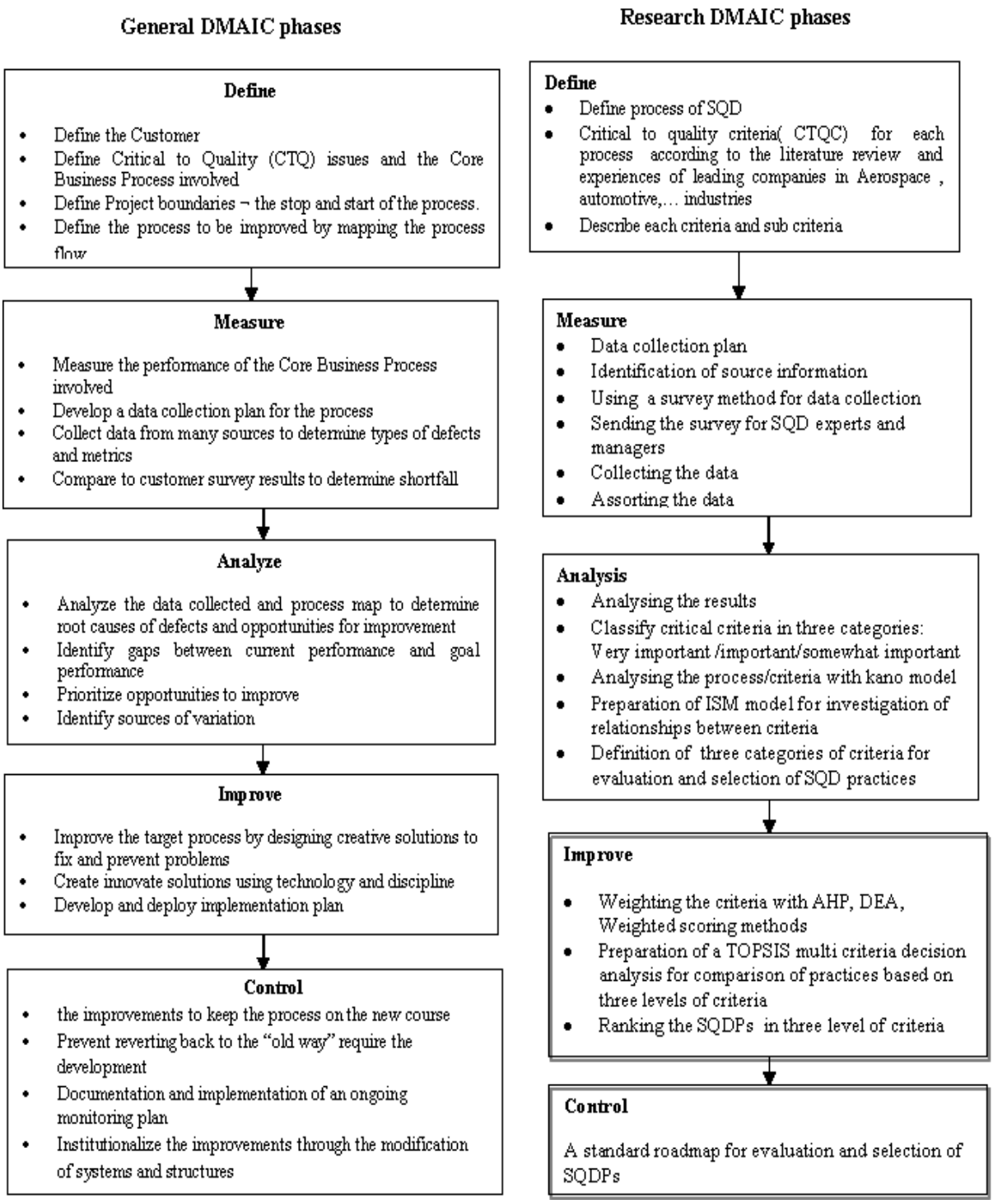

Fig. 3.1 General DMAIC phases and research DMAIC phases

Table 3.1 presents a summary of our solution approach using problems addressed information acquired and tools used in various phases.

Problem	Phase	Information acquired	Tools used
Comprehensive definition, steps and practices for SQD	Define	Steps/ parctices of SQD	Literature review and industrial practices
Critical factors/criteria for each step/practice of SQD		SQD criteria	
Priority and importance of criteria	Measure	Level of importance– focused on the three groups of responces	Data collection with survey
Relationship between supplier's quality needs and SQD criteria	Analyse	Analyse of each criterion in kano model	Kano model analysis
Interactions and relationships among defined criteria		Interactions and relationships between criteria	Interpretive Structural Modeling (ISM)
Method for evaluation and selection of best SQDPs based on the related criteria	Improve and control	A framework for evaluation and selection of SQDPs	Multi-criteria-analyse-TOPSIS-AHP-DEA-weighted scoring

Table 3.1: DMAIC roadmap

Figure 3.2 presents a summarization of phases/ acquired information and tools in our DMAIC methodology.

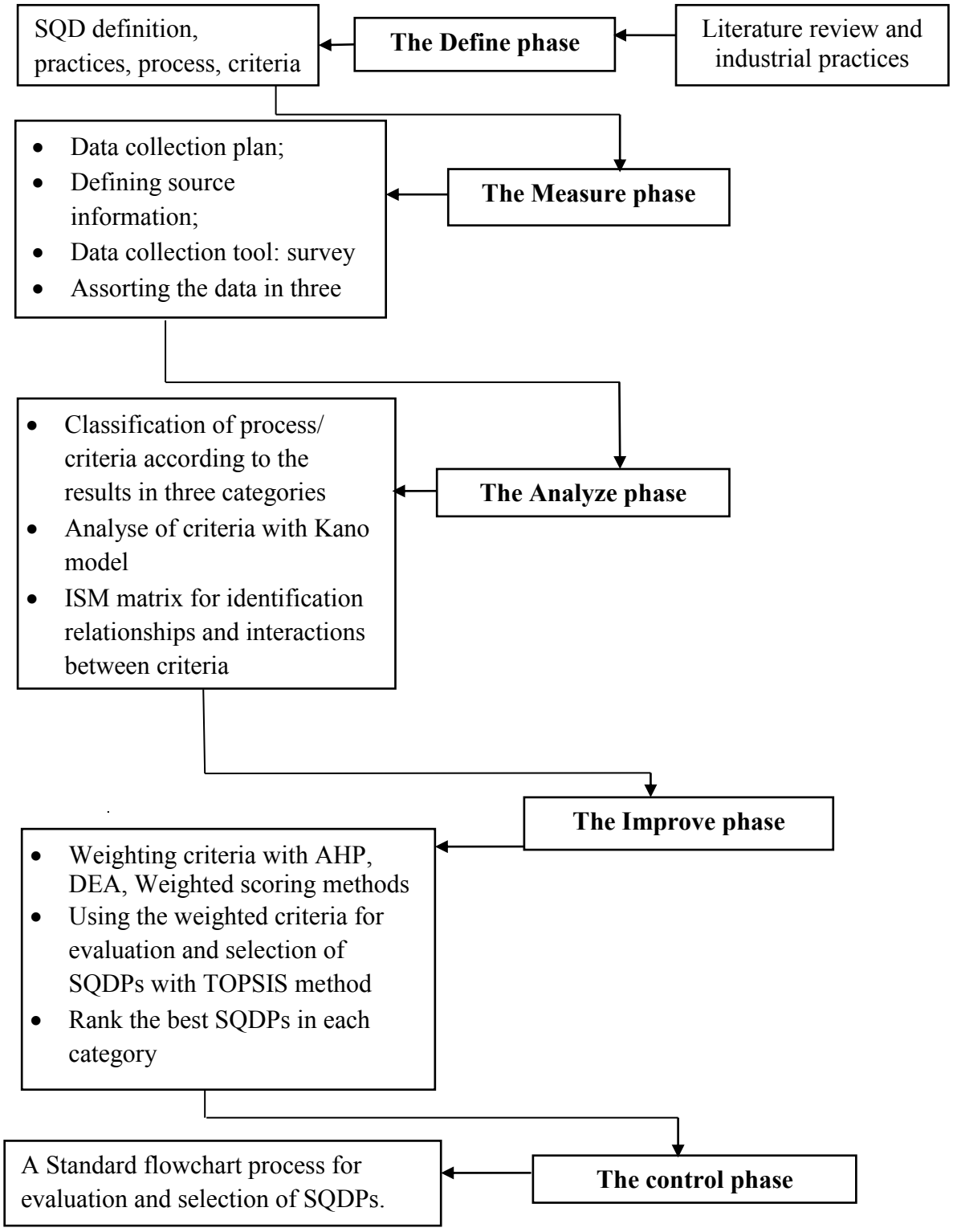

Fig. 3.2 Summarization of phases

Stepwise description of the various phases of our solution approach is presented as follows:

3.3 Define phase

Necessary Information for this phase is extracted from review of Literature and Industrial practices. SQD steps / practices classified in two steps and 8 practices based on the academic and industrial literature review.

3.3.1 Critical To Quality Criteria (CTQC)

The Critical to quality criteria (CTQC) are those criteria which are critical to the success of any organisation, in the sense that, if objectives associated with the criteria are not achieved, the organisation will fail (Rockart, 1979, Antony, 2000). Cooper and Kleinschmidt (2007) defined critical success criteria, the criteria that drive performance at the business unit level. Critical success criteria of processes or performance indicators are necessary in order to set a baseline for current performance and gauge future success. Performance indicators should be a mixture of the quantitative, (costs, cycle times, etc.) and the qualitative (level of satisfaction, appearance. etc.). However, they must serve their purpose, which is to provide a way of comparing processes and measuring success. This means they must be rigorous, capable of being collected over time and comparable over time and between processes. Once you have identified better processes, they are used to help forecast the impact of adopting new processes and monitor the effectiveness of the new process. If you do not have any data it is useful to ask: what do the customers require from the process? What resources does the process use? How customers measure the output of the process? What do other people, especially the “best in class” measure?

The last step in define phase is identification of CTQC for each process. These CTQC are needed for evaluation of SQDPs and selection of the best ones. Based on section 4 – literature review and industrial practices, we identified following critical to quality criteria (CTQC) for each step of SQD (Table 3.2)

Step/practice	Criteria	Sub criteria
1-Supplier quality evaluation	1-1 Evaluation methods	1-1-1 Cost Benefit
		1-1-2 Data Analysis (Monitoring growth using historical data)
		1-1-3Expert Ratings (Buyers, Departmental Heads)
	1-2 Criteria for evaluation	1-2-1 Price
		1-2-2 Delivery performance
		1-2-3 Service
		1-2-4 Flexibility
		1-2-5 Environment, health and safety:
	1-3 Frameworks are used for supplier evaluation	1-3-1ISO 9000 1-3-2Malcolm Baldrige 1-3-3EFQM
	1-4 Systems used for inputting data	1-4-1 Single user system 1-4-2 Internet based mechanized system
	1-5 Items to be evaluated in evaluation system	1-5-1 Quality management and organization policy
		1-5-2 Understanding of customer requirements
		1-5-3 Staff training and motivation
		1-5-4 Management of product and process evolution
		1-5-5: Quality of products received from suppliers
		1-5-6 Process control
		1-5-7 Inspection programs and measurement quality
		1-5-8 Process complaints
		1-5-9 A system for corrective action in areas that are not meeting requirements

Step/practice	Criteria	Sub criteria
2. Supplier qualification/certification	2-1 Monitor supplier certifications and quality system:	2-1-1 ISO 9001-2008 standard
		2-1-2 QS 9000 standard
		2-1-3 ISO 14000 standard:
		2-1-4 AS 9100 standard
		2-1-5 NADCAP / PRI standard
	2-2 Monitor Safety and risk assessment	2-2-1 Establish consistent safety standards
		2-2-2 Monitor supplier risk
		2-2-3 Verify insurance coverage
	2-3 Practices to ensure potential suppliers meet product quality requirements	2-3-1 Communicate product quality requirements
		2-3-2 Collect and review supplier self-assessments
		2-3-3 Confirm sample products' quality levels
3- Reward superior supplier performance and improvement	3-1 Honours outstanding suppliers with mark of excellence and targets for excellence driven quality's supplier award	N/A
	3-2 Publicity and personal ceremonies	
	3-3 Supplier incentives	
	3-4 Eliminating incoming inspection	
4-Supplier Relationship	4-1 Close communication	N/A
	4-2 Long-term relationship	
	4-3 Cross functional team	
	4-4 Shared quality information	
	4-5 Involve suppliers early in product and process development	
5-Measure supplier quality performance	5-1 Quality scorecard	N/A
	5-2 Supplier Performance Monitoring	
	5-3 A system for emerging capability of suppliers	
6-Training and implementation of quality tools and	6-1 A formal process defining the APQP process	N/A
	6-2 A tracking system	

Step/practice	Criteria	Sub criteria
methodologies (FMEA AND APQP, problem solving method, six sigma)	available to monitor the stages of APQP process	
	6-3 Consideration of best practices and lessons learned from similar part DFMEA, FMEA	
	6-4 Utilize a team approach and structured problem solving tools and methods	
	6-5 Continuous improvement program for suppliers	
7- Cost of poor quality	7-1 Proactively works with suppliers to improve their quality for reducing their own COPQ 7-2 Utilize a programme of improvement initiatives such as capacity improvement, scrap reduction and cost control for suppliers	N/A
	7-3 Measuring & tracking cost of poor supplier quality	
8-Commit the necessary resources to supplier quality development	-1 Quality development engineer/ representative of company to supplier's site	N/A
	8-2 Sending instructors and technical consultants to supplier's site	

Table 3.2 List of CTQC for SQD practices

3.4 Measure phase

In this phase, we conduct survey study with SQD experts to determine the weights of criteria identified in Define phase. Process of preparation and conduction a survey for research provided in Figure 3.4

3.4.1 Clarify purpose

Our main target for preparation and conduction of survey is access to opinions of managers and professionals in supply chain to verify our data including criteria / sub criteria of SQD.

Who are the stakeholders?

Quality managers and decision makers in supply chain those are responsible for SQD activities and improvement of supplier quality performance in aerospace, automotive, medical industries. They can be quality managers, supplier development manager or assume any role that involves responsibilities for development of suppliers.

Who is the population of interest?

We collect data from managers, experts that work in jobs related to improvement of supplier quality performance and development of quality system for suppliers in aerospace, automotive sectors, etc. Considering confidentiality of information for companies, we were limited in data collection. Depending on this limitation, our population is defined from interested managers and experts in some companies and also professional internet groups such as linked-in and other professional forums.

What issues need to be explored?

The survey is designed in a 5-point likert scale: Indifferent, Not Important, Somewhat Important, Important, Very Important. Respondents of survey give score to each criterion from these 5 scales. The target is exploring priorities of these criteria for each practice of SQD.

3.4.2 Assess Resources

What external resources and in-house resources can you make use of?

For accessing comprehensive experience and knowledge for our survey subjects, we used international information resources for data collection. (See Figure 3.3). We accessed these resources for survey based on their experience, related job, type of industry etc. There are four professional groups in linked-in that work in supplier quality and supplier quality development. The first group is *Supplier qualification and management group*. This group discusses supplier selection, qualification and performance management for purchasing and sourcing overseas. The mission of the group is to exchange ideas on how to find, qualify, select and manage global suppliers. The next group is *Supplier Quality Assurance in Automotive Industry*. The group includes some managers and experts are working in activities related to supplier quality assurance of automotive industry. Another group is *Supplier Quality Engineers & Supplier Development Engineers*. This group is for supplier quality engineers, supplier development engineers, Supply base engineers, supplier quality managers, and supply chain management professionals. Another group is called *Supplier Quality*, Inc. It reflects discussions related to supplier quality and process consulting. All members of these groups and forums are managers and experts of supplier quality and quality development with several years of related experience. Information related to experts and managers that participated as respondents to survey provided in Table 3.3.

