Supplier Selection and Supplier Management Improvements at an Analytical Instrument Manufacturing Company

by

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Abstract

This thesis addresses the challenges of improving the quality of parts received from suppliers at Waters, an analytical instrument manufacturing company. Preliminary analysis identified improvement opportunities at evaluation of supplier's capability, agreement on requirements with suppliers at early supplier selection stage as well as closed loop supplier management. A 4-step sequential process was designed to improve the supplier selection and management process. First, an initial supplier capability assessment process is incorporated in the quotation process and the Analytical Hierarchy Process is used to make an integrated supplier selection decision. Second, a production part approval process ensures that the supplier fully understands the requirements and proves whether or not it can meet the requirements consistently. Third, a formal inspection report acceptance process for the new product is established to utilize the supplier's inspection resource. Fourth, a formal supplier corrective request process for nonconformance is suggested to provide corrective feedback to the supplier in addition to instructions for improvement.

The overall new supplier selection and management process is expected to benefit both Waters and the suppliers. The suggested process is expected to have more visibility to the supplier's capability and improve the supplier quality. The non-value added activities such as incoming inspection rejections and the related disposition process are to be reduced and thus cost saving can be achieved.

Thesis Supervisor: Dr. Jung-Hoon Chun
Title: Professor of Mechanical Engineering

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Chapter 1 Introduction

1.1 Background and Project Motivation

Waters Corporation is an analytical instrument manufacturer that designs, manufactures, sells and services instrument systems and the accessories through its two business segments, Waters Division and TA Division. Waters Division mainly focuses on High Performance Liquid Chromatography (HPLC), Ultra Performance Liquid Chromatography (UPLC) and Mass Spectrometry (MS) product portfolios. TA Division primarily focuses on thermal analysis, rheometry and calorimetry instruments. The company's products are used in a broad range of industries, pharmaceutical sectors, research centers, universities and governmental customers.

The company is active in investment in research and design to improve its current products and as well as to commercialize new products. The company has been continuously increasing its investment in research and development, 92 million and 96 million and 101 million in 2011, 2012 and 2013, respectively.

Waters Milford Massachusetts is the global operation center of the company. It produces HPLC and UPLC instruments and the associated accessories. It is also the center of innovation and new product commercialization of the company. Almost all of the company's Liquid Chromatography products are developed at Milford. The Milford office has about 25 new product introductions every year. Therefore, it is necessary for the company to have a robust and efficient new product commercialization process. The manufacturing, quality and environment management should also comply with the ISO

standards and the US Food and Drug Administration (FDA) regulations. In order to achieve these objectives, the company has established Corporate Instrument Development Process (CIDP) a few years ago and it is being reviewed and adjusted to better fit the company's development. In this project, we will focus on the new product introduction (NPI) process, which is one crucial part of the instrument development process. NPI provides support to R&D to test the manufacturability and quality of the new product, as well as establishes a feasible process for volume production. The current process will be examined to identify the gaps of the process and a new process will be reengineered.

1.2 Waters New Product Introduction Process Overview

The following procedure flow in Figure 1 shows the major phases of new product introduction process at Waters Milford.

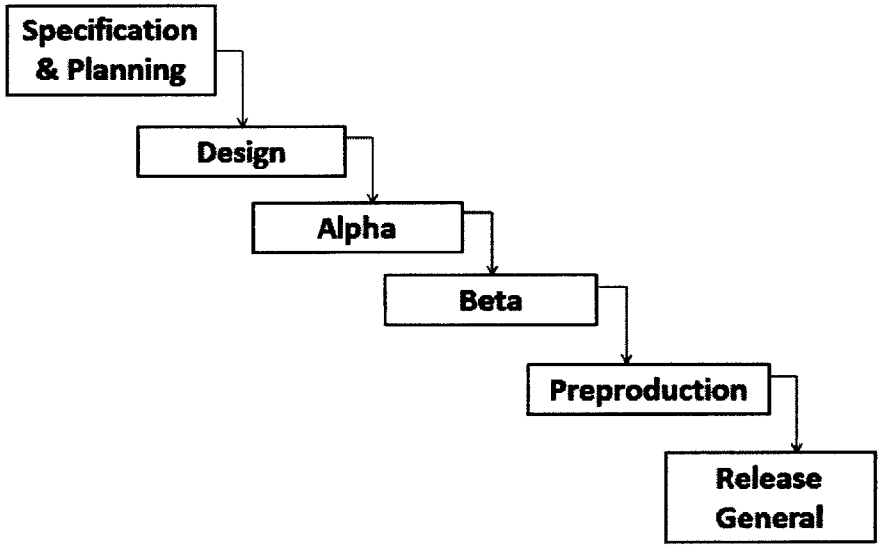

Figure 1: New product introduction process

During the specification phase, the project plans, manufacturing plans and service plans are created. The project cost is estimated, and a schedule is proposed. The design is tested in Alpha and Beta phases when procurement, building, evaluation and reengineering process happen iteratively to ensure the design can be manufactured and meets customer requirement. These are the phases where most engineering changes take place. At alpha phase, no structured engineering change order (ECO) is required from the R&D which gives the engineer the maximum flexibility to test the design. After alpha phase, the product should have its core product performance. Formal ECO is supposed to be generated for every engineering change. After beta phase, the product should be close to the final product and have well defined build process, test process and supply chain process within the cost estimation. First customer shipment happens in preproduction phase, and the product is transferred from NPI to full production team.

The key areas of activities of the flow include project management, supply chain, production and quality assurance activities. The team uses supply chain activities as a starting point to identify the key areas that need to be reengineered because of the most manifest problem identified in the incoming material inspection area.

1.3 Problems

The inspection area activity is now the bottleneck of the new product introduction process. It takes a long time to inspect all of the features of the parts and it is often too late to identify the parts that do not meet the design requirements. The rejection rate of the inspected parts is also high. Every rejection at the inspection will have a

nonconformance quality record raised in the TRACKWISE system, which is a quality management system used at Waters. The nonconformance quality records are categorized by the root causes as shown in Figure 2. The top three root causes are due to supplier, design and process.

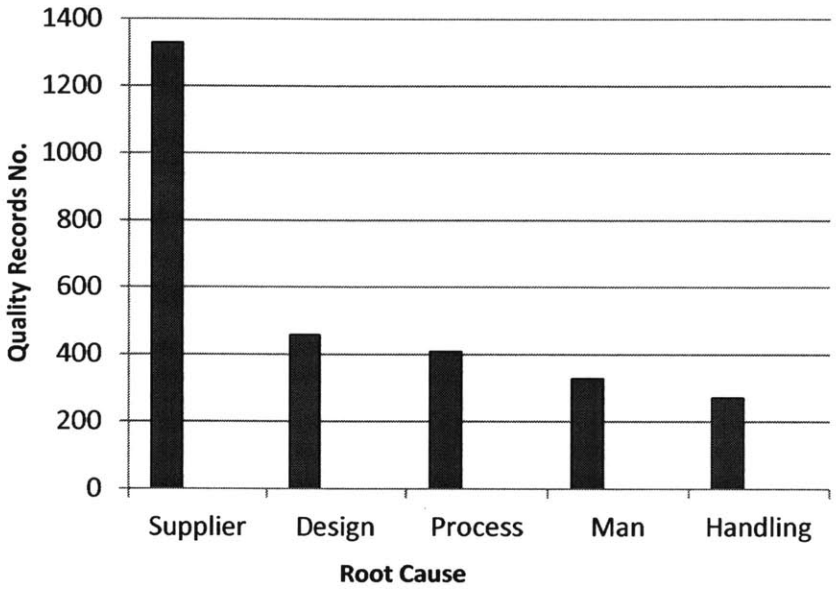

Figure 2: Quality records by root cause category

The problems manifested at the incoming inspection area can be traced upstream to supplier selection, management process and design process. No formal process is defined for supplier selection and management, and neither for the design documentation.

1.4 Objective and Scope

The overall objective of this project is to optimize the Waters commercialization process in order to shorten time to market, to improve project management and communication as well as to strengthen compliance to FDA compliance. The team will

focus on the supply chain process for new product, the new product introduction process as well as its interactions with the product design and development process.

The problems described above in Section 1.3 are not created by a single activity. It is the combination of the individual activities within a department and the flow of the activities between departments that determine a smooth process. The objective of the group's effort is to map the current new product introduction process and reengineer a streamlined process to address the problems within each department's activities and the problems in the interactions of departments.

The team work is divided into three areas. The author is responsible for reengineering the supplier selection and supplier performance management process to ensure that the suppliers provide Waters with quality parts. Mr. Aditya Ranjan is responsible for reengineering the new product introduction process and its interaction with supply chain process [1]. Mr. Shubhang Tandon takes charge of mapping and proposing a new process for the entire new product design and development process [2].

Chapter 2 Literature Review

Instead of manufacturing all of the parts in house, companies outsource their product components to suppliers so that the companies can focus on the core technology development. Cost saving can also be achieved by outsourcing production to low cost locations. However, if the supply chain is not properly designed and managed, the risk of outsourcing is high. The research shows that the cost of poor quality covers 10%~25% of sales, and the cost due to poor supplier quality makes up 25%~70% of the total cost of poor quality [3]. The company's performance and customer satisfaction is increasingly relied on suppliers' performance. According to the Supplier Performance Measurement Benchmarking Project conducted by the Aberdeen Group [4], managing the supplier performance in the supply chain is a critical activity at most companies. The excellent performance of the suppliers drives the company to provide excellent products and service to its customers.