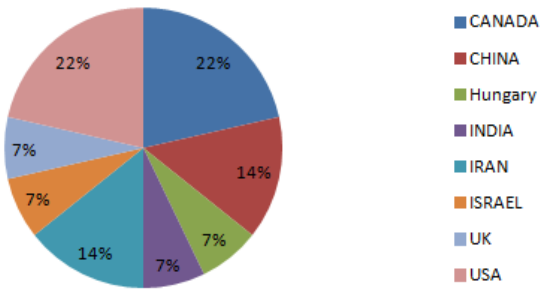

Fig.3.3 Geographic distribution of Data collection resources

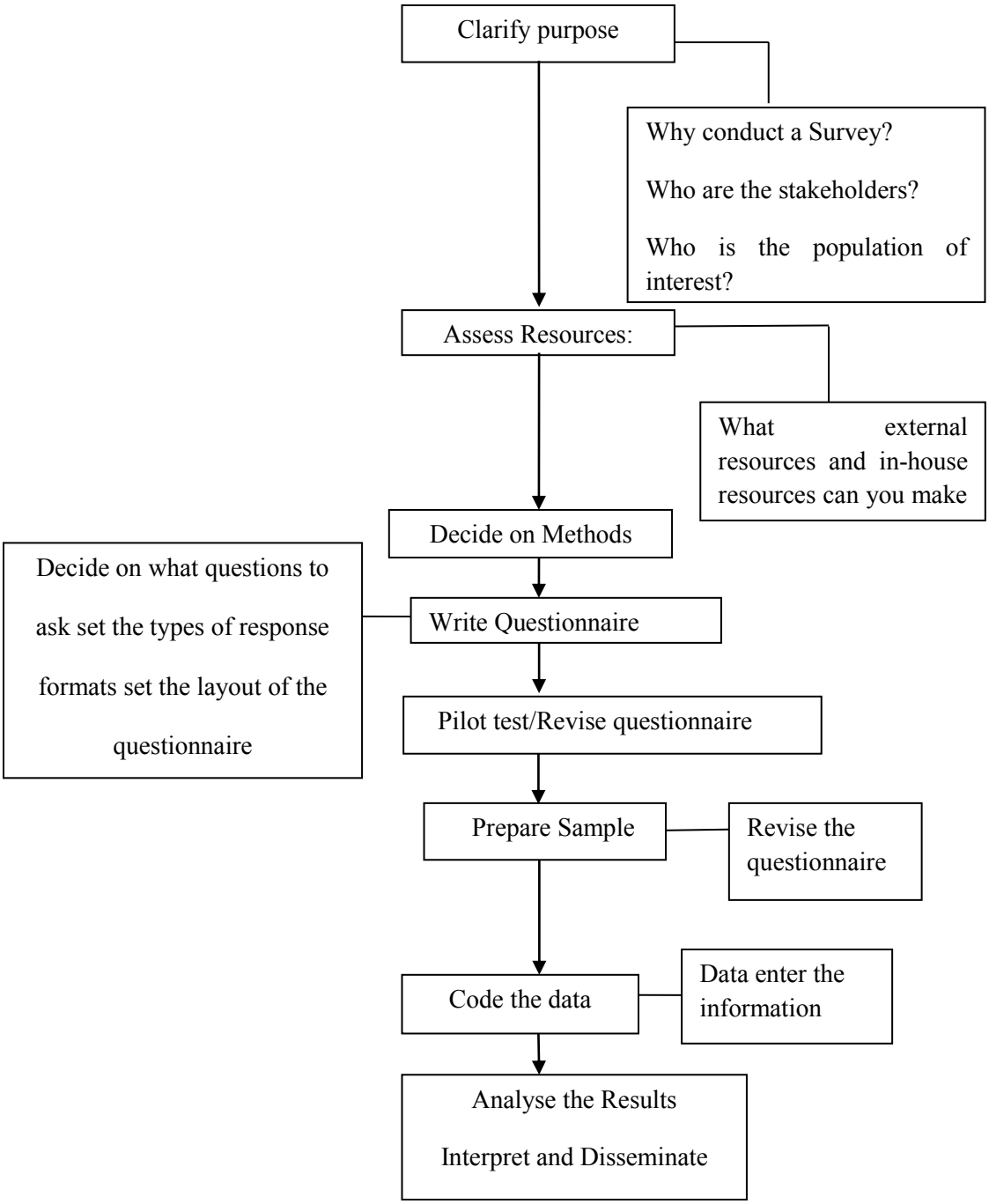

Fig.3.4 Process of preparation and conduction survey

No	Position	Company/industry	Country
1	Procurement Strategy Management	Microsoft/information technology	USA
2	Deputy Manager - Supplier Development	Volvo/automotive	India
3	SPR Manager	Iran Khodro - Renault Group/Automotive	Iran
4	Automotive New Product Development sourcing manager	Autokesher /Automotive	Israel
5	Quality general manager	Iran Khodro - Renault Group/Automotive	Iran
6	Directeur Qualité / Quality Manager	Bell helicopter. Textron/aerospace	Canada
7	Certified Quality Engineer	Applied Medical/Medical	USA
8	Supplier Quality Development manager	Knorr-Bremse/ Automotive	Hungary
9	Senior Consultant	B&G Management Consulting/Management	China
10	Supplier Quality Manager	Kone Plc/Electrical industry	UK
11	Executive/Professional, Corporate Quality Manager	IEC Holden Inc./Machinery	Canada
12	Supplier and Cost Reduction Engineer/ Project Manager	Bloomingdale/ Automotive	USA
13	General Manager	Letussmart/Consumer Electronics	China
14	Consultant in Quality Management, Business Excellence, Learning & Development, Performance Improvement	ASQ, Benchmarking For Excellence/ Management consulting	Canada

Table 3.3 List of respondents to survey

3.4.3 Writing a survey

We used structure of table 3.4 (criteria and sub criteria) for rating each criteria based on the Likert scale. It has 5 choices: from Indifferent to Very Important. (Table 3.4). Likert scale is a method of describing quantitative value to qualitative data, to make it amenable to statistical analysis. A numerical value is assigned to each potential choice and a mean figure for all the responses is computed at the end of the evaluation or survey. Likert scales usually have five potential choices (Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree).The final average score represents overall level of accomplishment or attitude toward the subject matter. For ensuring the suitability of format of questionnaires, several format of questionnaires related to supplier quality were reviewed. The final survey and cover letter is provided in appendix.

Indifference	This criteria / sub-criteria based on the experience of our company not used in this process
Not Important	This criteria / sub-criteria based on the experience of our company NOT IMPORTANT in this process
Somewhat Important	This criteria / sub-criteria based on the experience of our company SOMEWHAT IMPORTANT in this process
Important	This criteria / sub-criteria based on the experience of our company IMPORTANT in this process
Very important	This criteria / sub-criteria based on the experience of our company VERY IMPORTANT in this process

Table 3.4 Definitions of survey scales

3.4.4 Pilot test/Revise questionnaire/ Prepare Sample

The contents of survey before the last revision were discussed and modified per some members (experts and managers) comments. They accepted the current version of survey format with some small modifications.

3.4.5 Collect data

In the final step of data collection, survey was sent by the email to the representatives of aerospace, automotive, medical, machinery companies. Format of survey and cover letter provided in appendix D. Based on their interest and mutual agreement. A brief description of criteria and a cover letter joint with survey sent to emails of these representatives. List of main steps/practices and related criteria provided in Table 3.5.

No	Criteria
	Supplier quality measurement
1	**Supplier quality Evaluation**
1-1	• Methods used for supplier evaluation
1-1-1	✓ Cost Benefit Analysis
1-1-2	✓ Data Analysis (Monitoring growth using historical data)
1-1-3	✓ Expert Ratings (Buyers, Departmental Heads)
1-2	✓ Criteria for evaluating suppliers
1-2-1	✓ Price: The amount paid by the enterprise to buy goods from its suppliers
1-2-2	✓ Delivery performance: How well a supplier succeeds in delivering goods according to schedule?
1-2-3	✓ Service: The after-sales service and support provided by a supplier.
1-2-4	✓ Flexibility: The ability of a supplier to accommodate changes in the enterprise's production plans
1-2-5	✓ Environment, health and safety
1-3	• Frameworks used for supplier evaluation
1-3-1	✓ ISO 9000
1-3-2	✓ Malcolm Baldrige
1-3-3	✓ EFQM
1-4	• System used for inputting data
1-4-1	✓ Not mechanized system

No	Criteria
1-4-2	✓ A web based evaluation system
1-5	• Items to be evaluated
1-5-1	✓ Quality management and organization policy
1-5-2	✓ Understanding of customer requirements
1-5-3	✓ Staff training and motivation
1-5-4	✓ Management of product and process evolution.
1-5-5	✓ Quality of products received from suppliers
1-5-6	✓ Process control
1-5-7	✓ Inspection programs and measurement quality
1-5-8	✓ Process complaints
1-5-9	✓ A system for corrective action in areas that are not meeting requirements
2	**Supplier qualification/certification**
2-1	• Monitor supplier certifications and quality system
2-1-1	✓ ISO 9001
2-1-2	✓ Qs 9000
2-1-3	✓ ISO 14000
2-1-4	✓ AS 9100
2-1-5	✓ NADCAP / PRI
2-2	• Monitor Safety and risk assessment
2-2-1	✓ Establish consistent safety standards
2-2-2	✓ Monitor supplier risk
2-2-3	✓ Verify insurance coverage
2-3	• Practices to ensure potential suppliers meet product quality requirements
2-3-1	✓ Communicate product quality
2-3-2	✓ requirements ✓ Collect and review supplier self-assessments
2-3-3	✓ Confirm sample products' quality levels
2-3 3-1	• Conformance to specifications
2-3 3-2	✓ Process capability

No	Criteria
2-3 3-3	✓ Product reliability
3	**Reward superior supplier performance and improvement**
3-1	• Honours outstanding suppliers with mark of excellence and targets for excellence driven quality‘s supplier award
3-2	• Publicity and personal ceremonies
3-3	• Supplier incentives
3-4	• Eliminate receiving inspection on supplier’s material
4	**Supplier relationship management (SRM)**
4-1	• Face to face Communication
4-2	• Long-term relationship
4-3	• Cross functional team
4-4	• Shared quality information
4-5	• Involve suppliers early in product and process development
5	**Measure supplier quality performance**
5-1	• Quality scorecard
5-2	• Supplier Performance Monitoring
5-3	• A system for emerging capability of suppliers
6	**Training and implementation of quality tools and methodologies (FMEA AND APQP, Problem solving method, six sigma)**
6-1	• A formal process defining the APQP process
6-2	• A tracking system available to monitor the stages of APQP process
6-3	• Consideration of best practices and lessons learned from similar part DFMEA,FMEA
6-4	• Utilize a team approach and structured problem solving tools and methodologies such as 5-Why, Fault Tree/Fishbone Diagram, six sigma, lean , kaizen
6-5	• Continuous improvement program for suppliers to ensure improvements to quality, service, productivity
7	**Cost of poor quality**
7-1	• Proactively work with suppliers to improve their quality for reducing their own COPQ
7-2	• Utilize a programme of improvement initiatives such as capacity improvement, scrap reduction and cost control for suppliers
7-3	• Measuring & tracking cost of poor quality for suppliers

No	Criteria
8	**Commit the necessary resources to supplier quality development**
8-1	• Quality development engineer/ representative t of company in suppliers site
8-2	• Sending instructors and technical consultants to supplier's site

Table 3.5 list of steps/practices and criteria

3.5 Analysis phase

In this phase, we will analyse criteria results using Kano model. Suppliers are customers of buyers in SQDPs. Kano analysis of SQD criteria helps us to know which groups of criteria related to which needs of supplier based on the level of customer needs in Kano diagram. (Basic, performance and delight needs). To analyze the relationship between various criteria, we will use Interpretive Structural Modeling (ISM).

3.5.1 Kano model analysis

History of Kano model can be dated back to 1984, when Dr. Kano developed a two dimensional model of the relationship between performance (expected as performance measures) on the one hand, and value (expected as customer satisfaction) on the other. Kano Model Analysis is a useful technique for deciding which features we want to include in a product or service. Customer needs in Kano model can be classified as follows:

Basic attributes: Basic features are basic to the product and customers just expect them to work. These features are often taken for granted so customers rarely look for them. It is difficult to actively use basic attributes as a competitive advantage, but in

case of failure to comply with them, it will put the company at a severe competitive disadvantage.

Performance attributes: Performance attributes are features where there is a direct correlation between the degree of achievement and customer satisfaction.

Delight attributes: Delight attributes represent the unexpected – when you deliver the customer by over-delivering or doing something out of the ordinary. When a customer is faced with a delight attribute it completely takes them by surprise, often resulting in over-excitement with the product, making it an effective engine for word-of-mouth. (See Figure 3.5)

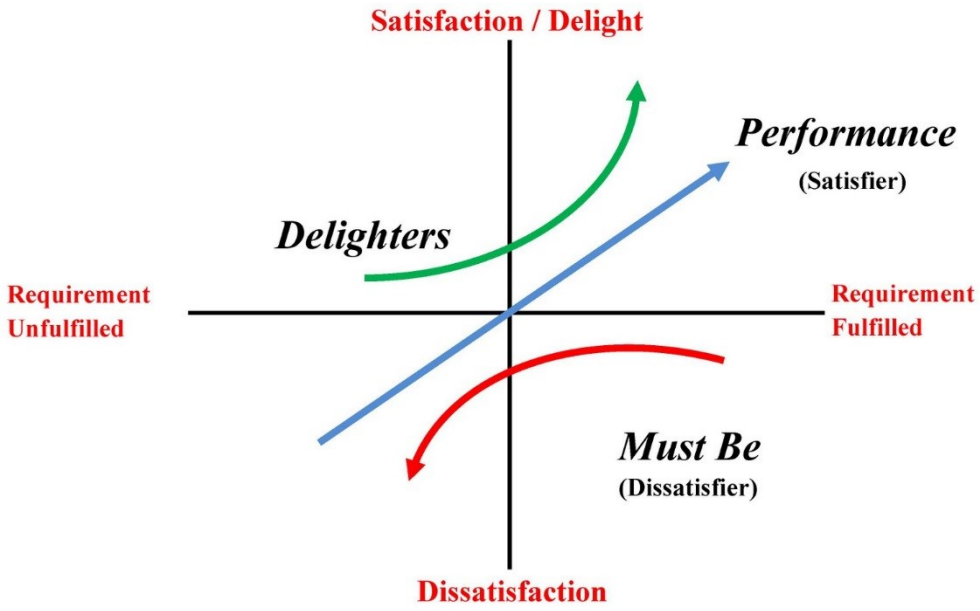

Fig.3.5 Diagram of Kano model

According to descriptions of needs in Kano model; we have following specifications for basic needs:

- Customers expect them to work
- Taken for granted so customers rarely look for them
- There is not a direct relationship between the degree of achievement and customer's satisfaction
- When you leave out a basic attribute, the entire customer experience is broken
- They don't have competitive advantage, but in case of failure to comply with them, the company will be at a severe competitive disadvantage

We relate very important (basic needs) criteria in our Likert scale to this category. Suppliers are evaluated with traditional criteria like price, delivery and service with an ISO 9000 framework, level of quality in product and process, corrective actions, certification, involving suppliers in product and process development, feedback of training, quality tools and tracking of cost reduction practices. This group of criteria related to minimum levels of development efforts for suppliers.

Performance needs have following characteristics:

- Direct correlation between the degree of achievement and customer satisfaction
- Consequence companies tend to compete on these attributes
- The product Differentiates more than competitors on certain performance attributes

Important criteria have more competitive capabilities and satisfaction abilities. They refer to known methods (cost-benefit- expert rating) for supplier evaluation. Suppliers are evaluated based on their flexibility. Buyers use a mechanized internet base system for supplier evaluation. Items referring to motivation and training, management of

process and product evolution and process complaints are evaluated. For certification, except of ISO 9001, many factors like risk, safety, insurance and sampling from production and also self-assessment would be considered. Supplier incentives and elimination of inspections on the material give motivation to suppliers. There are many methods for deepening effective supplier – buyer relationship including: face to face communication, cross functional teams and sharing quality information. For quality performance measurement there are well discipline system scorecard and system for emerging capability. APQP and team approach problem solving and continuous improvement can be assessed for development of suppliers. Company proactively work with suppliers for reducing the cost of quality and implement programs for cost control and reduction. As we can see these criteria give a comprehensive SQD that can be consider such as competitive distinction for each company in SQDPs.

Delighters have following specifications:

- They are unexpected delivery to the customer by over-delivering or doing something out of the ordinary
- Never expected by the customer
- Resulting in over-excitement with the product

The somewhat important criteria can be assigned to delighters. In Somewhat important criteria, company evaluates supplier based on the history of performance not by only the fixed and predefined criteria. Environment can be also considered in evaluation such as certification with ISO 14000. Superior performance reward with excellence award that is compliant with efforts of leading companies (section 2 –literature

review) is another unexpected thing. Rewarding supplier with publicity and personnel ceremonies that motivates suppliers can also be used. Companies also allocate technical resources to help suppliers.

3.5.2 Analysing the criteria relationships using ISM

The concept of Interpretive Structural Modeling (ISM) was primary introduced by J. Warfield in 1973. Warfield proposed ISM to evaluate the complex socioeconomic systems. ISM is interpretive as it is based on group's judgment and decision whether and how the system's elements are linked. It is structural as constructed on the relationship's foundation and final structure is exploited from complex set of system's variables. The structural self-interaction matrix represents these directional relationships among variables using following four symbols:

- V: Criterion *i* will assist to reach Criterion *j*
- A: Criterion *j* will assist to reach Criterion *i*
- X: Criterion *i* and *j* will assist to reach each other
- O: Criterion *j* and *i* are unrelated (Source: Astin ,2007)

According to Govindan K. *et al.* (2009) the various steps involved in the ISM methodology are:

- ✓ Step 1: Variables considered for the system under consideration are listed.
- ✓ Step 2: From the variables identified in Step 1, a contextual relationship is established among variables with respect to which pairs of variables would be examined.

- ✓ Step 3: A structural self-interaction matrix (SSIM) is developed for variables, which indicates pair-wise relationships among variables of the system under consideration.
- ✓ Step 4: Reachability matrix is developed from the SSIM and the matrix is checked for transitivity. The transitivity of the contextual relation is a basic assumption made in ISM. It states that if a variable A is related to B and B is related to C, then A is necessarily related to C.
- ✓ Step 5: The reachability matrix obtained in Step 4 is partitioned into different levels.
- ✓ Step 6: Based on the relationships given above in the reachability matrix, a directed graph is drawn and the transitive links are removed.
- ✓ Step 7: The resultant digraph is converted into an ISM, by replacing variable nodes with statements.
- ✓ Step 8: The ISM model developed in Step 7 is reviewed to check for conceptual Inconsistency and necessary modifications are made.

Ism has been used in several researches of supplier development, supply chain, knowledge management:

In supplier development and supply chain: Govindan *et al.* (2009) used ISM for to identify and rank the criteria of supplier development. They analyzed the interactions among the criteria such as competitive pressure, evaluation and certification system, incentives, supplier development programs, inter-organizational communication, buyer-supplier relationship, supplier commitment, supplier performance, asset specificity, joint action, trust, long-term strategic Goals, top management support,

purchasing performance, and supplier strategic objective. Pramod and. Banwet, (2010) used ISM to identify the driver-dependent relationships among various inhibitors of telecom service supply chain and categorize them into four clusters based on their driving powers and dependence powers. They proposed their research for identification of inhibitors and awareness of their driving power and dependence power helps the managers to focus on them and prioritize them as strategic issues.