In this chapter, the main supplier management activities will be discussed including supplier qualification, supplier selection, supplier performance evaluation and supplier partnership from Section 2.1 to Section 2.4. Section 2.5 discusses the tools of quality for process improvement, which was used in this project for problem analysis.

2.1 Supplier Qualification

The supplier qualification program is a lengthy evaluation of the suppliers. Manufacturing companies generally keep a supplier resource pool. In order to be placed in the supplier resource pool for business consideration, the suppliers first need to pass

the supplier qualification. This is the initial stage of the supplier management process. Sherry Gordon has summarized the main steps for the supplier qualification or referred as supplier assessment [5].The qualification aspects are decided by the company depending the company's supply chain strategy. The general aspects include financial strength, operational performance, business process, cultural factors and risk factors. The method to conduct the qualification can be onsite visit, paper questionnaire, web based questionnaire and certifications or report from third party standards. Each of the method has its own benefits and challenges, making each suitable for evaluating certain aspects of the performance. The company has to make judgment on which method to take considering the cost and return on investment. For effective supplier performance management, actionable feedback rather than just performance report should be given to the suppliers. This helps suppliers build continuous improvement and also build long term supplier relationship.

2.2 Supplier Selection

The traditional supplier relationship based on low price is now changing into long term supplier relationship development. Therefore, choosing a supplier is dependent on not just price but a variety of factors which can generate best total value. The traditional decision making based on price for supplier selection can no longer meet the contemporary supplier management requirements [6]. The multiple criteria for selecting suppliers can be both qualitative and quantitative. The two main concerns for the procurement are first deciding on the important criteria to use and second making an

optimal decision based on multiple criteria. The following sections review the supplier selection criteria that are mostly used and the multi-criteria decision making models.

2.2.1 Supplier Selection Criteria

A review research conducted in 1991 by Weber classified all the supplier selection articles published since 1966 and concluded that price, delivery, quality and production capacity and location are the most evaluated criteria by the companies [7]. Based on Weber's study, Zhang et al. continued the classification by collecting 49 articles from 1991 to 2003 and concluded the most important supplier selection criteria are net price, quality and delivery [8].

Most recently, a study carried by William et al. in 2009 has reviewed 78 international journal articles regarding multi-criteria supplier evaluation and selection approaches published from 2000 to 2008 [9]. Their study shows that the most popular supplier selection criteria are quality, delivery, price/cost, manufacturing capability, service, management, technology, research and development, finance, flexibility, reputation, relationship, risk and safety. 87% of the research papers reflect that quality is the selection consideration. The main attributes of quality criteria can be summarized as acceptance rate, supplier quality management system and supplier's process control for good quality. 82% of the research papers report delivery as the selection criteria. The delivery factor includes delivery on time, lead time, geographical locations and delivery conditions. The third popular criteria price is reported in 80% of the research papers.

The price criterion includes price competitiveness, cost reduction, price fluctuation and shipment cost.

The criteria quality, price and delivery are the basic criteria that are always the considerations for supplier selections though the importance level varies among the studies. As the global sourcing strategy changes over the years, some new selection criteria such as technology, service, management and relationship are also becoming important supplier selection criteria.

2.2.2 Multi-Criteria Decision Making Approaches for Supplier Selection

The decision making for supplier selection is hard because multiple criteria need to be considered. Most of the time, it is difficult to have one supplier to be the best in all of the criteria. In addition to that, because some of the criteria are quantitative while the others are qualitative, it is hard to have a structured decision making process. The decision is usually made by the buyer based on intuitive thinking.

In the academic studies, several multi-criteria supplier selection models have been proposed such as data envelopment analysis (DEA), mathematical programming, analytical hierarchy process (AHP), case based reasoning, analytical network process, fuzzy set theory, simple multi-attribute rating technique, genetic algorithm and the integrated form of the models. The extensive research conducted by Ho et al. concluded that the top three most popular approaches are DEA, mathematical programming and AHP [9]. DEA has attracted more research attention due to its robustness. The integrated AHP with other methodology is the most prevalent one. The reason for its

wide application is its simplicity, easiness to use and flexibility in incorporation with other methods. The following section explains more about the AHP model.

An AHP model is developed to establish a structured decision making methodology when multiple criteria need to be considered [10]. The Analytical Hierarchy Process is a methodology to structure the supplier selection process. It has the benefit of including people's insight, experience and intuitive thinking in the evaluation process. The method has three hierarchy levels namely the goal, the criteria and the alternatives as shown in Figure 3. In the context of its application in supplier selection, the goal is the optimal supplier. The criteria are the factors that we will use to evaluate the suppliers such as quality, price, delivery and others. The alternatives are the potential suppliers.

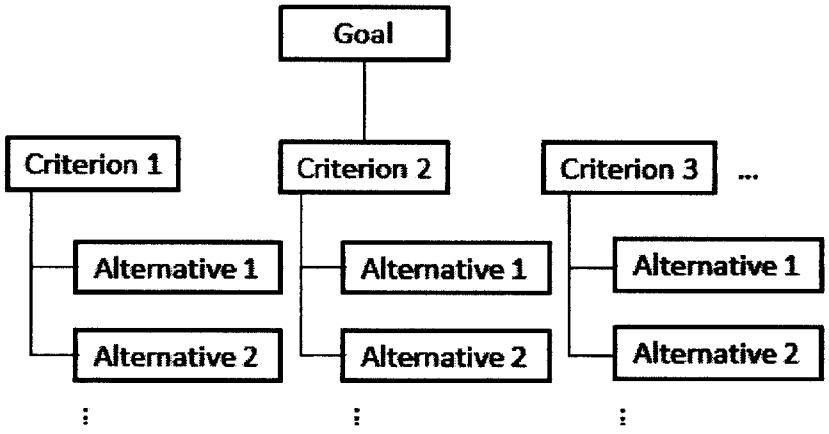

Figure 3: Analytical hierarchy process structure

The weight is assigned to each criterion by using a pair wise comparison matrix. This pair wise comparison matrix ensures that each criterion is evaluated over all of the other criteria and the final weight includes every paired comparison result. This method thus avoids biased consideration that focuses on only one or part of the factors. The same pair wise comparison is then conducted on the alternatives to give their score on each

criterion. The product of the criterion weight multiplied by one alternative's score on that criterion is the weighted score. The sum of the weighted score over all criteria is the final score for that alternative. The alternative with the highest score is the optimal choice.

This method developed in this project is established based on the AHP model, considering its easiness to use and relative robustness. The detail of the adoption of the method will be discussed in Section 4.2.

2.3 Supplier Performance Evaluation

Supplier performance evaluation is a process used to monitor the ongoing performance of the suppliers and to differentiate between suppliers. "Supplier performance evaluation includes the process of tracking, assessing and managing the supplier performance" [4]. The supplier performance is usually rated based on certain criteria such as quality, delivery, cost, services and others depending on the company's goal. Supplier performance management has the benefits of cost reduction, risk mitigation, and supplier performance improvement. Research shows that supplier performance management improves supplier performance by 26% [4]. Four key strategies that the best performance companies use were identified by the Aberdeen Aberdeen/iSource Supplier Performance Measurement Benchmarking Project [4]. First is to track the performance of a broader portion of the supplier base instead of only measuring the critical suppliers. The second is to have a standard supplier performance measurement procedure. The third is to work with supplier on improvements based on the evaluation

result. The last is to have an automate process for key supplier performance measurement activities.

The white paper published by MetricStream [11] reported the best practices in supplier quality management. One of them is to use scorecard to track the performance of the supplier based on the fact and reflects the supplies performance over time. Research has also been done by Robert J. Trent to explore how to create an effective supplier scorecard [12]. The key characteristics of an ideal scorecard system are identified by working with hundreds of supply chain organizations. Some of the key characteristics are summarized here. Other than just recording the quantitative data in the system, the internal participants should be able to give comments and ratings to the supplier's qualitative performance metrics. Scorecard should be reviewed and acknowledged by the supplier's managers. Only when the suppliers use the scorecard, the suppliers and customer can work on the same page to improve the process. The research shows that many companies do not show the rank of the supplier's performance due to confidentiality or they just do not have the awareness to give ranks. The ranking position of a supplier among the relative commodity group could be shown to the suppliers to create healthy competition. Most scorecards include quality, on time delivery and price as the measurement metrics, but cost based measures are usually not included. The total cost metrics include any quality or performance infraction into the cost of doing business with a supplier other than just the price.

The piece price of the part is usually the driving factor for a supplier selection decision making and also the performance monitoring of suppliers. However, the piece price usually includes only the supplier's manufacturing cost, overhead cost and profit, which is only part of the true cost borne by the customer's organization. When a supplier's quality does not meet the requirement, wastes can be realized and is usually carried by the customer. The resource spending on inspection of the receiving part and any additional test caused by the poor quality is one expensive item. Rework and repair of the supplier material are also costs to the company. Other than just the obvious monetary cost, additional processes have to be carried out to deal with the bad parts when they enter the value stream. More serious quality issue can create production line shutdown and can create problems in meeting the production schedule. Other costs are the costs of labor involved in the whole process to deal with the quality issues [13, 14]. These are just some of the wastes created because of poor supplier quality. The good supplier performance management tracks as many cost elements as possible to change the supplier management strategy.

The other good practice of supplier quality management is to have a closed loop corrective action [11]. Once a problem is identified, investigations need to be conducted to identify the root cause. Effective corrective actions need to be implemented to correct the problem and prevent future occurrence either at the suppliers or within the company itself. It is necessary to have an integrated close loop quality management system rather than just several separated function modules. The close loop quality

management ensures tracking the cost of poor quality. It is also valuable in identifying and eliminating the waste in the supply chain process.

2.4 Supplier Partnership

Supplier partnership relationship is being adopted by many companies inspired by the lean purchasing idea. Instead of frequently failing the suppliers and switching to other suppliers, company tends to work with less number of suppliers and develop these suppliers into long term partnership. The suppliers' performance is improved in the partnership relationship, which in return benefits the company [13].

On the 91st annual international supply management conference, it was addressed the importance of clear communication of requirements between supplier and customer. 50% of the cause of nonconformance is lack of proper communication on the requirements between supplier and customer. The requirements can be classified in three categories. Product specifications are the customer defined performance requirements. Process specifications define the manufacturing and control processes. The last one is service specifications including delivery requirement, support, certificates and other services required by the customer [6].

Production Part Approval Process (PPAP) is one of the partnership type supplier-customer relationships firstly developed in the automotive industry. The suppliers have to go through PPAP with the customer before any production part is shipped to customers. The process helps the company to establish confidence and trust in the suppliers' capability of producing good parts. The process makes sure that the

customers' design and specification requirements have been understood by the supplier and the supplier is capable to meet the requirements consistently. The quality management system should prevent nonconforming parts from being shipped to the customer. With the PPAP process, the manufacturer can fully trust the quality of the parts provided by the supplier. The received parts can be used immediately into production with little inspection. This eliminates the non-value added process of conducting extra inspection in the manufacturing value chain. The successful implementation of PPAP method enables the manufacturer to rely on robust and consistent supplier performance to achieve efficiency and cost reduction. After the success of PPAP in the automotive industry, the other industries start to implement the similar process in their system as well. The medical device industry is an industry that has to comply with strict regulatory for their quality and process control. The medical device companies that seek continued improvement on their supplier control start to monitor the supplier's production and process parameters. One of the strategies is the adoption of PPAP method. The PPAP method also complies with the FDA regulations of Good Manufacturing Practice (GMP) such as documented process control, verified process capability, identified critical characteristics and recorded inspection result [15].

In the process, a series of documents are required from the suppliers to prove their manufacturing process, control process, inspection process, process stability, risk management and others. Appendix I lists the documents that are included in the PPAP package. All of the documents in the PPAP package require approval by the customer.

Only when the customer has reviewed these documents and does not find any issues, the PPAP package will be approved.

2.5 Basic Tools for Quality

Ishikawa's basic seven tools of quality are often used in continuous improvement project. The seven tools include process map, check sheet, histogram, scatter plots, control charts, cause & effect diagrams and Pareto analysis [16]. The process map and Ishikawa diagram are the two quality tools that will be used later in the problem analysis section of the project. A process map is a diagram representation of a process. It is the first step in most process improvement project. It helps to visualize the process and identifies the part for improvement.

The other quality tool is cause& effect diagram also known as Ishikawa diagram. The cause & effect tool help to identify the root causes of a problem rather than just the symptoms. The diagram looks like a fishbone with the effect being the head and the ribs being the causes. The causes are grouped into several major categories. The typical cause categories used in manufacturing industry are the 6Ms namely machine, method, material, man, measurement and mother nature. The category varies based on the real problem. Under each category, the cause of problem is further explored.

These two methods are the major tools that this project team used to identify problems and improvement areas.

Chapter 3 Process Analysis of Current Supplier Selection and Management Process

A preliminary analysis of the supply chain process was conducted by interviews with key stakeholders, data collections from the system and corporate procedure documentations. Section 3.1 presents the data collected from TrackWise, a quality management system used at Waters. The current supply chain process and problems in the process are discussed in Section 3.2. Section 3.3 gives an overall analysis and summary of the problems identified in current process.

3.1 Preliminary Analysis on the Nonconformance due to Supplier Liability

TrackWise is the system used by Waters to keep track of the nonconformance. When a part is rejected at the incoming material inspection or at the assembly floor, it enters the nonconformance management process as shown in Figure 4. A nonconformance record (NCR) is then opened in the TrackWise system. The disposition and risk impact of the part is done at review and assessment process. The risk impact evaluation decides if further investigation is required or not. The root cause analysis identifies the responsibility of this nonconformance.

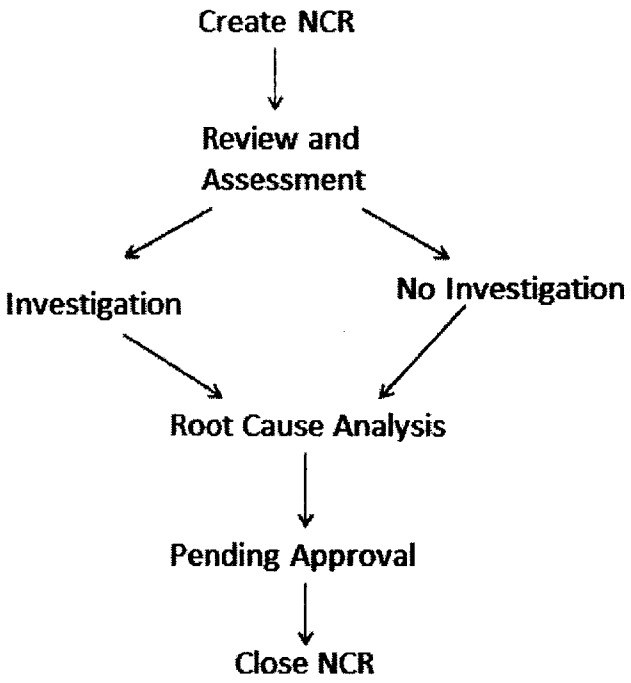

Figure 4: Nonconformance management process

Figure 2 in Section 1.3 presents the quality record by root cause category from TrackWise with data taken from Jan 2013 to Mar 2014. Each quality record may have different quantity of parts. Several part number of the same part rejected at the same time will be recorded as one quality record. The quality record due to supplier issues is 30% of the total quality record count. Even though out of the 30% quality records, some are both supplier and design liability, it is still an indication of suppliers unable to meet Waters' requirement.

These quality records due to supplier liability are further divided into symptom types and the top ones are shown in Table 1. The top three symptom types are dimension error, functional error and not resembling the drawing. Further investigation of the data

shows that the top nonconformance suppliers are sheet metal, machining and plastic suppliers.

Table 1: Top nonconformance symptom types

Symptom Type	Percentage (%)
Dimensional	17
Functional	14
Does not resemble drawing	9
Feature Missing	6
Burrs/Chips	5

In order to verify the performance of the current suppliers, 120 suppliers out of the 430 suppliers were selected and their acceptance and rejection data was collected. The 120 suppliers selected cover all commodity types. They also include all of the three categories: critical, subcritical and standard suppliers. The categories of the suppliers are discussed in Section 3.2.1. Figure 5 shows the acceptance rate and rejection rate due to supplier liability based on commodity types. Only the commodity types of the lowest acceptance rate and large order quantity are shown in this Figure 5. Other commodity types of acceptable acceptance rate or with low order quantity are not included here. Further investigation was conducted to identify the cause of the rejections. For the needle commodity type, the main rejection reason is finishing problems and scratches. For the manuals and glass capillary commodity type, labeling and barcoding are the major problems. By consulting with the supplier quality engineer, it is clarified that this is a miscommunication between supplier and Waters. For the distribution electrical commodity type, the main rejection reason is that the parts do not meet specifications.

For the plastic parts, machining parts and sheet metal parts, dimensional issues are the common rejection reasons.

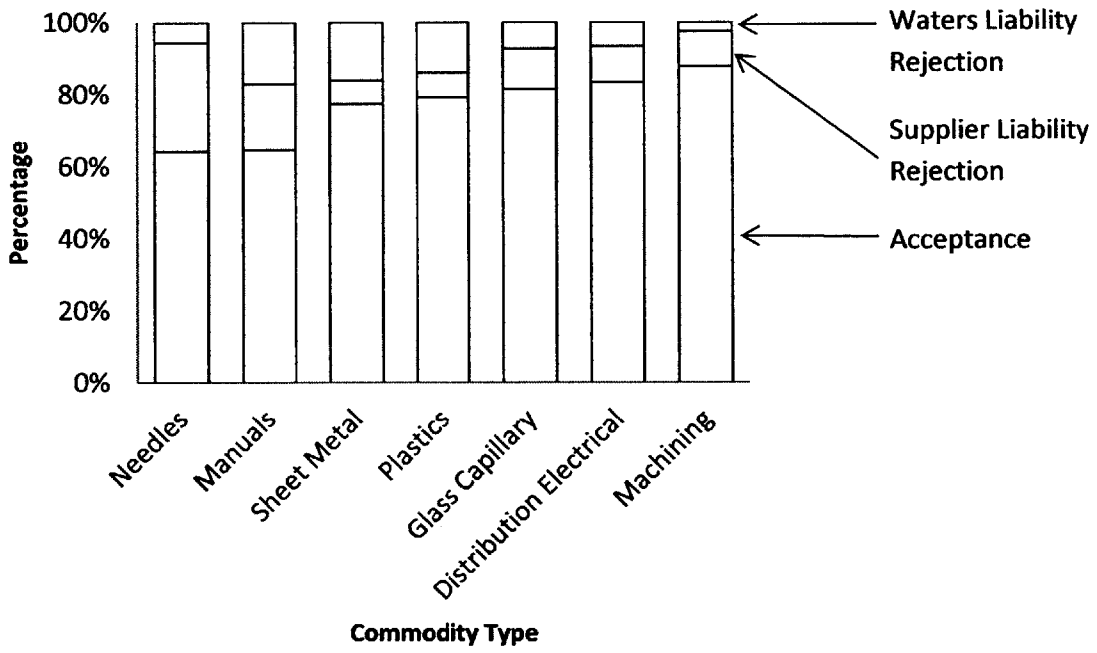

Figure 5: Commodities of lowest acceptance rate

Table 2 shows the acceptance and rejection rate due to supplier liability grouped by supplier category. The standard supplier acceptance rate is relatively lower as compared with critical and subcritical supplier.