In other areas: Salemabad, *et al.* (2010) proposed ISM to identify critical success factors of BPR (business process reengineering) projects in banking sector. Hen, *et al.* (2010) proposed an ISM method for developing new design approach for designing consumer preference-based products. Singh, (2008) and Tabrizi (2010) used ISM model to evolve mutual relationships among knowledge management barriers and to establish a structure of criteria for measuring KM results.

ISM methodology suggests the use of expert opinions based on various management techniques such as brain storming, nominal technique, etc. in developing the contextual relationship among the variables. Information source including: experts and expert supplier quality groups help us in identifying the contextual relationship among the interactions of SQD criteria/sub criteria.

Three groups of criteria/sub criteria (Very Important: basic, important: performance and somewhat important: delighters) analysed with ISM model for finding interactions and relationships among the each criteria.

3.5.2.1 MICMAC Analysis

The MICMAC analysis is an effective method for comparing the hierarchy of variables in the various classifications (direct, indirect and potential). It enables not

only to confirm the importance of certain variables but also to uncover certain variables which, because of their indirect actions, play an important role. This analyse consists in identifying the key variables, that is to say, those essential to the system's development, first by using direct classification (easy to set up), then through indirect classification (e.g. MICMAC for Impact Matrix Cross- Reference Multiplication Applied to a Classification). This indirect classification is obtained after increasing the power of the matrix. The driving power for each criterion is the total number of criteria (including itself), which it may help achieve. Dependence is the total number of criteria (including itself), which may help achieve it. analysis of interactions , relationships and dependencies and independencies of each criterion is useful for determination of their weights and values for evaluation and selection of SQDPs in improve phases with a multi criteria decision analysis method. We use a MICMAC analysis matrix. The objective of the MICMAC analysis is to analyze the driver power and the dependence power of criteria. Criteria are classified into four clusters the first cluster consists of the autonomous criteria that have weak driver power and weak dependence. These criteria are relatively disconnected from the system, with which they have only few links. Second cluster consists of the dependent criteria that have weak driver power but strong dependence. Third cluster has the linkage criteria that have strong driving power and also strong dependence. These criteria are unstable in the fact that any action on these criteria will have an effect on others and also a feedback on themselves. Fourth cluster includes the independent criteria that have strong driving power but weak dependence. It is observed that a variable with a very

strong driving power called the key variables falls into the category of independent or linkage criteria.

3.6 Improve phase

In Improve phase, we use multi-criteria decision making for evaluating and selecting SQDPs.

3.6.1 Multi-criteria Analysis (MCA) framework for evaluation and selection of SQDPs

Multi-criteria decision making usually involves evaluating a set of alternatives against a list of predefined criteria by a committee of decision makers. Decision making about proposals and selection of programs, especially when we are doing comparison and evaluation efforts, should normally follow the sequence below:

- Identifying objectives
- Identifying options for achieving the objectives
- Identifying the criteria to be used to compare the options
- Analysis of the options
- Making choices
- Feedback

Taking good decisions need clear objectives. These should be specific, measurable, agreed, realistic and time-dependent. The next stage is to decide on how to compare different options' contribution to meeting the objectives. This requires selection of appropriate criteria to reflect performance in meeting the objectives. Each criterion

must be measurable, in the sense that it must be possible to assess. MCDA techniques can be used to identify a single most preferred option, to rank options, to short-list a limited number of options for subsequent detailed appraisal, or simply to distinguish acceptable from unacceptable possibilities. Multi criteria analysis techniques commonly apply numerical analysis to a performance matrix in two stages:

1. Scoring: the expected consequences of each option are assigned a numerical Score on strength of preference scale for each option for each criterion. Most preferred options score higher on the scale, and less preferred options score lower
2. Weighting: numerical weights are assigned to define, for each criterion, the relative valuations of a shift between the top and bottom of the chosen scale.(2009, Multi-criteria analysis: Manual)

Frequently used techniques in MCA model for supplier selection, evaluation and development are provided in Table 3.6.

Technique	Subject	Reference
Fuzzy analytic hierarchy process	Supplier selection	Kahraman *et al.* (2003)
Fuzzy extended analytic hierarchy process (FEAHP)		Chan and Kumar (2005)
A weighted linear program		Lung (2007)
Analytical hierarchy process and non-linear integer and multi-objective programming		Kokangul and Susuz (2008)
Integration of the analytic hierarchy process (AHP) and a multi-objective possibility linear Programming(MOPLP)	Supplier evaluation	Dogaan and Ozgen (2007)

Technique	Subject	Reference
Fuzzy analytic network		Buyukozkan and Cifci (2011)
(TOPSIS)		Zaeri1 *et al.(*2011)
Interpretative structural modeling	Supplier development	Govindan *et al*. (2009)
Weighting AHP method and DEA	Ranking suppliers	Bronja (2011)
TOPSIS	A wide range of application areas and industrial sectors	Behzadian *et al.(* 2012)

Table 3.6 MCA methods used in supply chain management

3.6.2 A multi criteria analysis for evaluation and selection of SQDPs

The MCA technique we are applying for SQDPs evaluation is called TOPSIS (Technique for Order preference BY Similarity to Ideal Situation).

According the researches, TOPSIS is prevalent method used in multi criteria analysis (Chen and Hwang 1992; Hwang and Yoon, 1981). In TOPSIS, the basic principle is that the chosen alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution. The TOPSIS procedure consists of the following steps:

(1) Calculate the normalized decision matrix. The normalized value r_{ij} is calculated as:

$$r_{ij} - f_{ij} \Big/ \sqrt{\sum_{j-1}^{J} f_{ij}^2},$$
$$j - 1, \ldots, J; \quad i - 1, \ldots, n.$$

(2) Calculate the weighted normalized decision matrix. The weighted normalized value v_{ij} is calculated as:

$$v_{ij} - w_i r_{ij}, \quad j - 1, \ldots, J; \;\; i - 1, \ldots, n,$$

Where w_i is the weight of the $^i th$ attribute or criterion, and $\sum_{i-1}^{n} w_i - 1$ Determine the ideal and negative-ideal solution:

$$A^* - \{v_1^*, \ldots, v_n^*\}$$
$$- \{(\max_j v_{ij} | i \in I'), (\min_j v_{ij} | i \in I'')\},$$

$$A \; - \{v_1, \ldots, v_n\}$$
$$- \{(\min_i v_{ij} | i \in I'), (\max_i v_{ij} | i \in I'')\},$$

Where I' is associated with benefit criteria, and I'' is associated with cost criteria.

(3) Calculate the separation measures, using the n-dimensional Euclidean distance. The separation of each alternative from the ideal solution is given as:

$$D_j^* - \sqrt{\sum_{i-1}^{n} (v_{ij} - v_i^*)^2}, \quad j - 1, \ldots, J.$$

Similarly, the separation from the negative-ideal solution is given as:

$$D_j \; - \sqrt{\sum_{i-1}^{n} (v_{ij} - v_i \;)^2}, \quad j - 1, \ldots, J.$$

(4) Calculate the relative closeness to the ideal solution. The relative closeness of the alternative aj with respect to A^* is defined as:

$$C_j^* - D_j \, / (D_j^* + D_j \,), \quad j - 1, \ldots, J.$$

(5) Rank the preference order.

In step 4, the sentences ‘‘calculate the relative closeness to the ideal solution. Triantaphyllou (2000) states that ‘‘the best (optimal) alternative can now be decided according to the preference rank order of $C^*_{j.}$ Therefore, the best alternative is the one that has the shortest distance to the ideal solution. The previous definition can also be used to demonstrate that any alternative which has the shortest distance from the ideal solution is also guaranteed to have the longest distance from the negative-ideal solution. The chosen alternative has the maximum value of C^*_j, defined in Eq. ideal solution with the intention to minimize the distance from the ideal solution and to maximize the distance from the negative-ideal solution. (Opricovic and Tzeng ,2002)

TOPSIS has been used in following researches related to MCDA and supply chain:

Kahraman *et al.* 2006 proposed an integrated approach based on fuzzy heuristic MAUF and hierarchical fuzzy TOPSIS method to improve the quality and effectiveness of decision-making in new product introduction.

Park *et al.*, 2011 developed an integrated fuzzy (TOPSIS) method to improve the quality of decision-making for ranking alternatives.

Renato *et al.,* 2011 revised TOPSIS and fuzzy TOPSIS and developed a fuzzy TOPSIS for group decision making to tackle multi criteria decision problems affected by uncertainty and taking into account the preferences of the decision makers

Mehrparvar *et al.,* 2012 applied the SERVQUAL scale to measure ISQ in service units and prioritized service quality dimensions by using the TOPSIS technique.

Rodriguez (2012) proposed a modification to a method for multi criteria decision analysis as a support in evaluation. The method is based on a combination of fuzzy Analytic Hierarchy Process (AHP) and (TOPSIS).

3.7 Control phase

The main target of control phase is standardization of improve results phase and preparation of a logical procedure for implementation of solutions. Following steps provide standard process for evaluation and selection of SQDPs:

1. Define targets for SQD efforts: according to the research, companies have following targets for implementation of SQD efforts:

- ✓ Create and maintain a network of competent suppliers
- ✓ Appraise performance
- ✓ Motivate suppliers to improve their performance

2. Recognition of two type practices in SQD: Companies have two types of practices based on their targets*: 1-quality measurement* for systematically identifying opportunities to improve supplier performance 2-*quality development*: continuous improvement activities in the suppliers' production processes including training and implementation of quality tools.

3. Identification scale of SQDP for satisfaction of suppliers: company must identify for satisfaction of which categories of suppliers needs (basic, performance, delighters) they want to implement SQDPs.

4. Selection of appropriate criteria for evaluation of SQDPs (very important for basic needs, important for performance needs and somewhat important for delighters)

5. Evaluate SQDPs according to the selected criteria.

6. Select the high scores criteria. (See Figure 3.6)

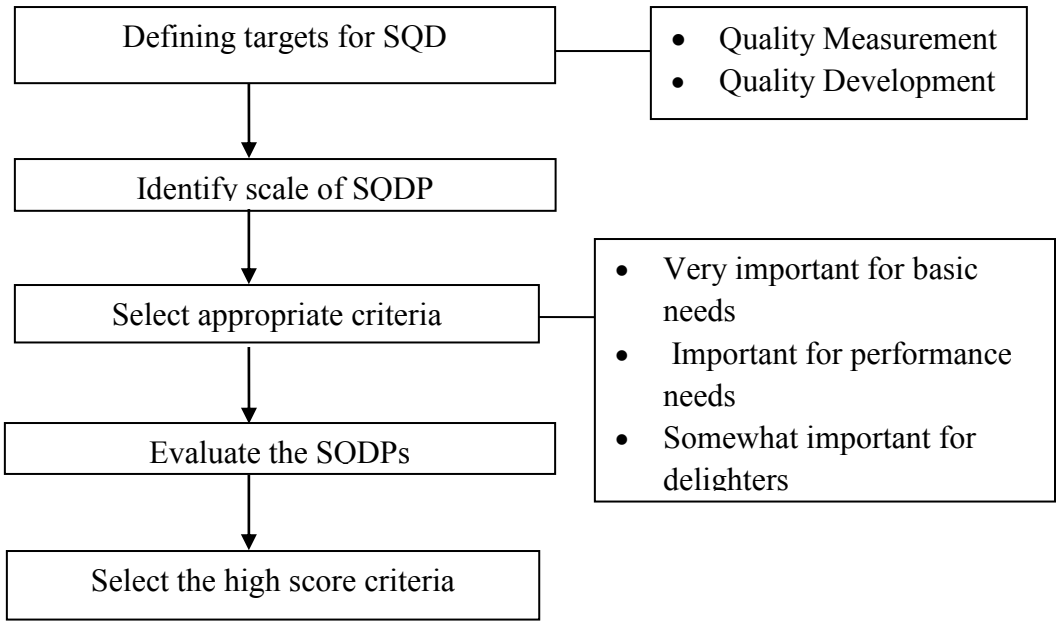

Fig. 3.6 Process of evaluation and selection of SQDPs for control phase

We recommend these steps to be incorporated within timely Audits so that the targets and the criteria can be updated with respect to the change in business market, organization requirements, or supplier conditions.

Chapter 4

Practical Application

4.1 Survey results

We sorted three different ranges of responses in Table 4.1 based on the majority rule (Selection of answer for each question depending on they were selected by the majority of respondents) we focused on the three categories of answers, including: Very important, important, and somewhat important. These three categories present minimum to maximum requirements of SQD for suppliers. These three groups of criteria will use for analyse and evaluation of all levels of supplier quality needs in the further steps of DMAIC roadmap.

No	Criteria/ sub criteria	Majority
1-1-1	Evaluating supplier with Cost Benefit Analysis method	*Important*
1-1-2	Evaluating supplier with Data Analysis (Monitoring growth using historical data)	*Somewhat Important*
1-1-3	Evaluating supplier with Expert Ratings (Buyers, Departmental Heads)	*Important*
1-2-1	Using Price as a criteria for supplier evaluation	*Very Important*
1-2-3	Using Service as a criteria for supplier evaluation	*Very Important*
1-2-2	Using Delivery performance as a criteria for supplier evaluation	*Very Important*
1-2-4	Evaluate supplier with Flexibility criteria	*Important*
1-2-5	Environment, health and safety	*Somewhat Important*
1-3-1	ISO 9000 Framework for supplier evaluation	*Very Important*
1-4-2	Using an internet based mechanized system for inputting data of supplier evaluation	*Important*
1-5-1	Evaluating Quality management and organization policy	*Very Important*
1-5-2	Evaluating Understanding of customer requirements	*Very Important*

No	Criteria/ sub criteria	Majority
1-5-3	Evaluating Staff training and motivation of suppliers	*Important*
1-5-4	Evaluating Management of product and process evolution.	*Important*
1-5-5	Evaluating Quality of products received from suppliers	*Very Important*
1-5-6	Evaluating Process control	*Very Important*
1-5-7	Evaluating Inspection programs and measurement quality	*Very Important*
1-5-8	Evaluating Process complaints	*Important*
1-5-9	Evaluating A system for corrective action in areas that are not meeting requirements	*Very Important*
2-1-1	Monitoring ISO 9001 for certification	*Important*
2-1-3	Monitoring ISO 14000 for certification	*Somewhat Important*
2-2-1	Establish consistent safety standards for certification	*Important*
2-2-2	Monitor supplier risk for certification	*Important*
2-2-3	Certify suppliers with Verify insurance coverage	*Important*
2-3-1	Communicate product quality requirements	*Very Important*
2-3-2	Collect and review supplier self-assessments for certification	*Important*
2-3-3-1	Confirm sample products' quality levels-Conformance to specifications for certification	*Important*
2-3-3-2	Confirm sample products' quality levels-Process capability for certification	*Important*
2-3-3-3	Confirm sample products' quality levels-product reliability for certification	*Important*
3-1	Targets for excellence driven quality's supplier award for Reward superior supplier performance	*Somewhat Important*
3-2	Publicity and personal ceremonies for Reward superior supplier performance	*Somewhat Important*
3-3	Supplier incentives for Reward superior supplier performance	*Important*
3-4	Eliminate receiving inspection on supplier's material for Reward superior supplier performance	*Important*
4-1	Face to face Communication	*Important*
4-2	Long-term relationship	*Important*
4-3	Cross functional team	*Important*
4-4	Shared quality information	*Important*
4-5	Involve suppliers early in product and process development	*Very Important*
5-1	Quality scorecard	*Important*
5-2	Supplier Performance Monitoring	*Very Important*
5-3	A system for emerging capability of suppliers	*Important*
6-1	Implementing quality tools -a formal process of APQP	*Important*

No	Criteria/ sub criteria	Majority
6-2	Implementing quality tools-a tracking system available to monitor the stages of APQP process	*Important*
6-3	Consideration of best practices and lessons learned from similar part DFMEA,FMEA in Training and implementation of quality tools	*Very Important*
6-4	Utilize a team approach and structured problem solving tools	*Important*
6-5	Continuous improvement program for suppliers to ensure improvements to quality, service, productivity	*Important*
7-1	Proactively work with suppliers to improve their quality for reducing COPQ	*Important*
7-2	Utilize a programmed of improvement initiatives such as capacity improvement, scrap reduction and cost control for suppliers	*Important*
7-3	Measuring & tracking cost of poor quality for suppliers	*Very Important*
8-1	Commit the necessary resources with sending quality development engineer/ representative of company to suppliers site	*Somewhat Important*

Table 4.1 Results of Survey

Table 4.2 presents responses in three categories. First group of criteria is the important category and is related to supplier quality evaluation. Suppliers are evaluated on the basis of economic criteria applied to elements such as: development of their processes/production, minimum process complaints, training and motivation. A web based system is used for inputting data for SQE. For certification of suppliers, ISO standard, safety, risk, insurance, data of self-assessment and sampling for checking conformance with specifications capability analysis and reliability is considered. Based on the periodic measurement of performance with scorecard and capability, they should be rewarded with incentives and/or elimination of inspection on their material and products. Problem solving and APQP system and continuous improvement practices are other important sub-criteria for quality tools implementation. Cost reduction and

measuring COPQ are, Face to face commutation, Cross functional teams in a long terms relationship and sharing information are considered as important sub-criteria.

In category of very important criteria/ sub criteria, buyer consider using a standard framework in supplier evaluation and focuses on elements like inspection and measurement, Quality Management System(QMS),customer requirements, process and product quality and corrective system. Supplier are evaluated with their performance on price, service and delivery (basic requirements), supplier certified based on the product quality and performance monitoring. According to the measurement of performance, buyer implements practices like the training, quality tools and COPQ. Feedback and learning from implementation of Quality tools such as FMEA, DFMEA are targets of buyers from these activities. In this group of SQD criteria, for supplier relationship, buyer involves supplier in development of production.

In category of somewhat important, suppliers are evaluated through data analysis (history of performance). Environment and safety, Certification such as ISO 14000 (environment –health factors) are considered. Excellence quality award and publicity and personnel ceremonies and committing resources like sending experts for helping the suppliers are most efforts of buyers for rewarding the supplier good performance.

Cross functional teams	Important	SR
Shared quality information		
Face to face commutation		
Long term relationship		
Involve suppliers early in product and process development	Very important	
Method for evaluation	Important	SQE
Evaluating supplier with Expert Ratings (Buyers, Departmental Heads)		

Cost Benefit Analysis method		
Criteria for evaluation		
Evaluate supplier with Flexibility criteria		
System for storing data		
An internet based mechanized system for inputting data of supplier evaluation		
Evaluation items		
Evaluating Staff training and motivation of suppliers		
Evaluating Management of product and process evolution.		
Evaluating Process complaints		
Criteria for evaluation	Very important	
Using Price as a criteria for supplier evaluation		
Using Service as a criteria for supplier evaluation		
Using Delivery performance as a criteria for supplier evaluation		
Frame work for evaluation		
ISO 9000 Framework for supplier evaluation		
Evaluation items		
Evaluating Quality management and organization policy		
Evaluating Understanding of customer requirements		
Quality of products received from suppliers		
Process control		
Inspection programs and measurement quality		
Corrective action		
Method for evaluation	Somewhat important	
Evaluating supplier with Data Analysis (Monitoring growth using historical data)		
Evaluation items		
Environment, health and safety		
Monitor supplier certification	Important	SQC
Monitoring ISO 9001 for certification		
Monitor Safety and risk assessment		
Consistent safety standards for certification		
Practices to ensure potential suppliers meet product quality requirements		
Monitor supplier risk for certification		

Certify suppliers with Verify insurance coverage		
Collect and review supplier self-assessments for certification		
Practices to ensure potential suppliers meet product quality requirements	Very important	
Communicate product quality requirements		
Monitor Safety and risk assessment	Somewhat important	
Monitoring ISO 14000 for certification		
Quality scorecard	Important	SQPM
A system for emerging capability of suppliers		
Supplier Performance Monitoring	very important	
Supplier incentives for Reward superior supplier performance	Important	RS
Eliminate receiving inspection on supplier's material for Reward superior supplier performance		
Targets for excellence driven quality's supplier award for Reward superior supplier performance	Somewhat Important	
Publicity and personal ceremonies for Reward superior supplier performance		
Implementing quality tools -a formal process of APQP	Important	TIQ
Implementing quality tools-a tracking system available to monitor the stages of APQP process		
Utilize a team approach and structured problem solving tools		
Continuous improvement program for suppliers to ensure improvements to quality, service, productivity		

Consideration of best practices and lessons learned from similar part DFMEA,FMEA in Training and implementation of quality tools	very important	
Proactively work with suppliers to improve their quality for reducing COPQ	Important	COPQ
Utilize a programme of improvement initiatives such as capacity improvement		
Measuring & tracking cost of poor quality for suppliers	very important	
Commit the necessary resources with sending quality development engineer/ representative of company	Somewhat important	CR

Table 4.2 three categories of survey responses

4.2 Kano's Model results

The results of Kano model for the various rated criteria obtained from survey study is provided in Figure 4.1

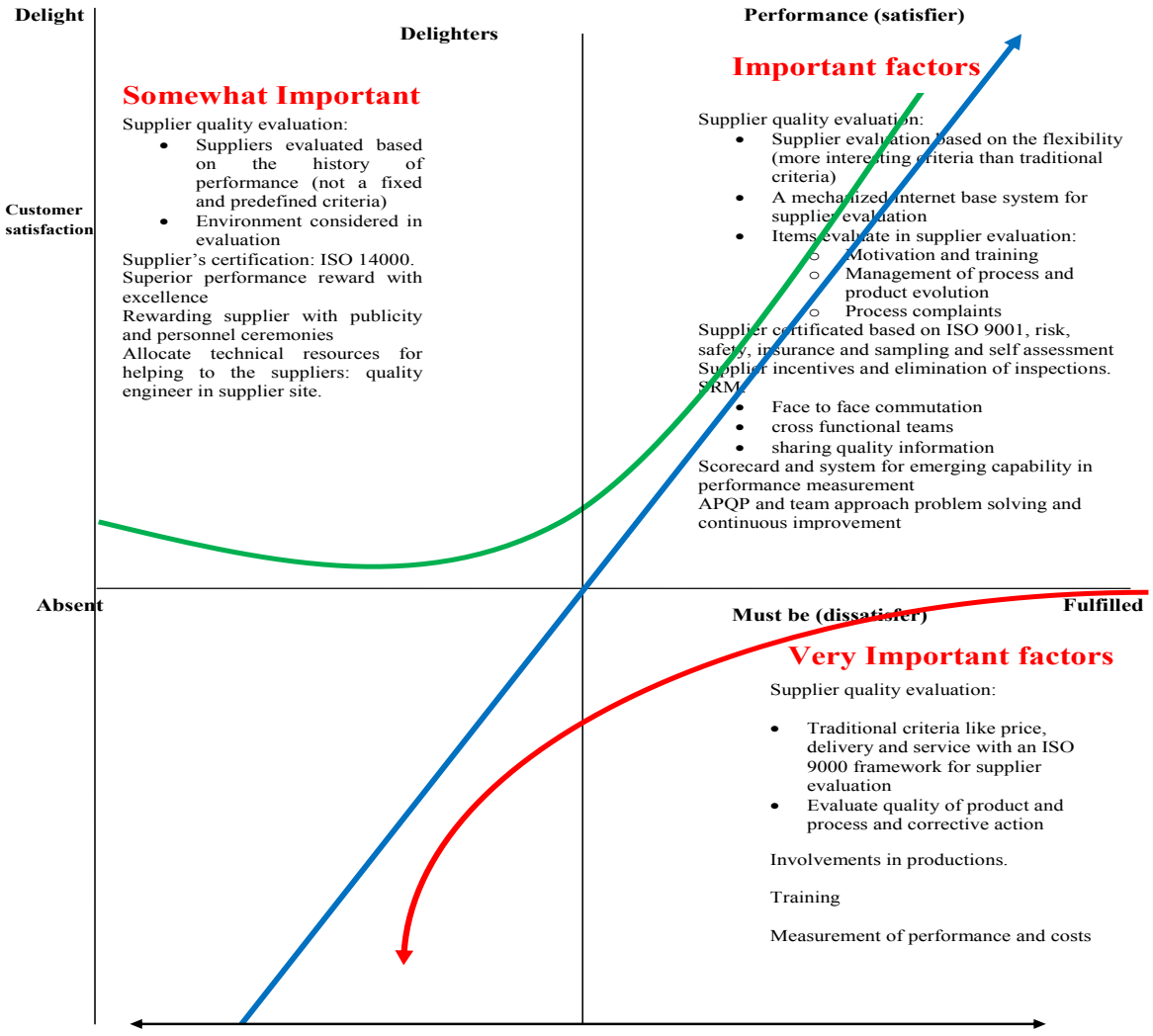

Fig.4.1 Kano analysis for SQD criteria

4.3 ISM results

For each of three categories (Very Important, Important and, Somewhat Important), we applied the ISM to investigate the interrelationships. Structural self-interaction matrix (SSIM) was made for the three criteria. (Tables 4.3-4.5) with the help of brain storming and discussions with the professional groups

No	Criteria/sub-criteria	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	1-2-1	O	O	O	O	V	O	O	O	O	O	O	X	O	O	
2	1-2-2	O	O	O	O	V	O	O	O	O	O	O	X	O		
3	1-2-3	O	O	O	O	V	O	O	O	O	O	O	X			
4	1-3-1	O	O	O	O	O	V	V	V	V	V	V				
5	1-5-1	O	O	O	O	V	X	X	X	X	X					
6	1-5-2	O	O	O	O	V	X	X	X	X						
7	1-5-5	O	O	O	O	V	X	X	X							
8	1-5-6	O	O	O	O	V	X	X								
9	1-5-7	O	O	O	O	V	X									
10	1-5-9	O	O	O	O	V										
11	2-3-1	O	V	O	V											
12	4-5	O	O	X												
13	5-2	V	V													
14	6-3	O														
15	7-3															

Table 4.3 Structural self-interaction matrix for very important

No	criteria	6	5	4	3	2	1
1	1-1-2	V	V	V	X	X	
2	1-2-5	O	O	O	V		
3	2-1-3	O	O	X			
4	3-1	X	X				
5	3-2	O					
6	8-1						

Table 4.4 Structural self-interaction matrix for somewhat important criteria

No	Criteria/ Sub-criteria	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	1-1-1	O	O	O	O	O	O	O	O	O	A	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	X	X	X	
2	1-1-3	O	O	O	O	O	O	O	O	O	A	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	X	X		
3	1-2-4	O	O	O	O	O	O	O	O	O	A	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	X			
4	1-4-2	O	O	O	O	O	O	O	O	O	A	O	O	O	O	O	O	O	O	O	O	O	X	X	X	X				
5	1-5-3	O	O	O	O	O	O	O	O	O	A	O	O	O	O	O	O	O	O	O	O	O	X	X	X					
6	1-5-4	O	O	O	O	O	O	O	O	O	A	O	O	O	O	V	V	V	V	V	V	V	V	X						
7	1-5-8	O	O	O	O	O	O	O	O	O	A	O	O	O	O	V	V	V	V	V	V	V	V							
8	2-1-1	O	O	O	O	O	O	O	O	O	O	O	O	V	V	X	X	X	X	X	X	X								
9	2-2-1	O	O	O	O	O	O	O	O	O	O	O	O	V	V	X	X	X	X	X	X									
10	2-2-2	O	O	O	O	O	O	O	O	O	O	O	O	V	V	X	X	X	X	X										
11	2-2-3	O	O	O	O	O	O	O	O	O	O	O	O	V	V	X	X	X	X											
12	2-3-2	O	O	O	O	O	O	O	O	O	O	O	O	V	V	X	X	X												
13	2-3-3-1	O	O	O	O	O	O	O	O	O	O	O	O	V	V	X	X													
14	2-3-3-2	O	O	O	O	O	O	O	O	O	O	O	O	V	V	X														
15	2-3-3-3	O	O	O	O	O	O	O	O	O	O	O	O	V	V															
16	3-3	O	O	O	O	O	O	A	A	X	X	A	X	X																
17	3-4	O	O	O	O	O	O	A	A	X	X	A	X																	
18	4-1	X	X	X	X	X	X	X	X	X	X	X																		
19	4-2	X	X	V	X	X	X	X	X	X	X																			
20	4-3	O	O	O	O	O	O	O	X	X																				
21	4-4	O	O	O	O	O	O	V	V																					
22	5-1	X	X	V	X	X	X	X																						
23	5-3	X	X	V	X	X	X																							
24	6-1	O	O	X	X	X																								
25	6-2	O	O	X	X																									
26	6-4	X	X	A																										
27	6-5	X	X																											
28	7-1	V																												
29	7-2																													

Table 4.5 Structural self-interaction matrix for important criteria

4.3.1 MICMAC Analysis

MICMAC analysis matrix of three category of criteria provided in (Figures 4.2-4.4)

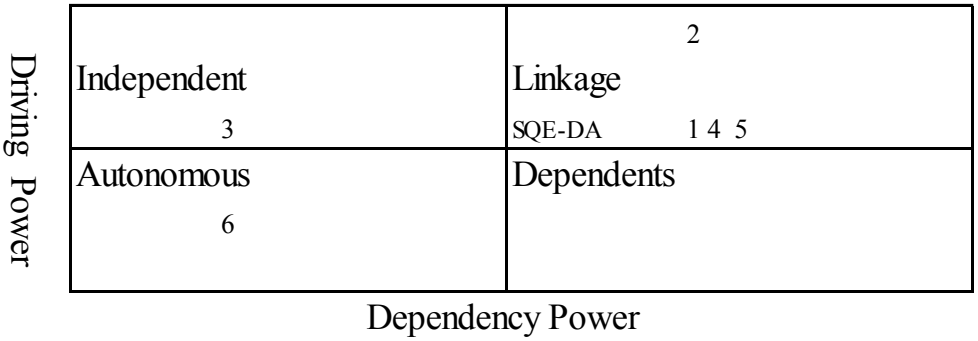

Fig. 4.2 MICMAC analysis matrix of somewhat important criteria

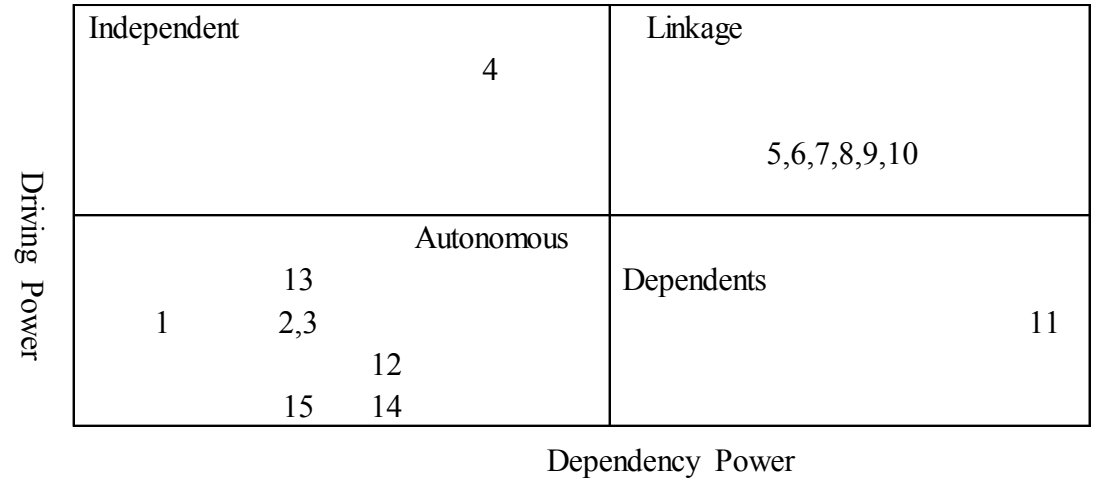

Fig. 4.3 MICMAC analysis matrix of very important criteria

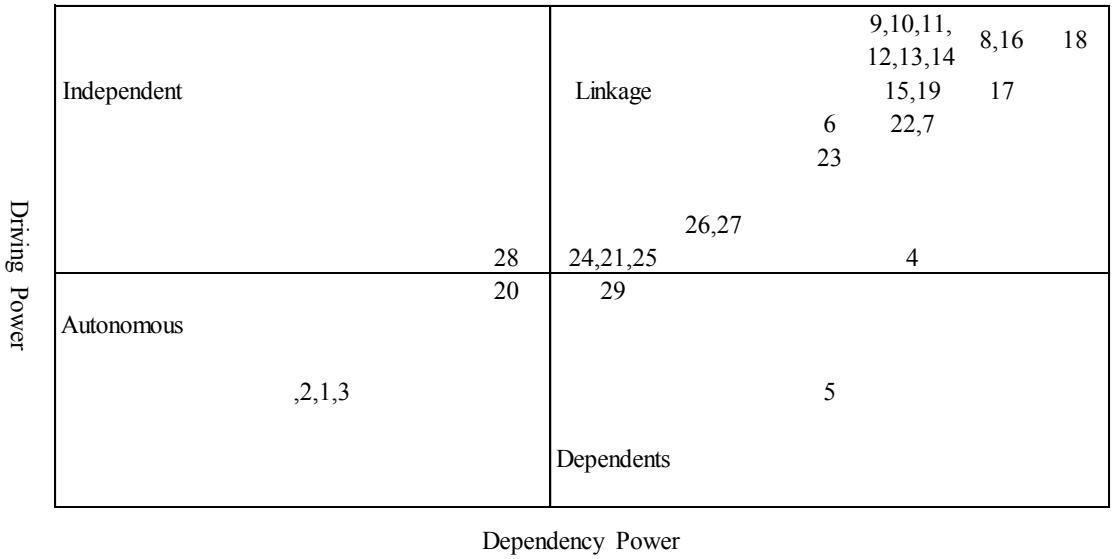

Fig. 4.4 MICMAC analysis matrix of important criteria

From the Figure 4.2 (analysis matrix of somewhat important criteria), we can observe that criterion 2 in supplier quality evaluation: Evaluation of Environment, health and safety of supplier has more driving power and it is located in the linkage cluster. The linkage criteria have strong driving and dependence power. Any action on these criteria will have an effect on the other criteria and also a feedback effect on

themselves. This criterion has good relationship and interaction with other related criteria. Other criteria like: Evaluation of supplier with Data Analysis (Monitoring growth using historical data) and Reward supplier are influenced by this criterion. In MICMAC matrix we can see, commit the necessary resources: supplier quality development engineer/ company representative are autonomous criteria and located in autonomous cluster. Autonomous criteria have weak driving power and weak dependence power and are relatively disconnected from the system. It means this criterion doesn't have many relationships with others and classified as not important criterion in this category. The criterion 3: Certification with ISO 14000 is located in independent cluster. Independent criteria have more driving power and are drivers for other criteria. The Environmental Certification criterion is driver for any rewarding criteria and it has important motivation in delighters needs.