Table 2: Acceptance and rejection rate based on supplier category

	No. of suppliers	Rejection rate due to supplier (%)	Acceptance rate (%)
Critical	17	0.95	99.02
Subcritical	16	0.37	99.41
Standard	87	3.61	94.95

3.2 Current Supplier Selection and Supplier Performance Management Process

The current supply chain system of Waters was studied by conducting interviews with the commodity managers, buyers, supplier quality engineers and the design engineers. A process map was created as shown in Figure 6. Each sub-process is explained and followed by the problems identified for that sub-process.

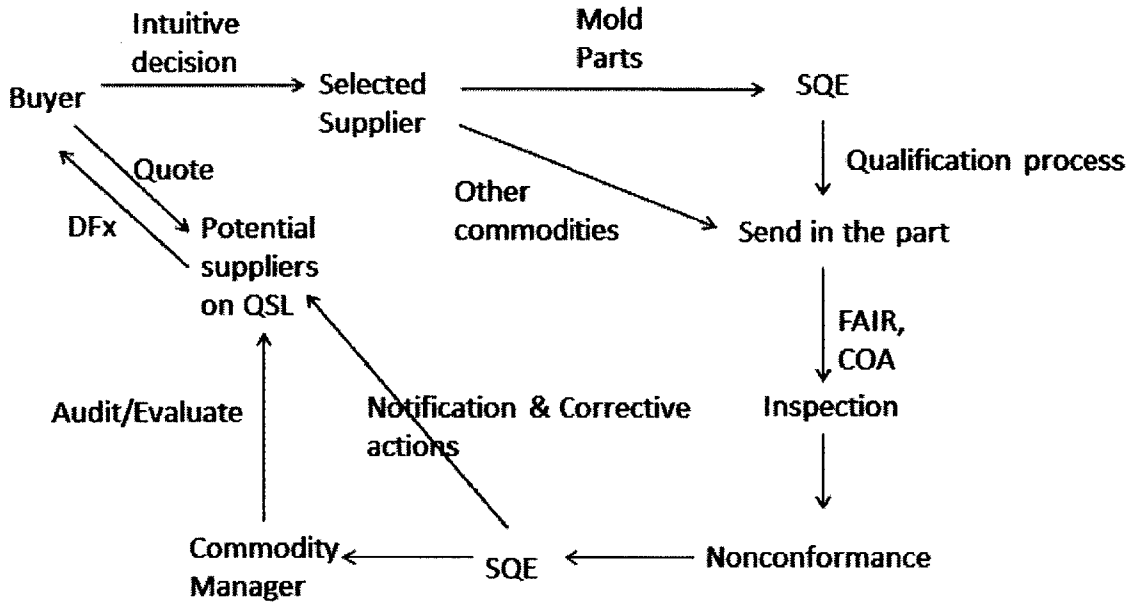

Figure 6: Current supply chain process

3.2.1 Qualified Supplier List

As most manufacturing companies do, a Qualified Supplier List (QSL) is managed by the commodity managers. The suppliers are classified as critical, subcritical and standard suppliers based on their business risk levels to Waters. A critical supplier supplies product related to Waters strategies and is a sole source of supply. A subcritical supplier supplies product related to Waters strategies and has strong performance in financial stability, technology or competitive price. The rest are classified as standard suppliers.

The top nonconformance suppliers identified in Section 3.1 are all in the standard supplier list. An audit process has to be completed for a supplier to be qualified in the QSL. The audit requirements for the three categories of suppliers are shown in Table 3.

Table 3: Supplier audit requirements

Supplier categories	Audit requirement
Critical supplier	On site quality audit, supplier profile questionnaire, risk assessment, C-TPAT
Sub-critical supplier	On site supplier audit (optional), self-appraisal (if no on site audit), supplier profile questionnaire, risk assessment, C-TPAT
Standard supplier	On site supplier audit (optional), self-appraisal (optional), supplier profile questionnaire, risk assessment (optional), C-TPAT, supplier visit with trip report (optional), ISO certification (optional)

A QSL status will be assigned to each supplier in the QSL. The status could be preferred, approved, conditional, evaluation and disapproved with preferred status being the most favorable one. The QSL status may be changed by the commodity manager based on the performance of the supplier. The judgment of whether to downgrade or upgrade the supplier is based both quantitative data and the commodity manager's knowledge of the supplier's qualitative performance. One of the quantitative data is the supplier's performance score based on quality and on time delivery, which would be discussed in Section 3.2.2.

3.2.2 Scorecard

A supplier scorecard is used to assess the suppliers' monthly performance on quality and on time delivery. The quality score is calculated by the percentage of rejections of the parts supplied by the suppliers. The delivery score is calculated by the percentage of

PO delivered just on time or within acceptable days of deviation. The quality and on time delivery are equally weighted to give the total score.

The calculation method of the quality score cannot correctly reflect the true performance of the supplier. The supplier may still have a high score regardless of the large quantity of rejections, because the total number of parts it sends in is so large. The other defect of the scorecard system is that the quality score is not a real time feedback of the supplier's performance. The data of the rejection numbers is retrieved from the TrackWise system introduced in Section 3.1. It is only when the nonconformance record reached pending approval stage the rejection will be reflected in the scorecard system. However, it takes almost three months or even longer time for the nonconformance records to reach that stage. There are 2000 open nonconformance records before pending approval stage and the number is still increasing because of high rejection rate. The supplier quality engineer is understaffed to process the nonconformance immediately. The scorecard is unable to give accurate and real time evaluation of the suppliers. The problem would have cascading effect in the commodity manager's rating on the supplier's QSL rating and the buyer's decision on supplier selection.

3.2.3 Supplier Selection and Evaluation

The buyers send the design drawings to several suppliers on the QSL for a quotation. The design for manufacturing form is sent together with the quotation for molded parts and sheet metal parts. For other commodity types, there is no design evaluation process with the suppliers. The buyer would select the supplier based on their past working

experience with the suppliers. Only the plastic parts will go through the part qualification process, in which the suppliers will be qualified for their manufacturing process, control plans and inspection method. Figure 7 shows the current molded parts qualification process. It is only after the qualification process, Waters can trust the supplier's capability of making the part and the supplier's reliability of inspection method. There is no qualification process done to any other commodity type because of the time driven working nature at Waters.

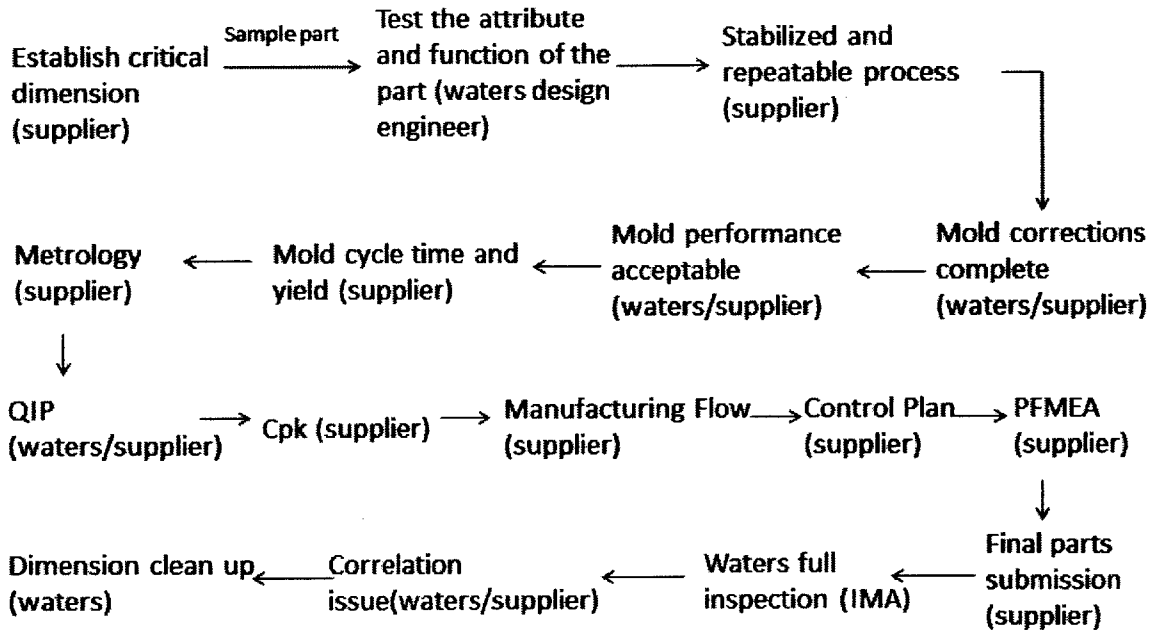

Figure 7: Plastic parts qualification process

To verify whether the part qualification process works or not, the acceptance and rejection data of the qualified plastic parts and unqualified parts are collected. Tables 4 and 5 show that the acceptance rate was improved for the qualified plastic parts but the improvement was not as significant as expected. The rejection due to supplier's liability has decreased but there are still large portion of rejection due to Waters liability.

Table 4: Plastic parts acceptance rate (include both the qualified and unqualified parts)

Supplier	Receive	Reject (Waters Liability)	Reject (Supplier Liability)	Acceptance	Acceptance rate (%)	Reject Rate (Supplier Liability) (%)	Overall Acceptance Rate (%)
S1	25638	45	100	25493	99	7	79
S2	11236	4347	424	6465	57		
S3	20587	1016	3205	16366	79		
S4	6785	80	131	6574	96		
S5	11094	2020	356	8718	78		
S6	28139	7001	2812	18326	65		

Table 5: Qualified plastic parts acceptance rate

Total sampled qualified parts	24
Total quantity	15473
Total rejection quantity due to Waters	2054
Rejection quantity due to supplier	505
Total acceptance quantity	12914
Acceptance rate	83%
Rejection rate due to supplier	3%

The problems in the supplier selection and evaluation process are identified. Even though the design for manufacturing form is sent out to the suppliers during the

quotation process, there are no specific requirements on the feedback that should be provided by the suppliers. The quality of the design for manufacturing varies among the suppliers. The interview with several buyers reveals that the buyers fully trust the suppliers on the qualified list. There is no evaluation of the suppliers on their capability to make this specific part. The decision is mainly driven by the lowest price that the supplier can provide while very little evaluation is given to the capability of the supplier. There is no structured evaluation considering all of other factors including quality, lead time, responsiveness to engineering changes, corrective actions and other factors. There is no verification of the match of the supplier's capability to the part.

Some of the problems in the current plastic parts qualification process are also identified. There is a lack of participation from several stakeholders. At the very first stage, the critical dimensions are identified by the suppliers instead of having the Design Engineer checking on the critical dimensions. The test of the sample parts by Design Engineer does not always happen and the process is not formal. The Quality Inspection Plan (QIP) is developed by the suppliers while Waters actually should input the requirements on QIP. The qualification information is not well communicated to Waters inspection department. The investigation shows that the inspection department does not have the QIP that is developed in the qualification process. At the end of the qualification process, Waters should clean up the design drawings, which often does not happen. This is part of the reason of the rejection due to Waters liability when later the parts come to incoming inspection.

3.2.4 Part Receiving

It is stated in the purchase order that the suppliers are required to send the first article inspection report together with the shipment to Waters for the new part. The inspection person is supposed to do the 100% inspection on one item and check with the supplier's inspection report. After three consecutive lots passing of the inspection, the following lots of the part from the supplier will not be inspected and go to dock-to-stock process.

The problem is that only 20% of the suppliers do send in the report. There is no formal process or channel for the supplier to send the first article report. The suppliers may email the electronic copy of the inspection report or send a hardcopy together with the shipment. There is no accountability of who should receive the report. The report is received by buyer, supplier quality engineer or inspection depending on the suppliers. Most of the time, the inspection department does not use or verify the supplier's inspection report. There is also no feedback from the inspection department to the procurement that if FAIR report is received and the quality of the FAIR report. The supplier quality assurance requirements are documented in the FDA Code of Federal Regulation Title 21. One of the regulations is that you could rely on the certificate of analysis from the supplier to determine the component specifications are met, only if the certificate of analysis is provided by the supplier and the certificate of analysis by the supplier is qualified through confirmation of the results of the supplier's tests. The certificate of analysis should include a description of the test or examination method used, limits of the test or examinations, and actual results of the tests or examinations. There is no requirement for Waters supplier to provide the certificates and their parts

would not be inspected after three times successful passing though certificate is not provided in the following lots.

3.2.5 Supplier Feedback

Figure 8 shows the disposition for the nonconformance parts due to supplier liability (data from Jan-2013 to Jun-2014). Only 26% of the nonconformance parts are sent back to the suppliers. Most of the time, Waters would choose to rework the parts or use as is if the risk is low due to time constraints.

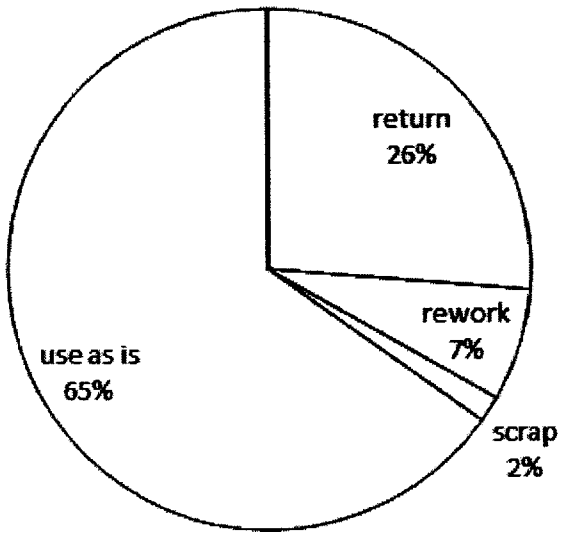

Figure 8: Disposition of the nonconformance due to supplier liability

There is no track of the cost due to poor supplier quality. The supplier selected at the early stage because of low price may generate more cost in the disposition process, including the cost of scrapping or reworking the material and the handling cost.

Suppliers are not always notified if the parts are rejected due to their liability for the use as is and rework disposition parts. Because of this lack of feedback to the suppliers, the next batch of parts from the supplier will be rejected again. The repeated process is a

waste of resources. It is only when a trend of the same problem for the same part is observed actions will be taken to the suppliers. However, there is no formal process to monitor how the corrective actions are performed by the suppliers. A closed loop corrective actions does not exist for correcting the supplier's behavior.

3.3 Summary of the Current Process Analysis

Based on the information collected from Section 3.2, a cause & effect analysis can be done to the current supply chain process. The cause & effect diagram shown in Figure 9 reveals four categories of causes. They are methods, people, communication and measurement. For the process aspect of the causes, there is a lack of process for DFx, FAIR and supplier evaluation of whether the supplier can make the specific part. There is a lack of formal process to deal with the supplier's change request or concerns. For the communication aspect of the causes, information is not well shared both internally within Waters and externally to the suppliers. The supplier's performance and Waters' requirement are not well communicated to the suppliers. Even within Waters itself, the information is not always communicated across departments. For the people's cause category, there is a lack of accountability for the process and problems. The decision making is not always based on data while based on intuitive thinking. At last, the supplier performance calculation does not reflect the true performance of the supplier. The suppliers are not measured by the total cost of poor supplier quality.

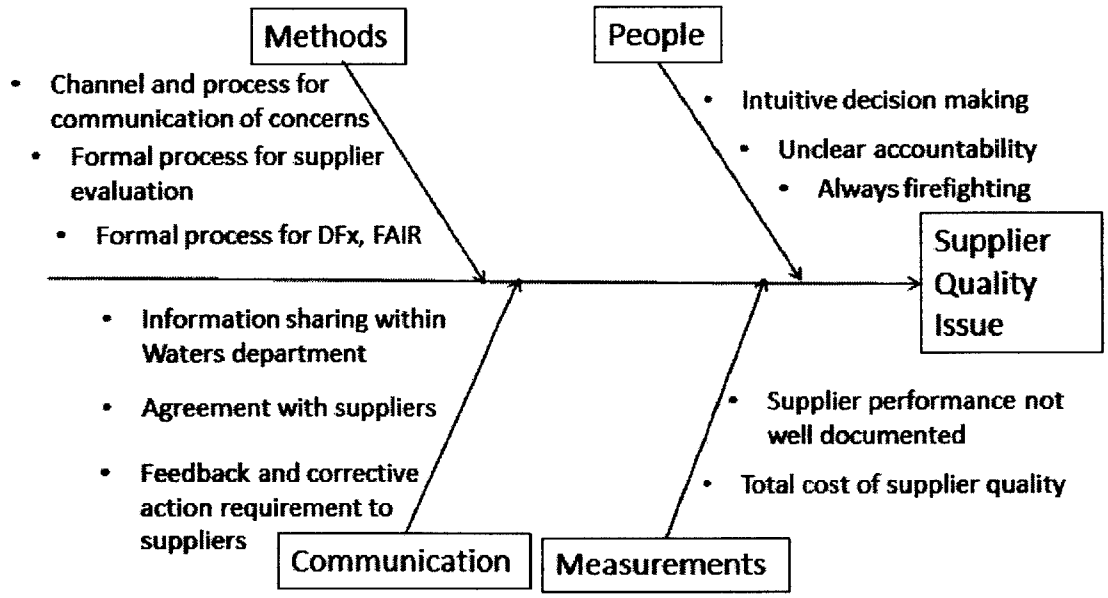

Figure 9: Cause & Effect diagram of the supply chain process

Because not enough planning is done at the early stage, more resource was consumed at the late stage firefighting with the problems. In order to reduce the development time, work is always pushed forward. The problems not solved at the beginning stage actually create more problems at the later stage. The problems accumulate and become more serious as the process flows. At the late stage, it is difficult to identify the cause of the problems because sometimes you have to trace long back the process. More people need to be involved at the late stage while it is hard to require corporation when people have moved on to other activities. Much more time and resource are wasted to solve problems at late stage of the process. If the problems could be identified and solved at the early stage, less resource is required because the cause of problems is clear and the action is easy to take.