Based on the Figure 4.3 (analysis matrix of very important criteria), criterion 4 (ISO 9000 Framework for supplier evaluation) is located in cluster independent; it has more driving power and can be a driver for other criteria. (A known standard frame work for supplier quality evaluation).There is not many interactions between the other criteria, because 7 criteria located in autonomous cluster. Criteria 15 and 14 (Training and implementation of quality tools- lessons learned from DFMEA,FMEA , Measuring & tracking cost of poor quality for suppliers), criteria 12 (Involve suppliers early in product and process development) 1,2,3,13 ,(using price, delivery and service as criteria for supplier evaluation and supplier performance monitoring) have minimum driving power and also dependency. It means these criteria cannot influence on the performance of total process of supplier quality development for basic needs of

suppliers. Criterion 11(Communicate product quality requirements for certification) has maximum dependency and more relationships to quality evaluation process and another quality evaluation elements that are requirements for this certification. Criteria 5 to 10 (they are elements of supplier quality evaluation) located in linkage cluster. They have influence on the other criteria and therefore they can get a new feedback from the all system. They are important criteria of the system. They can influence the results of SQD activities (certification, training, cost reduction)

In Figure 4.4 (MICMAC analysis matrix of important criteria) it is observed that 6 criteria are located in Independent cluster. These are criteria 16, 12, 17, 21, 29, 28, are independent criteria with more driving power and they can guide and influence on another criteria, the first criterion with more driving power is Supplier incentives for rewarding superior supplier performance. It can motivate other criteria of SQD. Another criterion is proactively working with suppliers to improve their quality for reducing COPQ. This criterion and five other criteria related to Eliminate receiving inspection and cost reduction and improvement are important criteria in this level of supplier needs. Implementing quality tool is located in dependent area. It means this criterion depends on start and completion of other criteria. APQP practices need many other sub activities and infra structures for implementation. Criteria 26, 27,25,23,22,18,19,20 are located in linkage cluster. They include criteria related to SRM (Face to face Communication, long-term relationship), quality tools and training (Team approach and structured problem solving tools, Continuous improvement program, a tracking system to monitor the stages of APQP process) and performance measurement (a system for emerging capability, quality scorecard).They facilitate

performance of other criteria and processes. Another 14 criteria have weak driving and dependency and located in autonomous cluster. Criteria related to evaluation and certification located in this cluster. It means for satisfaction of suppliers performance needs, evaluation and certification are less importance and considering performance rewarding, supplier relationships and implementation of quality tools are more important.

4.4 Results of weighting using with three methods

Results of calculation of criteria weights with AHP (analytic hierarchy process), Data Envelopment Analysis (DEA) and weighted scoring method in three categories presented in figures 4.5-4.7.

Analytic Hierarchy Process (AHP) is a Multi Criteria decision making method that was originally developed by Prof. Thomas L. Saaty. In short, it is a method to derive ratio scales from paired comparisons obtained through group decision making. (See Saaty, T.L. (2008),"Decision making with the analytic hierarchy process")

Data envelopment analysis (DEA) occasionally called frontier analysis, is widely used in the evaluation of performance of Decision Making Units (DMUs) through efficiency calculations. The objective is to determine weights of various inputs and output criteria that a DMU requires to be Pareto-efficient. These DMUs can be business units (for example points of sales, bank branches, dealers, franchisees, government agencies, police departments, hospitals, educational institutions, and even people.(A comprehensive information related to DEA provided in the book "Handbook on data envelopment analysis", written by Copper W, 1999)

The weighted scoring method, also known as “weighting and scoring”, is a form of multi-attribute or multi-criterion analysis. It involves identification of all the non-monetary factors (or "attributes") that are relevant to the project; the allocation of weights to each of them to reflect their relative importance; and the allocation of scores to each option to reflect how it performs in relation with each attribute. (For more information see “The weighted score and TOPSIS”, Cardinale Way, 2009)

Based on above mentioned techniques, we calculated criteria weights for the three categories (Very Important, Important, Somewhat Important) and observed that three methods follow the same trend. Weighted factor gives highest weights for majority of criteria and AHP gives least value. A weight calculated by DEA is between two methods. According to this difference and same trends in three methods, we decided to use average of three weights for SQDPs evaluation in TOPSIS method. (See Table 4.6-4.8). Other tables related to weight calculations for three categories are provided in appendix A.

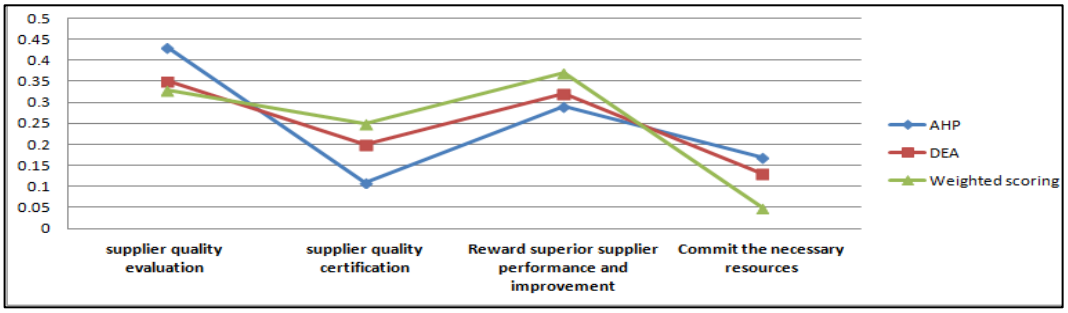

Fig.4.5 Weights of criteria in somewhat important category calculated by three methods

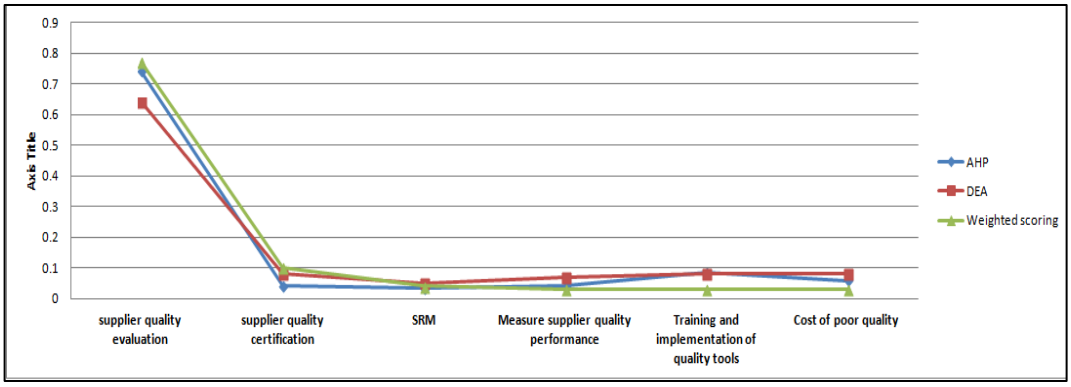

Fig. 4.6 Weights of criteria in very important category calculated by three methods

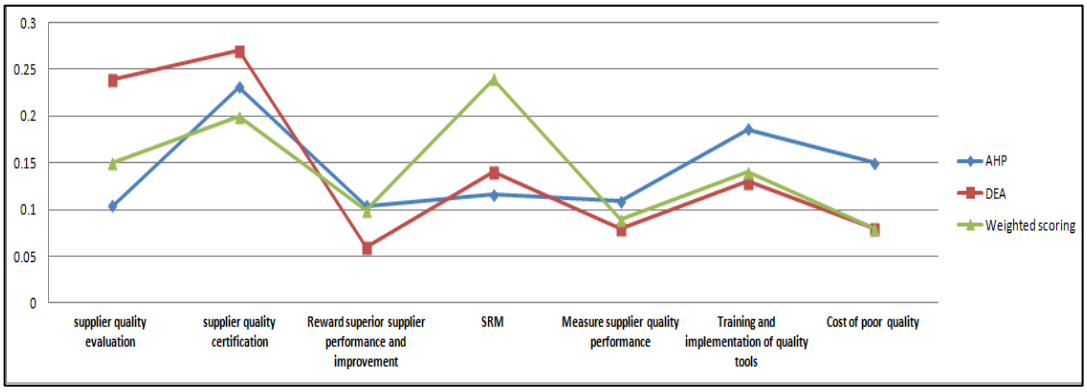

Fig. 4.7 Weights of criteria in important category calculated by three methods

No	Criteria	Weight
1-1-2	Evaluation with Data Analysis	0.19
1-2-5	Evaluation of Environment, health and safety	0.17
2-1-3	Certification with ISO 14000	0.19
3-1	Reward with targets for excellence	0.11
3-2	Reward with publicity and personal ceremonies	0.21
8-1	Supplier quality development engineer/ company representative	0.12

Table 4.6 Average weights for somewhat important criteria

No	Criteria	Weight
1-2-1	Using Price as a criteria for supplier evaluation	0.08
1-2-2	Using Delivery as a criteria for supplier evaluation	0.09
1-2-3	Using Service as a criteria for supplier evaluation	0.05
1-3-1	ISO 9000 Framework for supplier evaluation	0.09
1-5-1	Evaluating Quality management and organization policy	0.07
1-5-2	Evaluating Understanding of customer requirements	0.09
1-5-5	Evaluating Quality of products received from suppliers	0.07
1-5-6	Evaluating Process control	0.07
1-5-7	Evaluating Inspection programs and measurement quality	0.05
1-5-9	Evaluating A system for corrective action in areas that are not meeting requirements	0.06
2-3-1	Communicate product quality requirements for certification	0.08
4-5	Involve suppliers early in product and process development	0.04
5-2	Supplier Performance Monitoring	0.05
6-3	Training and implementation of quality tools- lessons learned from DFMEA,FMEA	0.07
7-3	Measuring & tracking cost of poor quality for suppliers	0.06

Table 4.7 Weights for very important criteria

No	Criteria	Weight
1-1-1	Evaluating supplier with Cost Benefit Analysis method	0.02
1-1-3	Evaluating supplier with Expert Ratings (Buyers, Departmental Heads)	0.02
1-2-4	Evaluate supplier with Flexibility criteria	0.04
1-4-2	Using an internet based mechanized system for inputting data of supplier evaluation	0.02
1-5-3	Evaluating Staff training and motivation of suppliers	0.02
1-5-4	Evaluating Management of product and process evolution.	0.02
1-5-8	Evaluating Process complaints	0.02
2-1-1	Monitoring ISO 9001 for certification	0.02
2-2-1	Establish consistent safety standards for certification	0.03
2-2-2	Monitor supplier risk for certification	0.04

No	Criteria	Weight
2-2-3	Certify suppliers with Verify insurance coverage	0.02
2-3-2	Collect and review supplier self-assessments for certification	0.04
2-3-3-1	Confirm sample products' quality levels-Conformance to specifications for certification	0.03
2-3-3-2	Confirm sample products' quality levels-Process capability for certification	0.03
2-3-3-3	Confirm sample products' quality levels-product reliability for certification	0.02
3-3	Supplier incentives for Reward superior supplier performance	0.05
3-4	Eliminate receiving inspection on supplier's material for Reward superior supplier performance	0.04
4-1	Face to face Communication	0.05
4-2	Long-term relationship	0.04
4-3	Cross functional team	0.03
4-4	Shared quality information	0.04
5-1	Quality scorecard	0.04
5-3	A system for emerging capability of suppliers	0.05
6-1	Implementing quality tools-a tracking system available to monitor the stages of APQP process	0.03
6-2	Implementing quality tools -a formal process of APQP	0.04
6-4	Utilize a team approach and structured problem solving tools	0.04
6-5	Continuous improvement program for suppliers to ensure improvements to quality, service, productivity	0.05
7-1	Proactively work with suppliers to improve their quality for reducing COPQ	0.06
7-2	Utilize a program of improvement initiatives such as capacity improvement, scrap reduction and cost control for suppliers	0.05

Table 4.8 Weights for important criteria

4.5 SQDPs evaluation using TOPSIS

We evaluated and selected five SQDPs with TOPSIS method in three categories: basic needs (very important), somewhat important (satisfiers) and important (performance needs). Finally, we have the highest ranked SQDP in each category. It will be the best SQDPs for satisfying related needs of suppliers. Following steps are used to find the best SQDPs:

- ✓ Define the criteria for selection of SQDPs in TOPSIS: Based on Define, Measure and Analyze phases we acquired three classes of criteria. We can evaluate each alternative SQDP for criteria related to each category of suppliers' needs and the maximum number will define the best SQDP for satisfaction of this level of supplier's needs.

  m = 5 alternatives (SQDPs)

  n = 6 criteria for somewhat important category, 15 criteria for very important category, 29 criteria for important category
- ✓ Evaluate five SQDPs (Table 4.9) using a Likert scale scored from 1-9 (see Table 4.10)

No	Description
SQDP1	Supplier quality evaluation of process/product, using problem solving method and reward suppliers
SQDP2	Supplier quality evaluation -Environment, health and safety and certification risk and product capability in cross functional teams, sharing quality information , tracking system of AQPQP and continuous improvement
SQDP3	Supplier quality evaluation -(evaluation of process) with supplier portal ,Supplier incentives ,Reward superior and eliminate receiving inspection on supplier's material
SQDP4	Supplier quality evaluation: customer requirements , Reward supplier with publicity and personal ceremonies ,Measuring & tracking cost of COPQ
SQDP5	Supplier quality evaluation: Inspection programs and measurement quality ,Evaluating A system for corrective action, risks, face to face communication and implementation of APQP and cost reduction

Table 4.9 Five supplier quality development programs

Scales for comparing the role of each criteria in each program		
1	Less important	The criteria is less important in SQD program
3	Moderate important	The criteria is moderate important in SQD program
5	Strong important	The criteria is strong important in SQD program
7	Very strong important	The criteria is very strong important in SQD program
9	Extreme importance	The criteria is extreme importance in SQD program
2,4,6,8 be used to express intermediate values		

Table 4.10 Likert scale for evaluation of SQDPs

- ✓ Assign the weights to each criterion based on the results of three methods defined in previous section
- ✓ Define benefit and loss criteria for implementation in TOPSIS matrix : (see Tables 4.11-4.13)
    - **Benefit criteria** related to criteria that don't have cost and loss for SQDPs (For example evaluation, measuring monitoring, inspection)
    - **Loss criteria** related to criteria need more investment in SQDPs and resulted in cost and loss for companies.(For example incentives, training, implementing quality tools, commit resources)

No	Criteria	Abbreviation	Benefit/Loss
1-1-2	Data Analysis (Monitoring growth using historical data)	SQE-MDA	Benefit
1-2-5	Environment, health and safety	SQE-CEHS	Benefit
2-1-3	Certification with ISO 14000	SQC-ENW	Benefit
3-1	Reward supplier with targets for excellence driven quality	RSP-TE	Loss
3-2	Reward supplier with publicity and personal ceremonies	RSP-P&P	Loss
8-1	Supplier quality development engineer/ company representative	CNS-QE&CR	Loss

Table 4.11 Benefit/loss category for somewhat important criteria

No	Criteria	Abbreviation	Benefit/Loss
1-1-1	Evaluating supplier with Cost Benefit Analysis method	SQEMCBA	Benefit
1-1-3	Evaluating supplier with Expert Ratings (Buyers, Departmental Heads)	SQEMER	Benefit
1-2-4	Flexibility: The ability of a supplier to accommodate changes in the enterprise's production plans(ability to ship to demand)	SQCEF	Benefit
1-3-2	Using an internet based mechanized system for inputting data of supplier evaluation	SQESD	Benefit
1-5-3	Evaluating Staff training and motivation of suppliers	SQEISM	Benefit
1-5-4	Evaluating Management of product and process evolution.	SQEI-P&P	Benefit
1-5-8	Evaluating Process complaints	SQEIEPC	Benefit
2-1-1	Monitoring ISO 9001 for certification	SQCISO	Benefit
2-2-1	Establish consistent safety standards for certification	SQCECS	Benefit
2-2-2	Monitor supplier risk for certification	SQCMSR	Benefit
2-2-3	Certify suppliers with Verify insurance coverage	SQCIC	Benefit
2-3-2	Collect and review supplier self-assessments for certification	SQCSA	Benefit
2-3-3-1	Confirm sample products' quality levels-Conformance to specifications for certification	SQCCTS	Benefit
2-3-3-2	Confirm sample products' quality levels-Process capability for certification	SQCPC	Benefit
2-3-3-3	Confirm sample products' quality levels-product reliability for certification	SQCPR	Benefit
3-4	Eliminate receiving inspection on supplier's material for Reward superior supplier performance	RSERI	Benefit
4-1	Face to face Communication	SRMFFC	Benefit
4-2	Long-term relationship	SRMLTR	Benefit

No	Criteria	Abbreviation	Benefit/Loss
4-3	Cross functional team	SRMCFT	Benefit
4-4	Shared quality information	SRMSQI	Benefit
5	Measure supplier quality performance	MSQP	
5-1	Quality scorecard	MSQPQS	Benefit
5-3	A system for emerging capability of suppliers	MSQPSEC	Loss
6-1	Implementing quality tools-a tracking system available to monitor the stages of APQP process	T&IQTMAPQP	Loss
6-2	Implementing quality tools -a formal process of APQP	T&IQSPAPQP	Loss
6-4	Utilize a team approach and structured problem solving tools	T&IQTSPS	Loss
6-5	Continuous improvement program for suppliers to ensure improvements to quality, service, productivity	T&IQTCI	Loss
7	Cost of poor quality	COPQ	
7-1	Proactively work with suppliers to improve their quality for reducing COPQ	COPQR	Loss
7-2	Utilize a program of improvement initiatives such as capacity improvement, scrap reduction and cost control for suppliers	COPQI	Loss

Table 4.12 Benefit/loss category for important criteria

No	Criteria	Abbreviation	Benefit/loss
1-2-1	Using Price as a criteria for supplier evaluation	SQECP	Benefit
1-2-2	Using Delivery as a criteria for supplier evaluation	SQECD	Benefit
1-2-3	Using Service as a criteria for supplier evaluation	SQECS	Benefit
1-3-1	ISO 9000 Framework for supplier evaluation	SQEFISO	Benefit

No	Criteria	Abbreviation	Benefit/loss
1-5-1	Evaluating Quality management and organization policy	SQEIQM	Benefit
1-5-2	Evaluating Understanding of customer requirements	SQEICR	Benefit
1-5-5	Evaluating Quality of products received from suppliers	SQEIQP	Benefit
1-5-6	Evaluating Process control	SQEIPC	Benefit
1-5-7	Evaluating Inspection programs and measurement quality	SQEI-I&M	Benefit
1-5-9	Evaluating A system for corrective action in areas that are not meeting requirements	SQEICA	Benefit
2-3-1	Communicate product quality requirements for certification	SQCCPQ	Benefit
4-5	Involve suppliers early in product and process development	SRMISE	Benefit
5-2	Supplier Performance Monitoring	MSQPSPM	Benefit
6-3	Training and implementation of quality tools- lessons learned from DFMEA,FMEA	T&IQTFMEA	Loss
7-3	Measuring & tracking cost of poor quality for suppliers	COPQM&T	Benefit

Table 4.13 Benefit/loss category for very important criteria

- ✓ Evaluate SQDPs using the TOPSIS approach: (See Appendix B.)

- ✓ Ranking the results and selection of high score SQDPs.

Very Important criteria			Important criteria			Somewhat Important criteria		
Rank	**SQDPs**	**scores**	**Rank**	**SQDPs**	**scores**	**Rank**	**SQDPs**	**scores**
1	p5	0.64	1	p5	0.54	1	p2	0.62
2	p4	0.58	2	p3	0.53	2	p4	0.56
3	p2	0.47	3	p2	0.52	3	p1	0.45
4	p3	0.45	4	p4	0.47	4	p3	0.45
5	p1	0.44	5	p1	0.46	5	p5	0.39

Table 4.14 Final Ranking Results

Table 4.14 presents the SQDPs evaluation results with TOPSIS for the three category criteria. According to the "Very Important" criteria (Basic needs) program 5 has highest score among the five compared programs. For the "Important" criteria, also program 5 scores the highest whereas for "somewhat important" criteria, program 2 scores the highest. Based on the majority vote criteria, program 5 is finally selected. Ideal solution A* matrix in each category is presented in appendix C.

Chapter 5

Conclusions and Future Works

5.1 Conclusions

In this thesis, our main goal was to investigate various criteria for supplier quality development (SQD) and demonstrate their application in evaluating supplier quality development programs (SQDPs). To investigate the SQD and its criteria, we reviewed several papers to find general steps and practices that make main structure of SQD activities. Academic literature review provides us 2 steps and 8 practices. We also reviewed industrial practices of leading companies in aerospace, automotive and other industries to find SQD practices. By comparison of academic and industrial practices on SQD, we developed critical characteristic (criteria) for SQD. Using the DMAIC methodology we prepared a multi-criteria framework for evaluation and selection of SQDPs. The techniques implemented in 5 phases of DMAIC are Kano model analysis, ISM, and TOPSIS methods. With using our evaluation system, companies can also design new or modify existing SQDPs according to level of suppliers' needs. They can also communicate the evaluated results of their SQDPs for the satisfaction and motivation of suppliers.

5.2 Future works

Our future research consists of following subjects:

- Study on the practices of SQD in specific industries like aerospace, automotive, etc.
- Study on the impact of specific practices like SQE, SQC, implementation of quality tools (APQP,FMEA,six sigma,…) or quality training, rewarding and etc. on the supplier satisfaction in Kano model.

Our method can be extended for benchmarking SQD practices and can help companies to prepare action plans for filling their gaps in SQDPs. This involves:

1. Study on the factors affecting supplier quality performance.
2. Study on the implementation issues on the Supplier quality development.
3. Study on the customer-focused rating system of supplier quality performance.
4. Study on the Continuous Improvement Programs in SQD and supply chain.
5. Study on the critical success factors of SQD and their impact on Performance of specific industries.

5.3 Strengths and limitations

Figure 5.1 presents a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis of the research work pursued in this thesis.

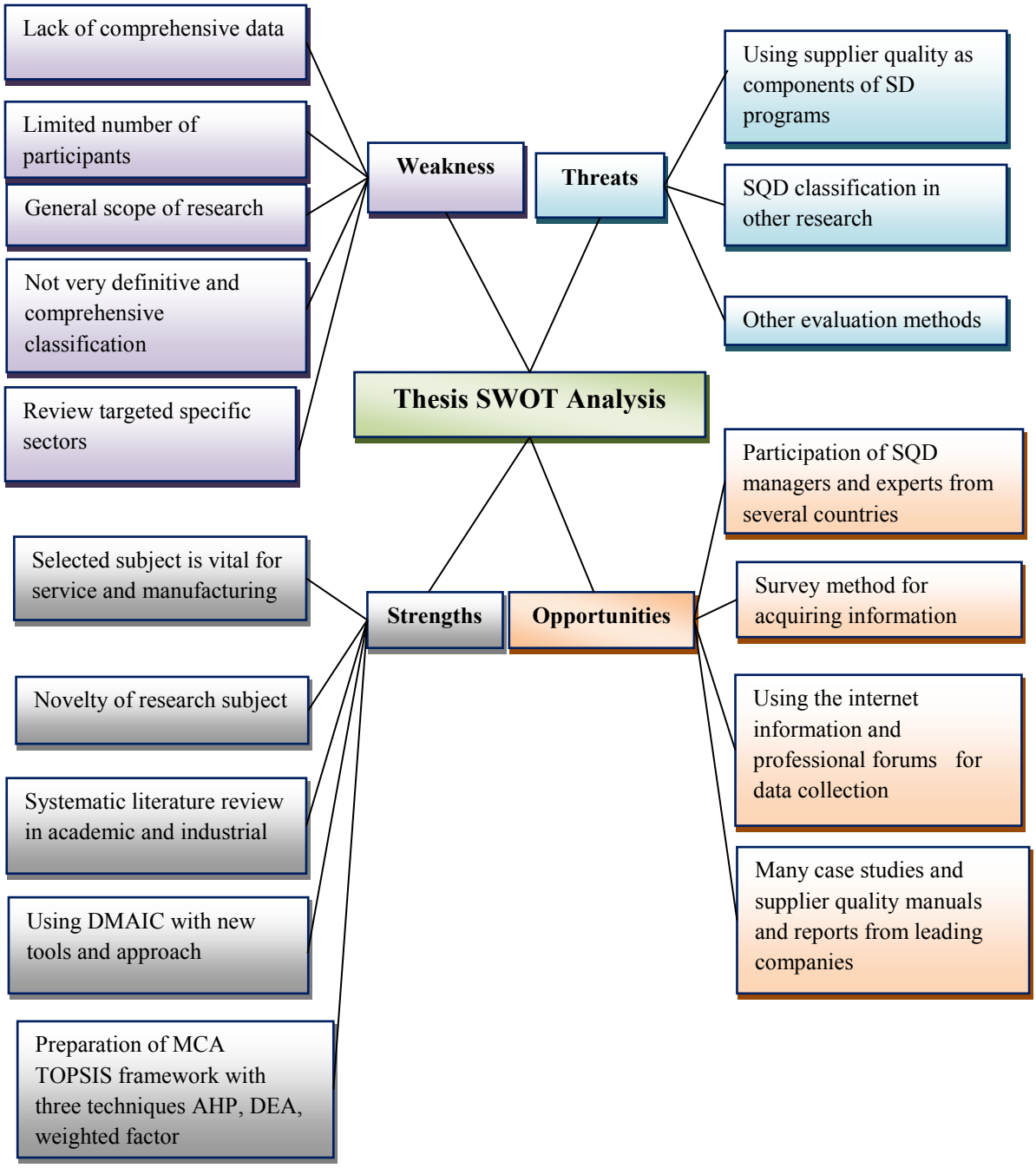

Fig. 5.1 Thesis SWOT Analysis

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Appendix A: Three methods for criteria weight calculation namely DEA, AHP, and weighted scoring method

No	criteria	AHP	DEA	Weighted scoring	average
1	supplier quality evaluation	0.43	0.35	0.33	0.37
2	supplier quality certification	0.11	0.2	0.25	0.19
3	Reward superior supplier performance and improvement	0.29	0.32	0.37	0.32
8	Commit the necessary resources	0.17	0.13	0.05	0.12

Weights of criteria for somewhat important category

No	criteria	AHP	DEA	Weighted scoring	average
1	supplier quality evaluation	0.74	0.64	0.77	0.72
2	supplier quality certification	0.04	0.08	0.1	0.07
4	SRM	0.03	0.05	0.04	0.04
5	Measure supplier quality performance	0.04	0.07	0.03	0.05
6	Training and implementation of quality tools	0.08	0.08	0.03	0.06
7	Cost of poor quality	0.06	0.08	0.03	0.06

Weights of criteria for very important category

No	criteria	AHP	DEA	Weighted scoring	average
1	supplier quality evaluation	0.1	0.24	0.15	0.16
2	supplier quality certification	0.23	0.27	0.2	0.23
3	Reward superior supplier performance and improvement	0.1	0.06	0.1	0.09
4	SRM	0.12	0.14	0.24	0.17
5	Measure supplier quality performance	0.11	0.08	0.09	0.09
6	Training and implementation of quality tools	0.19	0.13	0.14	0.15
7	Cost of poor quality	0.15	0.08	0.08	0.11

Weights of criteria for important category

Appendix B: Calculations for TOPSIS for criteria in the three categories

	↑	↑	↑	↓	↓	↓	
	SQE-MDA	**SQE-CEHS**	**SQC-ENW**	**RSP-TE**	**RSP-P&P**	**CNS-QE&CR**	
	benfit	**benfit**	**benfit**	**loss**	**loss**	**loss**	
weight	0.19	0.17	0.19	0.11	0.21	0.12	
SQDPs	**SQE-MDA**	**SQE-CEHS**	**SQC-ENW**	**RSP-TE**	**RSP-P&P**	**CNS-QE&CR**	
P1	9	3	1	3	7	5	
p2	5	9	9	7	5	7	
p3	5	1	3	9	3	3	
p4	3	5	7	5	1	9	
p5	1	7	5	7	9	1	
weight	0.19	0.17	0.19	0.11	0.21	0.12	
SQDPs	**SQE-MDA**	**SQE-CEHS**	**SQC-ENW**	**RSP-TE**	**RSP-P&P**	**CNS-QE&CR**	
p1	81	9	1	9	49	25	
p2	25	81	81	49	25	49	
p3	25	1	9	81	9	9	
p4	9	25	49	25	1	81	
p5	1	49	25	49	81	1	
∑xij2	141	165	165	213	165	165	
(∑x2)1/2	11.87434209	12.84523258	12.84523258	14.59451952	12.84523258	12.84523258	
weight	0.19	0.17	0.19	0.11	0.21	0.12	
SQDPs	**SQE-MDA**	**SQE-CEHS**	**SQC-ENW**	**RSP-TE**	**RSP-P&P**	**CNS-QE&CR**	
p1	0.76	0.23	0.08	0.21	0.54	0.39	
p2	0.42	0.70	0.70	0.48	0.39	0.54	
p3	0.42	0.08	0.23	0.62	0.23	0.23	
p4	0.25	0.39	0.54	0.34	0.08	0.70	
p5	0.08	0.54	0.39	0.48	0.70	0.08	
SQDPs	**SQE-MDA**	**SQE-CEHS**	**SQC-ENW**	**RSP-TE**	**RSP-P&P**	**CNS-QE&CR**	
p1	0.14	0.04	0.01	0.02	0.11	0.05	
p2	0.08	0.12	0.13	0.05	0.08	0.07	
p3	0.08	0.01	0.04	0.07	0.05	0.03	
p4	0.05	0.07	0.10	0.04	0.02	0.08	
p5	0.02	0.09	0.07	0.05	0.15	0.01	
A* =	0.14	0.12	0.13	0.02	0.02	0.01	
A' =	0.02	0.01	0.01	0.07	0.15	0.08	
SQDPs	**SQE-MDA**	**SQE-CEHS**	**SQC-ENW**	**RSP-TE**	**RSP-P&P**	**CNS-QE&CR**	**P.I.S**
p1	0.00	0.01	0.01	0.00	0.01	0.00	0.18
p2	0.00	0.00	0.00	0.00	0.00	0.00	0.11
p3	0.00	0.01	0.01	0.00	0.00	0.00	0.16
p4	0.01	0.00	0.00	0.00	0.00	0.01	0.14
p5	0.02	0.00	0.00	0.00	0.02	0.00	0.20
SQDPs	**SQE-MDA**	**SQE-CEHS**	**SQC-ENW**	**RSP-TE**	**RSP-P&P**	**CNS-QE&CR**	**N.I.S**
p1	0.02	0.00	0.00	0.00	0.00	0.00	0.15
p2	0.00	0.01	0.01	0.00	0.00	0.00	0.18
p3	0.00	0.00	0.00	0.00	0.01	0.00	0.13
p4	0.00	0.00	0.01	0.00	0.02	0.00	0.17
p5	0.00	0.01	0.00	0.00	0.00	0.01	0.12

Evaluation of SQDPs for SOMEWHAT IMPORTANT criteria with TOPSIS method

	SQEMCBA	SQEMER	SQCEF	SQESD	SQEISM	SQEI-P&P	SQEIEPC	SQCISO
	Benfit	Benfit	Benfit	Benfit	Benfit	Benfit	Benfit	Benfit
weight	0	0	0	0	0	0	0	0
SQDPs	SQEMCBA	SQEMER	SQCEF	SQESD	SQEISM	SQEI-P&P	SQEIEPC	SQCISO
p1	1	7	5	3	7	7	7	1
p2	3	5	7	5	1	3	3	3
p3	7	9	3	7	5	5	9	5
p4	5	3	7	3	3	7	5	9
p5	9	1	1	1	9	1	1	1
weight	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
SQDPs	SQEMCBA	SQEMER	SQCEF	SQESD	SQEISM	SQEI-P&P	SQEIEPC	SQCISO
p1	1	49	25	9	49	49	49	1
p2	9	25	49	25	1	9	9	9
p3	49	81	9	49	25	25	81	25
p4	25	9	49	9	9	49	25	81
p5	81	1	1	1	81	1	1	1
∑xij2	165	165	133	93	165	133	165	117
(∑x2)1/2	13	13	12	10	13	12	13	11
weight	0	0	0	0	0	0	0	0
SQDPs	SQEMCBA	SQEMER	SQCEF	SQESD	SQEISM	SQEI-P&P	SQEIEPC	SQCISO
p1	0.0778	0.5449	0.4336	0.3111	0.5449	0.6070	0.5449	0.0925
p2	**0.2335**	**0.3892**	**0.6070**	**0.5185**	**0.0778**	**0.2601**	**0.2335**	**0.2774**
p3	0.5449	0.7006	0.2601	0.7259	0.3892	0.4336	0.7006	0.4623
p4	0.3892	0.2335	0.6070	0.3111	0.2335	0.6070	0.3892	0.8321
p5	0.7006	0.0778	0.0867	0.1037	0.7006	0.0867	0.0778	0.0925
weight	0.0200	0.0200	0.0400	0.0200	0.0200	0.0200	0.0200	0.0200
SQDPs	SQEMCBA	SQEMER	SQCEF	SQESD	SQEISM	SQEI-P&P	SQEIEPC	SQCISO
p1	0.0016	0.0109	0.0173	0.0062	0.0109	0.0121	0.0109	0.0018
p2	0.0047	0.0078	0.0243	0.0104	0.0016	0.0052	0.0047	0.0055
p3	0.0109	0.0140	0.0104	0.0145	0.0078	0.0087	0.0140	0.0092
p4	0.0078	0.0047	0.0243	0.0062	0.0047	0.0121	0.0078	0.0166
p5	0.0140	0.0016	0.0035	0.0021	0.0140	0.0017	0.0016	0.0018
A* =	0.0140	0.0140	0.0243	0.0145	0.0140	0.0121	0.0140	0.0166
A' =	0.0016	0.0016	0.0035	0.0021	0.0016	0.0017	0.0016	0.0018
SQDPs	SQEMCBA	SQEMER	SQCEF	SQESD	SQEISM	SQEI-P&P	SQEIEPC	SQCISO
p1	0.000155	0.000010	0.000048	0.000069	0.000010	0.000000	0.000010	0.000219
p2	0.000087	0.000039	0.000000	0.000017	0.000155	0.000048	0.000087	0.000123
p3	0.000010	0.000000	0.000192	0.000000	0.000039	0.000012	0.000000	0.000055
p4	0.000039	0.000087	0.000000	0.000069	0.000087	0.000000	0.000039	0.000000
p5	0.000000	0.000155	0.000433	0.000155	0.000000	0.000108	0.000155	0.000219
SQDPs	SQEMCBA	SQEMER	SQCEF	SQESD	SQEISM	SQEI-P&P	SQEIEPC	SQCISO
p1	0.000000	0.000087	0.000192	0.000017	0.000087	0.000108	0.000087	0.000000
p2	0.000010	0.000039	0.000433	0.000069	0.000000	0.000012	0.000010	0.000014
p3	0.000087	0.000155	0.000048	0.000155	0.000039	0.000048	0.000155	0.000055
p4	0.000039	0.000010	0.000433	0.000017	0.000010	0.000108	0.000039	0.000219
p5	0.000155	0.000000	0.000000	0.000000	0.000155	0.000000	0.000000	0.000000