Chapter 4 Solutions to the Supplier Evaluation and Management Process

This chapter describes the solutions to the problems identified in the previous chapters. A new supplier selection and management process was created, from very beginning supplier quotation to the end supplier scorecard calculation and all the processes in between. The sections in this chapter are arranged in the sequence of the process flow. The steps in the new process include supplier capability assessment at the early supplier selection stage, structured AHP for decision making, production part approval process, process for using inspection report from suppliers, closed loop feedback process to suppliers and supplier performance evaluation on scorecard. Figure 10 shows the overall process at a high level. The details of each step will be described in the following sections.

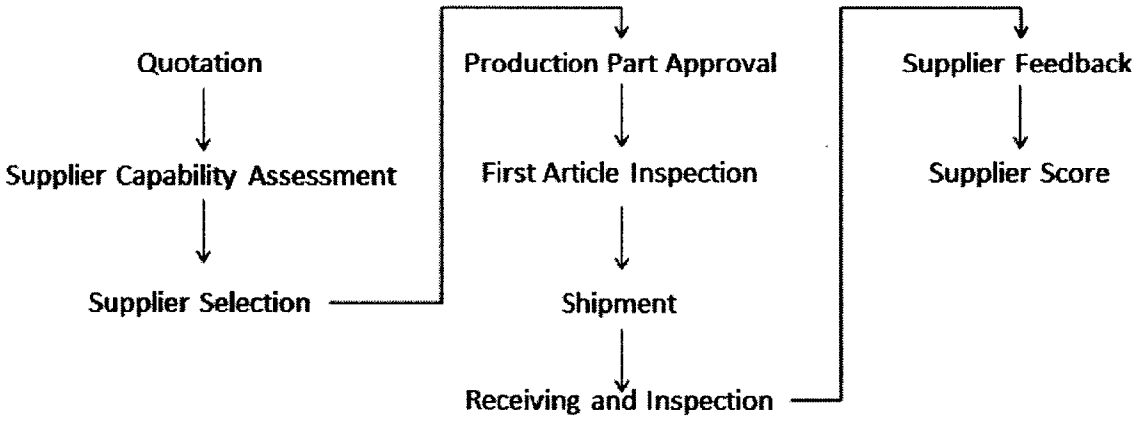

Figure 10: High level view of the new supply chain process

4.1 Early Supplier Evaluation in Quotation Process

Figure 11 depicts the process for initial supplier evaluation at quotation stage. The process differs from the old quotation process by involve more representatives to have a comprehensive assessment of the supplier's capability and to clear the problems at early supplier selection stage. As addressed in Section 2.4, almost 50% of the poor quality problems are due to miscommunication of requirements between suppliers and customers. This early supplier evaluation and quotation process is designed to solve the requirement clarification problems.

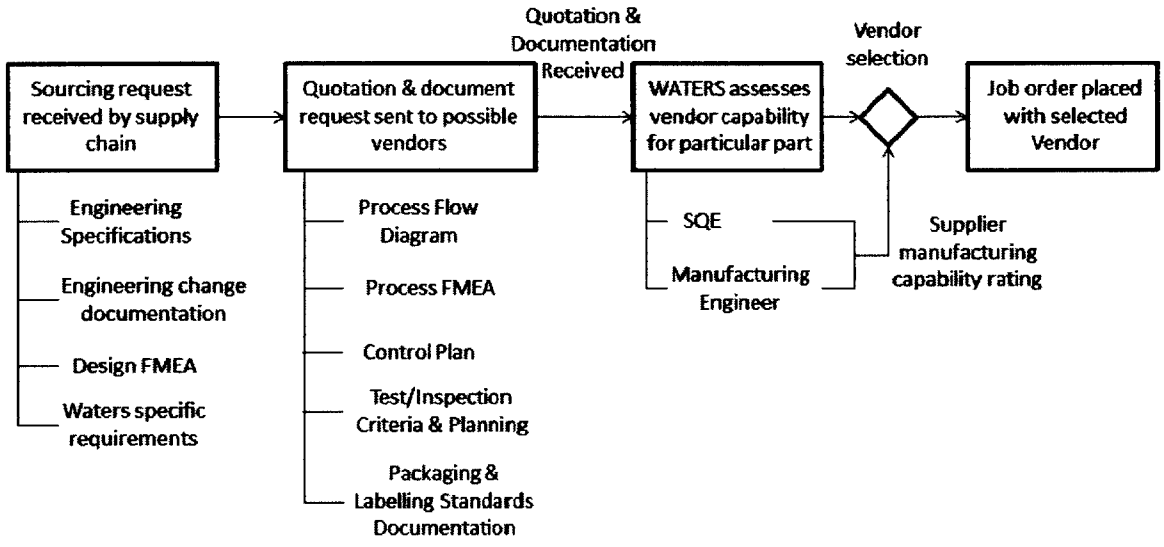

Figure 11: Initial supplier capability evaluation at quotation stage

In the new quotation process, the sourcing request and a questionnaire are sent to the suppliers together with the Request for Quote (RFQ). The sourcing request contains the requirement from Waters, which includes the Engineering Specifications, the Engineering change documentation, the Design Failure Mode Effect and Analysis (DFMEA) and Waters specific requirements. The questionnaire aims to establish a discussion channel with the suppliers for design requirements, manufacturing process,

inspection process and PPAP requirements. The template for the questionnaire is shown in Appendix II. The questionnaire requires the supplier to conduct a self-evaluation on three main aspects including manufacturing capability, DFx and ability to satisfy the PPAP requirement. A template of the questionnaire was created for generic parts. A section in the questionnaire is reserved for the design and supplier quality engineer to input special requirements for the specific part. This is done at the first step of the PPAP process which will be introduced in Section 4.3. Before sending the questionnaire to suppliers, the design engineer and supplier quality engineer can add in the special requirements in the questionnaire if necessary. For example, some parts may have requirements of critical clean, labeling and others.

The manufacturing capability section contains questions to evaluate the manufacturing equipment and inspection equipment the supplier has. The questionnaire requires the supplier to answer if they understand raw material specification and the way to verify the material and possibly to provide the raw material source.

In the DFx section, the questions are created to provide a guideline for the supplier to provide DFx feedback. The suppliers should check if they have the right drawings, specifications and CAD models for all of the components. The suppliers are required to assess if the specifications and tolerances are manufacturable and measurable. If not, the suppliers should give reasons and feedbacks on possible changes. Suppliers are also asked to suggest changes for cost saving and improving performances.

The PPAP section of the questionnaire assesses the suppliers if they have the ability to work with Waters for the PPAP process. The suppliers should provide information of if they have PPAP experience before. In the quotation process, the suppliers are required to provide the planning PPAP documents that show their planned process for satisfying Waters requirements.

When the questionnaire is received from the suppliers, the design engineer should work with the suppliers to clarify any changes that should be made. The manufacturing capability and PPAP sections will be assessed by Waters manufacturing engineer and supplier quality engineer, and an overall score of the supplier's capability is given. An example of a scale for giving the score is presented in Section 4.2 Table 9. Waters can use any other appropriate scale as the guideline for giving score. The capability score will later be used in the AHP model for the supplier selection as discussed in Section 4.2.

4.2 Analytical Hierarchy Process for Supplier Selection

The Analytical Hierarchy Process is introduced in the previous Section 2.2. This section explains how this model can be applied to the Waters supplier selection decision making.

The first step for the AHP supplier selection process is to identify the criteria for evaluating the suppliers. The literature review in Section 2.2.1 reveals that the most popular supplier selection criteria are quality, cost and delivery and these criteria are considered important in every research studies. The studies conducted most recently shows additional criteria such as service, technology, management and other factors are also considered in contemporary supplier selection. Interviews were conducted with

Waters purchasing group to identify the factors that are important to Waters. The key factors identified are quality, price, delivery, service and capability. Here quality means the supplier's past performance and buyers' judgment on the supplier quality based on their past experience with this supplier. Capability criteria is the capability assessment conducted at quotation stage as explained in Section 4.1. The capability criterion provides an evaluation of the level of supplier-part match.

With the selection criteria identified, the second step is to conduct a pair-wise comparison of the criteria. Each criterion is compared with the other criteria and a preference level is assigned. Table 6 shows an example of the standard judgment scales for AHP. The intermediate values of 2, 4, 6 and 8 or any other appropriate scales can also be used as alternative preference levels.

Table 6: Preference level

Preference	Level
Extremely Preferred	9
Very Strongly Preferred	7
Strongly Preferred	5
Moderately Preferred	3
Equally Preferred	1

The pair-wise comparison is recorded in a preference matrix and an example is shown in Table 7. The row criterion is compared to each column criterion. Take the first row of

the preference matrix as an example, if quality is slightly preferred than price, a preference level of 2 is assigned to this pair-wise comparison. If the quality is moderately to strongly preferred than service, a preference level of 4 is given. The similar preference level assignment process can be conducted for the rest of the pairs. Any criterion is equally preferred to itself so the diagonal of the matrix are all 1. If the preference level of quality to price comparison is 2, then the preference level of price to quality comparison is ½. Therefore, in the matrix table the cells symmetrical to the diagonal are reciprocals of each other. At the end of this step, the sum of each column is calculated and will be used in the next step for giving weight.