Evaluation of SQDPs for IMPORTANT criteria with TOPSIS method

SQCECS	SQCMSR	SQCIC	SQCSA	SQCCTS	SQCPC	SQCPR	RSSI
Benfit	Benfit	Benfit	Benfit	Benfit	Benfit	Benfit	loss
0	0	0	0	0	0	0	0
SQCECS	**SQCMSR**	**SQCIC**	**SQCSA**	**SQCCTS**	**SQCPC**	**SQCPR**	**RSSI**
3	3	7	5	5	3	7	9
1	7	9	7	1	9	3	5
3	5	3	3	3	1	5	1
5	1	3	1	7	5	9	7
7	7	1	5	9	7	1	3
0	**0**	**0**	**0**	**0**	**0**	**0**	**0**
SQCECS	**SQCMSR**	**SQCIC**	**SQCSA**	**SQCCTS**	**SQCPC**	**SQCPR**	**RSSI**
9	9	49	25	25	9	49	81
1	49	81	49	1	81	9	25
9	25	9	9	9	1	25	1
25	1	9	1	49	25	81	49
49	49	1	25	81	49	1	9
93	133	149	109	165	165	165	165
10	12	12	10	13	13	13	13
0	0	0	0	0	0	0	0
SQCECS	**SQCMSR**	**SQCIC**	**SQCSA**	**SQCCTS**	**SQCPC**	**SQCPR**	**RSSI**
0.3111	0.2601	0.5735	0.4789	0.3892	0.2335	0.5449	0.7006
0.1037	**0.6070**	**0.7373**	**0.6705**	**0.0778**	**0.7006**	**0.2335**	**0.3892**
0.3111	0.4336	0.2458	0.2873	0.2335	0.0778	0.3892	0.0778
0.5185	0.0867	0.2458	0.0958	0.5449	0.3892	0.7006	0.5449
0.7259	0.6070	0.0819	0.4789	0.7006	0.5449	0.0778	0.2335
0.0300	0.0400	0.0200	0.0400	0.0300	0.0300	0.0200	0.0500
SQCECS	**SQCMSR**	**SQCIC**	**SQCSA**	**SQCCTS**	**SQCPC**	**SQCPR**	**RSSI**
0.0093	0.0104	0.0115	0.0192	0.0117	0.0070	0.0109	0.0350
0.0031	0.0243	0.0147	0.0268	0.0023	0.0210	0.0047	0.0195
0.0093	0.0173	0.0049	0.0115	0.0070	0.0023	0.0078	0.0039
0.0156	0.0035	0.0049	0.0038	0.0163	0.0117	0.0140	0.0272
0.0218	0.0243	0.0016	0.0192	0.0210	0.0163	0.0016	0.0117
0.0218	0.0243	0.0147	0.0268	0.0210	0.0210	0.0140	0.0039
0.0031	0.0035	0.0016	0.0038	0.0023	0.0023	0.0016	0.0350
SQCECS	**SQCMSR**	**SQCIC**	**SQCSA**	**SQCCTS**	**SQCPC**	**SQCPR**	**RSSI**
0.000155	0.000192	0.000011	0.000059	0.000087	0.000196	0.000010	0.000970
0.000348	0.000000	0.000000	0.000000	0.000349	0.000000	0.000087	0.000242
0.000155	0.000048	0.000097	0.000235	0.000196	0.000349	0.000039	0.000000
0.000039	0.000433	0.000097	0.000528	0.000022	0.000087	0.000000	0.000545
0.000000	0.000000	0.000172	0.000059	0.000000	0.000022	0.000155	0.000061
SQCECS	**SQCMSR**	**SQCIC**	**SQCSA**	**SQCCTS**	**SQCPC**	**SQCPR**	**RSSI**
0.000039	0.000048	0.000097	0.000235	0.000087	0.000022	0.000087	0.000000
0.000000	0.000433	0.000172	0.000528	0.000000	0.000349	0.000010	0.000242
0.000039	0.000192	0.000011	0.000059	0.000022	0.000000	0.000039	0.000970
0.000155	0.000000	0.000011	0.000000	0.000196	0.000087	0.000155	0.000061
0.000348	0.000433	0.000000	0.000235	0.000349	0.000196	0.000000	0.000545

Continue: Evaluation of SQDPs for IMPORTANT criteria with TOPSIS method

RSERI	SRMFFC	SRMLTR	SRMCFT	SRMSQI	MSQPQS	MSQPSEC	T&IQTMAPQP
Benfit	Benfit	Benfit	Benfit	Benfit	Benfit	loss	loss
↑	↑	↑	↑	↑	↑	↓	↓
0	0	0	0	0	0	0	0
RSERI	**SRMFFC**	**SRMLTR**	**SRMCFT**	**SRMSQI**	**MSQPQS**	**MSQPSEC**	**T&IQTMAPQP**
3	3	9	5	5	9	3	3
1	5	5	9	9	7	9	1
9	7	3	7	7	3	5	5
7	1	1	3	3	1	1	3
5	9	7	1	1	5	7	7
0	**0**	**0**	**0**	**0**	**0**	**0**	**0**
RSERI	**SRMFFC**	**SRMLTR**	**SRMCFT**	**SRMSQI**	**MSQPQS**	**MSQPSEC**	**T&IQTMAPQP**
9	9	81	25	25	81	9	9
1	25	25	81	81	49	81	1
81	49	9	49	49	9	25	25
49	1	1	9	9	1	1	9
25	81	49	1	1	25	49	49
165	165	165	165	165	165	165	93
13	13	13	13	13	13	13	10
0	0	0	0	0	0	0	0
RSERI	**SRMFFC**	**SRMLTR**	**SRMCFT**	**SRMSQI**	**MSQPQS**	**MSQPSEC**	**T&IQTMAPQP**
0.2335	0.2335	0.7006	0.3892	0.3892	0.7006	0.2335	0.3111
0.0778	**0.3892**	**0.3892**	**0.7006**	**0.7006**	**0.5449**	**0.7006**	**0.1037**
0.7006	0.5449	0.2335	0.5449	0.5449	0.2335	0.3892	0.5185
0.5449	0.0778	0.0778	0.2335	0.2335	0.0778	0.0778	0.3111
0.3892	0.7006	0.5449	0.0778	0.0778	0.3892	0.5449	0.7259
0.0400	0.0500	0.0400	0.0300	0.0400	0.0400	0.0500	0.0300
RSERI	**SRMFFC**	**SRMLTR**	**SRMCFT**	**SRMSQI**	**MSQPQS**	**MSQPSEC**	**T&IQTMAPQP**
0.0093	0.0117	0.0280	0.0117	0.0156	0.0280	0.0117	0.0093
0.0031	0.0195	0.0156	0.0210	0.0280	0.0218	0.0350	0.0031
0.0280	0.0272	0.0093	0.0163	0.0218	0.0093	0.0195	0.0156
0.0218	0.0039	0.0031	0.0070	0.0093	0.0031	0.0039	0.0093
0.0156	0.0350	0.0218	0.0023	0.0031	0.0156	0.0272	0.0218
0.0280	0.0350	0.0280	0.0210	0.0280	0.0280	0.0039	0.0031
0.0031	0.0039	0.0031	0.0023	0.0031	0.0031	0.0350	0.0218
RSERI	**SRMFFC**	**SRMLTR**	**SRMCFT**	**SRMSQI**	**MSQPQS**	**MSQPSEC**	**T&IQTMAPQP**
0.000349	0.000545	0.000000	0.000087	0.000155	0.000000	0.000061	0.000039
0.000621	0.000242	0.000155	0.000000	0.000000	0.000039	0.000970	0.000000
0.000000	0.000061	0.000349	0.000022	0.000039	0.000349	0.000242	0.000155
0.000039	0.000970	0.000621	0.000196	0.000349	0.000621	0.000000	0.000039
0.000155	0.000000	0.000039	0.000349	0.000621	0.000155	0.000545	0.000348
RSERI	**SRMFFC**	**SRMLTR**	**SRMCFT**	**SRMSQI**	**MSQPQS**	**MSQPSEC**	**T&IQTMAPQP**
0.000039	0.000061	0.000621	0.000087	0.000155	0.000621	0.000545	0.000155
0.000000	0.000242	0.000155	0.000349	0.000621	0.000349	0.000000	0.000348
0.000621	0.000545	0.000039	0.000196	0.000349	0.000039	0.000242	0.000039
0.000349	0.000000	0.000000	0.000022	0.000039	0.000000	0.000970	0.000155
0.000155	0.000970	0.000349	0.000000	0.000000	0.000155	0.000061	0.000000

Continue: Evaluation of SQDPs for IMPORTANT criteria with TOPSIS method

T&IQSPAPQP	T&IQTSPS	T&IQTCI	COPQR	COPQI	
loss	loss	loss	loss	loss	
0	0	0	0	0	
T&IQSPAPQP	T&IQTSPS	T&IQTCI	COPQR	COPQI	
9	1	7	7	7	
5	5	1	9	3	
3	7	9	3	5	
7	3	5	1	9	
1	9	3	5	1	
0	**0**	**0**	**0**	**0**	
T&IQSPAPQP	T&IQTSPS	T&IQTCI	COPQR	COPQI	
81	1	49	49	49	
25	25	1	81	9	
9	49	81	9	25	
49	9	25	1	81	
1	81	9	25	1	
165	165	165	165	165	
13	13	13	13	13	
0	0	0	0	0	
T&IQSPAPQP	T&IQTSPS	T&IQTCI	COPQR	COPQI	
0.7006	0.0778	0.5449	0.5449	0.5449	
0.3892	**0.3892**	**0.0778**	**0.7006**	**0.2335**	
0.2335	0.5449	0.7006	0.2335	0.3892	
0.5449	0.2335	0.3892	0.0778	0.7006	
0.0778	0.7006	0.2335	0.3892	0.0778	
0.0400	0.0400	0.0500	0.0600	0.0500	
T&IQSPAPQP	T&IQTSPS	T&IQTSPS	COPQR	COPQI	
0.0280	0.0031	0.0272	0.0327	0.0272	
0.0156	0.0156	0.0039	0.0420	0.0117	
0.0093	0.0218	0.0350	0.0140	0.0195	
0.0218	0.0093	0.0195	0.0047	0.0350	
0.0031	0.0280	0.0117	0.0234	0.0039	
0.0031	0.0031	0.0039	0.0047	0.0039	
0.0280	0.0280	0.0350	0.0420	0.0350	
T&IQSPAPQP	T&IQTSPS	T&IQTCI	COPQR	COPQI	P.I.S
0.000621	0.000000	0.000545	0.000785	0.000545	0.077026
0.000155	0.000155	0.000000	0.001396	0.000061	0.073335
0.000039	0.000349	0.000970	0.000087	0.000242	0.065805
0.000349	0.000039	0.000242	0.000000	0.000970	0.080661
0.000000	0.000621	0.000061	0.000349	0.000000	0.070259
T&IQSPAPQP	T&IQTSPS	T&IQTCI	COPQR	COPQI	N.I.S
0.000000	0.000621	0.000061	0.000087	0.000061	0.065627
0.000155	0.000155	0.000970	0.000000	0.000545	0.078807
0.000349	0.000039	0.000000	0.000785	0.000242	0.074559
0.000039	0.000349	0.000242	0.001396	0.000000	0.071416
0.000621	0.000000	0.000545	0.000349	0.000970	0.081192

Continue: Evaluation of SQDPs for IMPORTANT criteria with TOPSIS method

	↑	↑	↑	↑	↑	↑	↑	↑
SQDPs	0.08	0.09	0.05	0.07	0.09	0.07	0.07	0.05
	SQECP	**SQECD**	**SQECS**	**SQEIQM**	**SQEICR**	**SQEIQP**	**SQEIPC**	**SQEI-I&M**
p1	3	7	3	7	5	9	5	7
p2	9	1	9	3	7	5	9	1
p3	3	9	5	9	3	7	3	5
p4	5	3	7	5	9	3	1	3
p5	7	5	1	1	3	1	7	9
SQDPs	0	0	0	0	0	0	0	0
	SQECP	**SQECD**	**SQECS**	**SQEIQM**	**SQEICR**	**SQEIQP**	**SQEIPC**	**SQEI-I&M**
p1	9	49	9	49	25	81	25	49
p2	81	1	81	9	49	25	81	1
p3	9	81	25	81	9	49	9	25
p4	25	9	49	25	81	9	1	9
p5	49	25	1	1	9	1	49	81
SQDPs	173	165	165	165	173	165	165	165
	13	13	13	13	13	13	13	13
p1	0	1	0	1	0	1	0	1
p2	1	0	1	0	1	0	1	0
p3	0	1	0	1	0	1	0	0
p4	0	0	1	0	1	0	0	0
p5	1	0	0	0	0	0	1	1
SQDPs	**SQECP**	**SQECD**	**SQECS**	**SQEIQM**	**SQEICR**	**SQEIQP**	**SQEIPC**	**SQEI-I&M**
p1	0.02	0.05	0.01	0.04	0.03	0.05	0.03	0.03
p2	0.05	0.01	0.04	0.02	0.05	0.03	0.05	0.00
p3	0.02	0.06	0.02	0.05	0.02	0.04	0.02	0.02
p4	0.03	0.02	0.03	0.03	0.06	0.02	0.01	0.01
p5	0.04	0.04	0.00	0.01	0.02	0.01	0.04	0.04
A* =	0.05	0.06	0.04	0.05	0.06	0.05	0.05	0.04
A' =	0.02	0.01	0.00	0.01	0.02	0.01	0.01	0.00
SQDPs	**SQECP**	**SQECD**	**SQECS**	**SQEIQM**	**SQEICR**	**SQEIQP**	**SQEIPC**	**SQEI-I&M**
P1	0.0013	0.0002	0.0005	0.0001	0.0007	0.0000	0.0005	0.0001
P2	0.0000	0.0031	0.0000	0.0011	0.0002	0.0005	0.0000	0.0010
P3	0.0013	0.0000	0.0002	0.0000	0.0017	0.0001	0.0011	0.0002
P4	0.0006	0.0018	0.0001	0.0005	0.0000	0.0011	0.0019	0.0005
P5	0.0001	0.0008	0.0010	0.0019	0.0017	0.0019	0.0001	0.000000
SQDPs	**SQECP**	**SQECD**	**SQECS**	**SQEIQM**	**SQEICR**	**SQEIQP**	**SQEIPC**	**SQEI-I&M**
P1	0.0000	0.0018	0.0001	0.0011	0.0002	0.0019	0.0005	0.0005
P2	0.0013	0.0000	0.0010	0.0001	0.0007	0.0005	0.0019	0.0000
P3	0.0000	0.0031	0.0002	0.0019	0.0000	0.0011	0.0001	0.0002
P4	0.0001	0.0002	0.0005	0.0005	0.0017	0.0001	0.0000	0.0001
P5	0.0006	0.0008	0.0000	0.0000	0.0000	0.0000	0.0011	0.0010

Evaluation of SQDPs for VERY IMPORTANT criteria with TOPSIS method

↑	↑	↑	↑	↓	↑
0.06	0.08	0.04	0.05	0.07	0.06
SQEICA	SQCCPQ	SRMISE	MSQPSPM	T&IQTFMEA	COPQM&T
7	7	7	3	7	5
3	3	1	9	1	7
1	9	5	1	5	3
5	3	3	7	3	9
7	1	1	5	9	1
0	0	0	0	0	0
SQEICA	SQCCPQ	SRMISE	MSQPSPM	T&IQTFMEA	COPQM&T
49	49	49	9	49	25
9	9	1	81	1	49
1	81	25	1	25	9
25	9	9	49	9	81
49	1	1	25	81	1
133	149	85	165	165	165
12	12	9	13	13	13
1	1	1	0	1	0
0	0	0	1	0	1
0	1	1	0	0	0
0	0	0	1	0	1
1	0	0	0	1	0
SQEICA	SQCCPQ	SRMISE	MSQPSPM	T&IQTFMEA	COPQM&T
0.04	0.05	0.03	0.01	0.04	0.02
0.02	0.02	0.00	0.04	0.01	0.03
0.01	0.06	0.02	0.00	0.03	0.01
0.03	0.02	0.01	0.03	0.02	0.04
0.04	0.01	0.00	0.02	0.05	0.00
0.04	0.06	0.03	0.04	0.01	0.04
0.01	0.01	0.00	0.00	0.05	0.00

SQEICA	SQCCPQ	SRMISE	MSQPSPM	T&IQTFMEA	COPQM&T	P.I.S
0.0000	0.0002	0.0000	0.0005	0.0011	0.0003	0.0585
0.0004	0.0015	0.0007	0.0000	0.0000	0.0001	0.0698
0.0010	0.0000	0.0001	0.0010	0.0005	0.0008	0.0667
0.0001	0.0015	0.0003	0.0001	0.0001	0.0000	0.0766
0.0000	0.0027	0.0007	0.0002	0.0019	0.0014	0.0867
SQEICA	SQCCPQ	SRMISE	MSQPSPM	T&IQTFMEA	COPQM&T	N.I.S
0.0010	0.0015	0.0007	0.0001	0.0001	0.0003	0.0739
0.0001	0.0002	0.0000	0.0010	0.0019	0.0008	0.0745
0.0000	0.0027	0.0003	0.0000	0.0005	0.0001	0.0805
0.0004	0.0002	0.0001	0.0005	0.0011	0.0014	0.0563
0.0010	0.0000	0.0000	0.0002	0.0000	0.0000	0.0495

Continue: Evaluation of SQDPs for VERY IMPORTANT criteria with TOPSIS method

Appendix C: Ideal solution in TOPSIS for criteria in three categories

SQDPs	SQECP	SQECD	SQECS	SQEIQM	SQEICR	SQEIQP	SQEIPC	SQEI-I&M	SQEICA
P1	0.0013	0.0002	0.0005	0.0001	0.0007	0.0000	0.0005	0.0001	0.0000
P2	0.0000	0.0031	0.0000	0.0011	0.0002	0.0005	0.0000	0.0010	0.0004
P3	0.0013	0.0000	0.0002	0.0000	0.0017	0.0001	0.0011	0.0002	0.0010
P4	0.0006	0.0018	0.0001	0.0005	0.0000	0.0011	0.0019	0.0005	0.0001
P5	0.0001	0.0008	0.0010	0.0019	0.0017	0.0019	0.0001	0.000000	0.0000
SQDPs	**SQECP**	**SQECD**	**SQECS**	**SQEIQM**	**SQEICR**	**SQEIQP**	**SQEIPC**	**SQEI-I&M**	**SQEICA**
P1	0.0000	0.0018	0.0001	0.0011	0.0002	0.0019	0.0005	0.0005	0.0010
P2	0.0013	0.0000	0.0010	0.0001	0.0007	0.0005	0.0019	0.0000	0.0001
P3	0.0000	0.0031	0.0002	0.0019	0.0000	0.0011	0.0001	0.0002	0.0000
P4	0.0001	0.0002	0.0005	0.0005	0.0017	0.0001	0.0000	0.0001	0.0004
P5	0.0006	0.0008	0.0000	0.0000	0.0000	0.0000	0.0011	0.0010	0.0010

Ideal solution A* matrix in TOPSIS model of very important category

SQDPs	SQEMCBA	SQEMER	SQCEF	SQESD	SQEISM	SQEI-P&P
p1	0.0778	0.5449	0.4336	0.3111	0.5449	0.6070
p2	**0.2335**	**0.3892**	**0.6070**	**0.5185**	**0.0778**	**0.2601**
p3	0.5449	0.7006	0.2601	0.7259	0.3892	0.4336
p4	0.3892	0.2335	0.6070	0.3111	0.2335	0.6070
p5	0.7006	0.0778	0.0867	0.1037	0.7006	0.0867
weight	0.0200	0.0200	0.0400	0.0200	0.0200	0.0200
SQDPs	SQEMCBA	SQEMER	SQCEF	SQESD	SQEISM	SQEI-P&P
p1	0.0016	0.0109	0.0173	0.0062	0.0109	0.0121
p2	0.0047	0.0078	0.0243	0.0104	0.0016	0.0052
p3	0.0109	0.0140	0.0104	0.0145	0.0078	0.0087
p4	0.0078	0.0047	0.0243	0.0062	0.0047	0.0121
p5	0.0140	0.0016	0.0035	0.0021	0.0140	0.0017
A* =	0.0140	0.0140	0.0243	0.0145	0.0140	0.0121
A' =	0.0016	0.0016	0.0035	0.0021	0.0016	0.0017
SQDPs	SQEMCBA	SQEMER	SQCEF	SQESD	SQEISM	SQEI-P&P
p1	0.000155	0.000010	0.000048	0.000069	0.000010	0.000000
p2	0.000087	0.000039	0.000000	0.000017	0.000155	0.000048
p3	0.000010	0.000000	0.000192	0.000000	0.000039	0.000012
p4	0.000039	0.000087	0.000000	0.000069	0.000087	0.000000
p5	0.000000	0.000155	0.000433	0.000155	0.000000	0.000108
SQDPs	SQEMCBA	SQEMER	SQCEF	SQESD	SQEISM	SQEI-P&P
p1	0.000000	0.000087	0.000192	0.000017	0.000087	0.000108
p2	0.000010	0.000039	0.000433	0.000069	0.000000	0.000012
p3	0.000087	0.000155	0.000048	0.000155	0.000039	0.000048
p4	0.000039	0.000010	0.000433	0.000017	0.000010	0.000108
p5	0.000155	0.000000	0.000000	0.000000	0.000155	0.000000

Ideal solution A* matrix in TOPSIS model of important category

SQEIEPC	SQCISO	SQCECS	SQCMSR	SQCIC	SQCSA	SQCCTS
0.5449	0.0925	0.3111	0.2601	0.5735	0.4789	0.3892
0.2335	**0.2774**	**0.1037**	**0.6070**	**0.7373**	**0.6705**	**0.0778**
0.7006	0.4623	0.3111	0.4336	0.2458	0.2873	0.2335
0.3892	0.8321	0.5185	0.0867	0.2458	0.0958	0.5449
0.0778	0.0925	0.7259	0.6070	0.0819	0.4789	0.7006
0.0200	0.0200	0.0300	0.0400	0.0200	0.0400	0.0300
SQEIEPC	**SQCISO**	**SQCECS**	**SQCMSR**	**SQCIC**	**SQCSA**	**SQCCTS**
0.0109	0.0018	0.0093	0.0104	0.0115	0.0192	0.0117
0.0047	0.0055	0.0031	0.0243	0.0147	0.0268	0.0023
0.0140	0.0092	0.0093	0.0173	0.0049	0.0115	0.0070
0.0078	0.0166	0.0156	0.0035	0.0049	0.0038	0.0163
0.0016	0.0018	0.0218	0.0243	0.0016	0.0192	0.0210
0.0140	0.0166	0.0218	0.0243	0.0147	0.0268	0.0210
0.0016	0.0018	0.0031	0.0035	0.0016	0.0038	0.0023
SQEIEPC	**SQCISO**	**SQCECS**	**SQCMSR**	**SQCIC**	**SQCSA**	**SQCCTS**
0.000010	0.000219	0.000155	0.000192	0.000011	0.000059	0.000087
0.000087	0.000123	0.000348	0.000000	0.000000	0.000000	0.000349
0.000000	0.000055	0.000155	0.000048	0.000097	0.000235	0.000196
0.000039	0.000000	0.000039	0.000433	0.000097	0.000528	0.000022
0.000155	0.000219	0.000000	0.000000	0.000172	0.000059	0.000000
SQEIEPC	**SQCISO**	**SQCECS**	**SQCMSR**	**SQCIC**	**SQCSA**	**SQCCTS**
0.000087	0.000000	0.000039	0.000048	0.000097	0.000235	0.000087
0.000010	0.000014	0.000000	0.000433	0.000172	0.000528	0.000000
0.000155	0.000055	0.000039	0.000192	0.000011	0.000059	0.000022
0.000039	0.000219	0.000155	0.000000	0.000011	0.000000	0.000196
0.000000	0.000000	0.000348	0.000433	0.000000	0.000235	0.000349

Continue: Ideal solution A* matrix in TOPSIS model of important category

SQCPC	SQCPR	RSSI	RSERI	SRMFFC
0.2335	0.5449	0.7006	0.2335	0.2335
0.7006	**0.2335**	**0.3892**	**0.0778**	**0.3892**
0.0778	0.3892	0.0778	0.7006	0.5449
0.3892	0.7006	0.5449	0.5449	0.0778
0.5449	0.0778	0.2335	0.3892	0.7006
0.0300	0.0200	0.0500	0.0400	0.0500
SQCPC	**SQCPR**	**RSSI**	**RSERI**	**SRMFFC**
0.0070	0.0109	0.0350	0.0093	0.0117
0.0210	0.0047	0.0195	0.0031	0.0195
0.0023	0.0078	0.0039	0.0280	0.0272
0.0117	0.0140	0.0272	0.0218	0.0039
0.0163	0.0016	0.0117	0.0156	0.0350
0.0210	0.0140	0.0039	0.0280	0.0350
0.0023	0.0016	0.0350	0.0031	0.0039
SQCPC	**SQCPR**	**RSSI**	**RSERI**	**SRMFFC**
0.000196	0.000010	0.000970	0.000349	0.000545
0.000000	0.000087	0.000242	0.000621	0.000242
0.000349	0.000039	0.000000	0.000000	0.000061
0.000087	0.000000	0.000545	0.000039	0.000970
0.000022	0.000155	0.000061	0.000155	0.000000
SQCPC	**SQCPR**	**RSSI**	**RSERI**	**SRMFFC**
0.000022	0.000087	0.000000	0.000039	0.000061
0.000349	0.000010	0.000242	0.000000	0.000242
0.000000	0.000039	0.000970	0.000621	0.000545
0.000087	0.000155	0.000061	0.000349	0.000000
0.000196	0.000000	0.000545	0.000155	0.000970

Continue: Ideal solution A* matrix in TOPSIS model of important category

SRMLTR	SRMCFT	SRMSQI	MSQPQS	MSQPSEC	T&IQTMAPQP	T&IQSPAPQP
0.7006	0.3892	0.3892	0.7006	0.2335	0.3111	0.7006
0.3892	**0.7006**	**0.7006**	**0.5449**	**0.7006**	**0.1037**	**0.3892**
0.2335	0.5449	0.5449	0.2335	0.3892	0.5185	0.2335
0.0778	0.2335	0.2335	0.0778	0.0778	0.3111	0.5449
0.5449	0.0778	0.0778	0.3892	0.5449	0.7259	0.0778
0.0400	0.0300	0.0400	0.0400	0.0500	0.0300	0.0400
SRMLTR	**SRMCFT**	**SRMSQI**	**MSQPQS**	**MSQPSEC**	**T&IQTMAPQP**	**T&IQSPAPQP**
0.0280	0.0117	0.0156	0.0280	0.0117	0.0093	0.0280
0.0156	0.0210	0.0280	0.0218	0.0350	0.0031	0.0156
0.0093	0.0163	0.0218	0.0093	0.0195	0.0156	0.0093
0.0031	0.0070	0.0093	0.0031	0.0039	0.0093	0.0218
0.0218	0.0023	0.0031	0.0156	0.0272	0.0218	0.0031
0.0280	0.0210	0.0280	0.0280	0.0039	0.0031	0.0031
0.0031	0.0023	0.0031	0.0031	0.0350	0.0218	0.0280
SRMLTR	**SRMCFT**	**SRMSQI**	**MSQPQS**	**MSQPSEC**	**T&IQTMAPQP**	**T&IQSPAPQP**
0.000000	0.000087	0.000155	0.000000	0.000061	0.000039	0.000621
0.000155	0.000000	0.000000	0.000039	0.000970	0.000000	0.000155
0.000349	0.000022	0.000039	0.000349	0.000242	0.000155	0.000039
0.000621	0.000196	0.000349	0.000621	0.000000	0.000039	0.000349
0.000039	0.000349	0.000621	0.000155	0.000545	0.000348	0.000000
SRMLTR	**SRMCFT**	**SRMSQI**	**MSQPQS**	**MSQPSEC**	**T&IQTMAPQP**	**T&IQSPAPQP**
0.000621	0.000087	0.000155	0.000621	0.000545	0.000155	0.000000
0.000155	0.000349	0.000621	0.000349	0.000000	0.000348	0.000155
0.000039	0.000196	0.000349	0.000039	0.000242	0.000039	0.000349
0.000000	0.000022	0.000039	0.000000	0.000970	0.000155	0.000039
0.000349	0.000000	0.000000	0.000155	0.000061	0.000000	0.000621

Continue: Ideal solution A* matrix in TOPSIS model of important category

T&IQTSPS	T&IQTCI	COPQR	COPQI
0.0778	0.5449	0.5449	0.5449
0.3892	**0.0778**	**0.7006**	**0.2335**
0.5449	0.7006	0.2335	0.3892
0.2335	0.3892	0.0778	0.7006
0.7006	0.2335	0.3892	0.0778
0.0400	0.0500	0.0600	0.0500
T&IQTSPS	**T&IQTSPS**	**COPQR**	**COPQI**
0.0031	0.0272	0.0327	0.0272
0.0156	0.0039	0.0420	0.0117
0.0218	0.0350	0.0140	0.0195
0.0093	0.0195	0.0047	0.0350
0.0280	0.0117	0.0234	0.0039
0.0031	0.0039	0.0047	0.0039
0.0280	0.0350	0.0420	0.0350
T&IQTSPS	**T&IQTCI**	**COPQR**	**COPQI**
0.000000	0.000545	0.000785	0.000545
0.000155	0.000000	0.001396	0.000061
0.000349	0.000970	0.000087	0.000242
0.000039	0.000242	0.000000	0.000970
0.000621	0.000061	0.000349	0.000000
T&IQTSPS	**T&IQTCI**	**COPQR**	**COPQI**
0.000621	0.000061	0.000087	0.000061
0.000155	0.000970	0.000000	0.000545
0.000039	0.000000	0.000785	0.000242
0.000349	0.000242	0.001396	0.000000
0.000000	0.000545	0.000349	0.000970

Continue: Ideal solution A* matrix in TOPSIS model of important category

A* =	0.14	0.12	0.13	0.02	0.02	0.01	
A' =	0.02	0.01	0.01	0.07	0.15	0.08	
SQDPs	**SQE-MDA**	**SQE-CEHS**	**SQC-ENW**	**RSP-TE**	**RSP-P&P**	**CNS-QE&CR**	**P.I.S**
p1	0.00	0.01	0.01	0.00	0.01	0.00	0.18
p2	0.00	0.00	0.00	0.00	0.00	0.00	0.11
p3	0.00	0.01	0.01	0.00	0.00	0.00	0.16
p4	0.01	0.00	0.00	0.00	0.00	0.01	0.14
p5	0.02	0.00	0.00	0.00	0.02	0.00	0.20
SQDPs	**SQE-MDA**	**SQE-CEHS**	**SQC-ENW**	**RSP-TE**	**RSP-P&P**	**CNS-QE&CR**	**N.I.S**
p1	0.02	0.00	0.00	0.00	0.00	0.00	0.15
p2	0.00	0.01	0.01	0.00	0.00	0.00	0.18
p3	0.00	0.00	0.00	0.00	0.01	0.00	0.13
p4	0.00	0.00	0.01	0.00	0.02	0.00	0.17
p5	0.00	0.01	0.00	0.00	0.00	0.01	0.12

Ideal solution A* matrix in TOPSIS model of somewhat important category

Appendix D: Cover letter and survey format.

You are being invited to voluntarily fill-in the criteria Evaluation survey for supplier quality development. The purpose of this survey is to find importance of provided criteria for evaluation of supplier quality Development activities.

Please rate each criterion and sub criteria related to importance of that for SQD with four scales:

- Indifferent
- Not Important
- Somewhat Important
- Important
- Very Important

You can modify and put any comments based on your experience .Your assistance in completing and returning this survey relating to my research project "A multi-criteria framework for Supplier Quality Development "For completing my master in quality system engineering will be greatly appreciated.my contact number is 514-659-0055 and my email is Noshadravan1@yahoo.com.

Best Regards

Khosrow Noshad

Supplier Quality Development survey

Your Function: Country:

Number of suppliers dealt with: Industry Type:

Other Comments:

No	Criteria	Please rate the following items as (Indifferent, Not Important, Somewhat Important, Important, Very Important)
1	**Supplier quality Evaluation**	
1-1	Methods used for supplier evaluation	
1-1-1	Cost Benefit Analysis	
1-1-2	Data Analysis (Monitoring growth using historical data)	
1-1-3	Expert Ratings (Buyers, Departmental Heads)	
1-1-4	Others (Please specify...)	
1-2	Criteria for evaluating suppliers	
1-2-1	Price: The amount paid by the enterprise to buy goods from its suppliers	
1-2-2	Delivery performance: How well a supplier succeeds in delivering goods according to schedule?	
1-2-3	Service: The after-sales service and support provided by a supplier.	
1-2-4	Flexibility: The ability of a supplier to accommodate changes in the enterprise's production plans	
1-2-5	Environment, health and safety	
1-3	Frameworks used for supplier evaluation	
1-3-1	ISO 9000	
1-3-2	Malcolm Baldrige	
1-3-3	EFQM	

No	Criteria	Please rate the following items as (Indifferent, Not Important, Somewhat Important, Important, Very Important)
1-4	System used for inputting data	
1-4-1	Manually form	
1-4-2	A web based evaluation system	
1-5	Items to be evaluated	
1-5-1	Quality management and organization policy	
1-5-2	Understanding of customer requirements	
1-5-3	Staff training and motivation	
1-5-4	Management of product and process evolution.	
1-5-5	Quality of products received from suppliers	
1-5-6	Process control	
1-5-7	Inspection programs and measurement quality	
1-5-8	Process complaints	
1-5-9	A system for corrective action in areas that are not meeting requirements	
2	**Supplier qualification/certification**	
2-1	Monitor supplier certifications and quality system	
2-1-1	ISO 9001	
2-1-2	Qs 9000	
2-1-3	ISO 14000	
2-1-4	AS 9100	
2-1-5	NADCAP / PRI	
2-2	Monitor Safety and risk assessment	
2-2-1	Establish consistent safety standards	
2-2-2	Monitor supplier risk	
2-2-3	Verify insurance coverage	
2-3	Practices to ensure potential suppliers meet product quality requirements	
2-3-1	Communicate product quality	

No	Criteria	Please rate the following items as (Indifferent, Not Important, Somewhat Important, Important, Very Important)
2-3-2	Requirements Collect and review supplier self-assessments	
2-3-3	Confirm sample products' quality levels	
2-3-3-1	Conformance to specifications	
2-3-3-2	Process capability	
2-3-3-3	Product reliability	
3	**Reward superior supplier performance and improvement**	
3-1	Honours outstanding suppliers with mark of excellence and targets for excellence driven quality's supplier award	
3-2	Publicity and personal ceremonies	
3-3	Supplier incentives	
3-4	Eliminate receiving inspection on supplier's material	
4	**Supplier relationship management (SRM)**	
4-1	Face to face Communication	
4-2	Long-term relationship	
4-3	Cross functional team	
4-4	Shared quality information	
4-5	Involve suppliers early in product and process development	
5	**Measure supplier quality performance**	
5-1	Quality scorecard	
5-2	Supplier Performance Monitoring	
5-3	A system for emerging capability of suppliers	

No	Criteria	Please rate the following items as (Indifferent, Not Important, Somewhat Important, Important, Very Important)
6	**Training and implementation of quality tools and methodologies (FMEA AND APQP, Problem solving method, six sigma)**	
6-1	A formal process defining the APQP process	
6-2	A tracking system available to monitor the stages of APQP process	
6-3	Consideration of best practices and lessons learned from similar part DFMEA,FMEA	
6-4	Utilize a team approach and structured problem solving tools and methodologies such as 5-Why, Fault Tree/Fishbone Diagram, six sigma, lean , kaizen	
6-5	Continuous improvement program for suppliers to ensure improvements to quality, service, productivity	
7	**Cost of poor quality**	
7-1	Proactively work with suppliers to improve their quality for reducing their own COPQ	
7-2	Utilize a programme of improvement initiatives such as capacity improvement, scrap reduction and cost control for suppliers	
7-3	Measuring & tracking cost of poor quality for suppliers	
8	**Commit the necessary resources to supplier quality development**	
8-1	Quality development engineer/ representative t of company in suppliers site	
8-2	Sending instructors and technical consultants to supplier's site	

THANK YOU