Table 7: Preference matrix

	Quality	Price	Service	Delivery	Capability
Quality	1	2	4	3	1
Price	1/2	1	3	3	1/2
Service	1/4	1/3	1	2	1/4
Delivery	1/3	1/3	1/2	1	1/3
Capability	1	2	4	3	1
Column Total	37/12	17/3	25/2	12	37/12

After the pair-wise comparison, the third step is to calculate the weight for each criterion. Each cell is divided by the column sum calculated in the previous step. After this, the row average is the weight for that criterion. Table 8 is an example of the calculation and the weight for quality, price, service, delivery and capability are 0.314, 0.198, 0.094, 0.080, and 0.314 respectively. All of the weights should add up to 1.

Table 8: Weight distribution to criteria

	Quality	Price	Service	Delivery	Capability	Weights (Row Avg.)
Quality	12/37	6/17	8/25	1/4	12/37	0.314
Price	6/37	3/17	6/25	1/4	6/37	0.198
Service	3/37	1/17	2/25	1/6	3/37	0.094
Delivery	4/37	1/17	1/25	1/12	4/37	0.080
Capability	12/37	6/17	8/25	1/4	12/37	0.314

The fourth step is to give score for each supplier on each criterion. In the original AHP model, all of the suppliers are also pair-wise compared to give a weight for each criterion. In order to simplify the process, the pair-wise comparison for the suppliers is eliminated. For each evaluation criterion, the suppliers are ranked and scores are assigned to the suppliers. The general performance score guideline is given in Table 9 [17]. The supplier with best performance is given a score of 10. Table 10 gives an example of the scores of three suppliers on each selection criterion.

Table 9: Guideline for giving score to supplier performance

Grade	Very dissatisfied	Poor	Acceptable	Good	Very satisfied
Scores	0/1	2/3	5	7/8	9/10

Table 10: Suppliers' scores on the criteria

	Quality	Price	Service	Delivery	Capability
Supplier 1	9	7	6	7	8
Supplier 2	8	6	6	8	9
Supplier 3	7	9	7	5	5

The supplier's score on each criterion is then weighted based on the weighting that has been derived in Step 3. The sum of the weighted score over all of the criteria gives the final score of the supplier. For example, Table 11 shows the total score for the three suppliers. Based on this example, the optimal supplier is Supplier 1 and Supplier 2 is also a comparable good choice.

Table 11: Final score calculation for the suppliers

	Total
Supplier 1	7.848
Supplier 2	7.730
Supplier 3	6.608

The above preference levels, weights and scores calculated are only one example to show the steps for using the AHP model. The real preference levels, weights and scores must be assigned case by case based on the real situation. The purchasing strategy for certain part may emphasize on some criteria while a specific part may emphasize on other criteria.

The above proposed supplier selection process adopted the most popular multi-criteria supplier selection model AHP. The pair-wise comparison of the suppliers is modified for ease of use. This selection process incorporates the information of supplier capability obtained at the quotation process. The process also helps the buyer to seriously consider and justify the relevance of criteria. By incorporating the information from the

quotation process, the opinions from different stakeholders other than just the buyers are considered in the supplier selection process.

After the supplier being selected, the next process is to work with the supplier to ensure their manufacturing process and process control can meet Waters' requirement consistently. This is achieved through production part approval process, which will be discussed in Section 4.3.

4.3 Production Part Approval Process

Section 2.4 discusses the industry practice of using PPAP to improve the supplier performance and build trust in suppliers. This method is adapted into Waters supplier evaluation and management process. Ideally, the production part approval process should be applied to all new components, drawing or design changes, supplier process changes or any significant changes that may influence the end product quality. In Waters situation, due to limited resources and it is a new process to company, the company can start implementing the process on parts of high risk, critical to the product performance and expensive parts. The process can also be implemented with the suppliers that require more Waters' control to improve their quality performance.

In the process, Waters is responsible for identifying the project team members and assisting the suppliers in completing the PPAP process. Generally the project team includes the Supplier Quality Engineer, Commodity Manager and Design Engineer as required representatives. Other specialists typical to the part type and any other necessary representatives can also be included. The Supplier Quality Engineer shall

coordinate the completion of PPAP activities with the project team. The supplier is responsible to create their own cross functional PPAP team and to develop and execute the PPAP plan.

The PPAP planning process starts by setting the PPAP requirements by Waters PPAP. The PPAP requirement is sent to the suppliers together with the Request for Quotation as mentioned in Section 4.1. In order to make it easy for Waters to start the PPAP process, a template of the PPAP requirement lists the necessary PPAP documents for generic parts as shown in Appendix II. The PPAP team can use this as starting point and add in any other necessary document requirements. Appendix I lists all the PPAP documents used in the automotive industry. The PPAP project team can refer to the list to add in the other necessary document requirement. The justification of additional documents can be the requirement specific to that part. For example, the part may require critical clean procedures, and thus a critical clean document should be provided by the suppliers. A Measurement System Analysis document may be required to check the supplier's inspection ability for high precision part. At the planning stage, Waters and the suppliers also agree on the timeline to complete the PPAP process.

After reviewing the PPAP requirement procedures of several top companies from automotive, pharmaceutical and food industries and comparing them with Waters product type, the general PPAP requirements identified are Part Submission Warranty, Process Flow Diagram, Process Control Plan, Process Failure Mode Effects Analysis (PFMEA), Dimensional Test and sample parts that the dimensional test has used. Part

Submission Warranty summarizes the whole PPAP package. It specifies the reason for this PPAP package, information of the part and all the PPAP documents. The Process Flow Diagram should record all the steps in the process, from receiving the material to shipping the product. Both of the Process Control Plan and PFMEA must follow the steps in the Process Flow Diagram. The PFMEA identifies and evaluates the potential failure and risks in the manufacturing process. The actions to the failures should also be included. Process Control Plan documents the operations that are used for controlling the manufacturing process such as the test and inspection. All the critical characteristics should be included in the control plan. The critical characteristics are the features that are significant to the performance of a product. Section 7.1 of Mr. Ranjan's thesis addresses the process for getting the critical characteristics at Waters [1].

The suppliers are required to provide the planning PPAP document at quotation stage for evaluation of their capability. The formal PPAP document should be prepared after the supplier is selected and the production process is stabilized.

The Waters PPAP team reviews the documents and confirms the supplier's product and process conformity. Any correlations in the requirements, design drawings, inspection method and other issues should be cleared before the PPAP document package is approved. The PPAP final approval should have all the signature of the stakeholders, generally the PPAP team assigned for this part. At the end of the approval, make sure the right document is kept at the right person and have the signature of the person in

the PPAP approval package. The Supplier Quality Engineer should keep the PPAP package for future reviewing or auditing of the supplier's performance.

This is the beginning step for Waters to implementing PPAP, as the employees are more familiar with the PPAP process and more knowledge is gained through the process, the formal PPAP requirement specific to each commodity type could be established by the commodity manager. Only special considerations have to be then added to the PPAP process.

4.4 Acceptance and Usage of Supplier's Inspection

A formal process for first article inspection report (FAIR) is created and shown in Figure 12. In this new process, key accountabilities, communication channels and process control methods are identified.

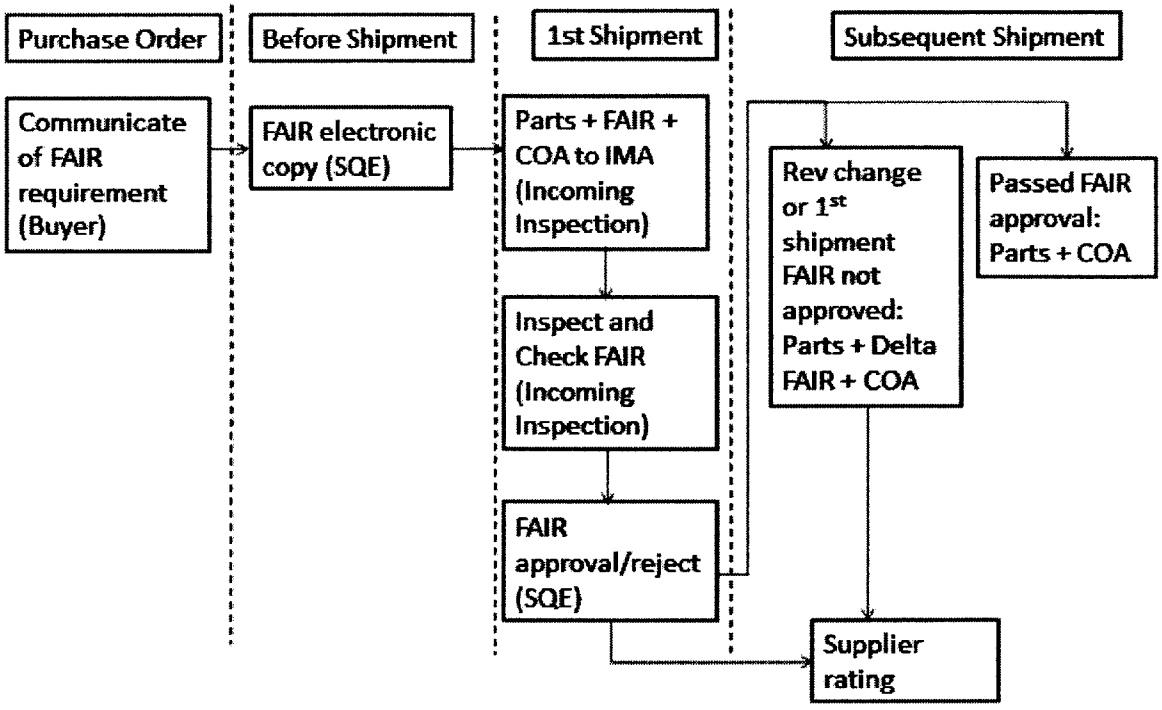

Figure 12: FAIR process map

The process begins at when the purchase order is passed to the suppliers. The buyers should be responsible for communicating the requirement of providing FAIR to Waters for the new parts. The buyer should also make sure that the process is communicated to and understood by the supplier. The supplier should send an electronic copy of FAIR to the Supplier Quality Engineer before the shipment. The supplier can use Waters FAIR format or use their own as long as the required information on Waters format is included. The Supplier Quality Engineer should check if all the specifications and requirements are met on the FAIR provided by the supplier. Only after the Supplier Quality Engineer checked the FAIR can the supplier send in the products. The supplier is required to send a hardcopy of the FAIR together with the shipment. The hardcopy of the FAIR is used by the inspection people. Waters inspection will conduct a 100% inspection of the first part and compare with the supplier's FAIR. Any discrepancy should be recorded down and given to the Supplier Quality Engineer. The Supplier Quality Engineer contacts the supplier to resolve the discrepancy. Appendix III is the template created to facilitate the measurement correlation study. The process is repeated only when the FAIR passed approval. The other circumstance that the supplier is required to provide a FAIR is when the revision of the design is changed. A new FAIR should be submitted for the new revision. In every shipment, the supplier is still required to send in inspection report for every batch. The inspection or test result, statistical process control information and capability study for the critical dimensions should be included in the inspection report. The incoming inspection people should keep track of the FAIR and inspection report receiving status from the suppliers. The

receiving status of the FAIR and inspection report will be used by the Supplier Quality Engineer to give ratings in the supplier's scorecard.

This process enforces the supplier to conduct inspection and send in the inspection report to Waters. It makes sure the supplier identify the defects before sending the parts to Waters. It emphasizes the supplier's liability to ensure no defect parts should be sent to Waters. In the suggested part acceptance process, the key responsible person for each process flow is identified. The formal communication channel and file submission channel are established such that there is no confusion about the process.

4.5 Supplier Performance Feedback Process

4.5.1 Supplier Corrective Actions

As discussed in Section 3.2.5, in the current supplier performance control process, there is a lack of formal process to give feedback to the suppliers. A new process is proposed and shown in Figure 13.

In the disposition process as discussed in Section 3.2.5, the supplies are notified of the quality issue only when the nonconformance parts are sent back to the suppliers. Most of the time, if the part is use as is, reworked or scrapped at Waters, the suppliers are often not notified. In the new proposed process, the suppliers should be notified for any nonconformance due to the supplier's liability, regardless of the disposition type. Waters will let the supplier to solve the problem on its own on the following situations: the problem is the first time occurrence, the rejected quantity is small, or the nonconformance has low impact on the product performance.

A formal Supplier Corrective Action Request (SCAR) process will be required if the problems satisfy the following conditions: the problem has repeated occurrence, the rejected quantity is large, or the impact on the product performance is high. The formal SCAR process follows the Eight Disciplines (8D) problem solving principle. The 8D methodology is a structured 8 step process for facts based problem solving. The eight steps are: establish a team, define problem, containment actions, root cause analysis, permanent corrective actions, verify effectiveness of corrective actions, preventive actions and congratulate the team.

The suppliers are required to follow the 8D problem solving steps and document each step. The document helps the supplier to structure the problem solving and is submitted to Waters as evidence. The 8D steps are divided into two sections as shown in Figure 13. The first section requires the supplier to take action immediately when the SCAR is received. Containment actions should be the actions that stop shipment of nonconformance part to Waters and the actions that stop the manufacturing of these nonconformance parts. A longer time period is given to the suppliers to conduct further investigation of the problems. Documentation and evidence of the steps should be returned to Waters Supplier Quality Engineer. The supplier should show they have used formal problem solving tools to identify the root causes such as Five Why's, Fishbone Diagram, Histograms, Flowcharts and any other reasonable tools. The permanent actions should solve the root cause problem identified. The supplier then need to list the steps taken to verify the permanent corrective action is effective. Preventive actions are required for avoidance of future occurrence of the problem or similar problems.

The supplier's responsiveness to the SCAR will be reflected in the supplier scorecard. Missing the deadline for conducting the SCAR actions or ineffectiveness of the actions will all lead to a deduction of the supplier's score.

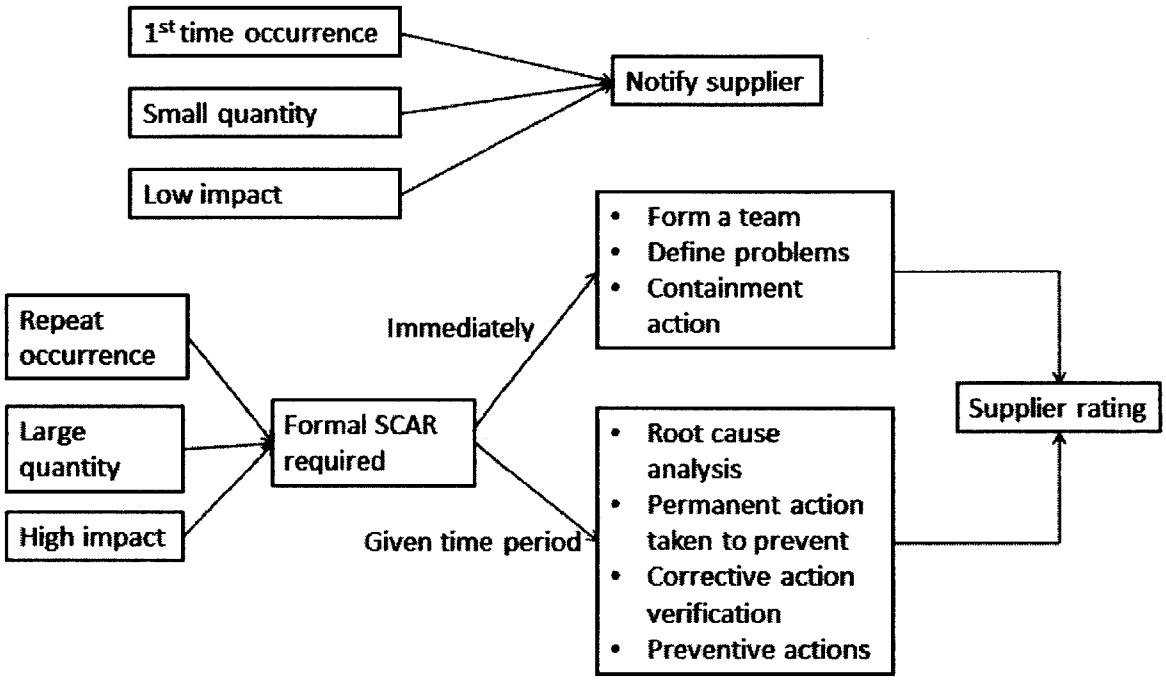

Figure 13: Closed loop supplier feedback for corrective action

4.5.2 Supplier Score

With the proposed new processes, the scorecard needs to be changed to measure the suppliers' performance on these processes. Three additional factors are suggested to be considered in the supplier scorecard. They are the capability of providing PPAP, the provision of inspection report and the response to SCAR.

Some other suggestions are given based on the observation of the design of the scorecard and its effectiveness in use. The weight distribution to the criteria on the

scorecard is assigned arbitrarily. It is suggested that the pair-wise comparison method of AHP can be applied in scorecard design in giving weights.

The other suggestion is to evaluate the suppliers based on commodity type group. The Commodity Managers reflect that different commodity type of products have different emphasize on the supplier's performance. It is suggested to have the same criteria but the weightings are given on commodity type base. For example, a tube supplier may have a high rating on quality than a manual supplier. The overall score of a supplier can be rated among its commodity types, because the same commodity group will have comparable order quantity and cost. The ranking gives benchmark reference for Waters.

As discussed in Section 2.3, instead of only using scorecard to track the bad supplier performances, the industry best practice companies use scorecard to identify improvement opportunities with the suppliers. Supplier improvement plans can be created based on the scorecard. The part per million (PPM) can be easily retrieved from the scorecard, which is the rejection rate multiplied by one million. Waters should set PPM improvement target together with suppliers. The supplier should submit the plans that they have for improving PPM. This agreement is used to set and monitor PPM performance. Targets are set for a period of time generally in year scale and PPM is measured each month. If the supplier does not meet the agreed PPM target, they shall submit a formal action plan.

Chapter 5 Expected Implementation Results and Obstacles

The ultimate result of the proposed supply chain process is to improve the quality of the parts provided by the suppliers. This is achieved by having a robust supplier selection and management process. This Chapter discusses the expected benefits of the improvement processes and also the obstacles for implementing the process.

The initial supplier assessment of the suppliers at the quotation stage provides Waters more information that can be used to make a sound supplier selection decision. The AHP model ensures a rational supplier selection decision making process. This supplier selection process also forces the Supplier Quality Engineer and Manufacturing Engineer to put in their expertise in the decision making process. Opinions from different functional group are considered in the selection process. At Waters, the audit of the supplier is only conducted every 3 years for critical suppliers and every 5 years for subcritical suppliers. The onsite audit for the suppliers is even optional for the standard suppliers. Therefore, the capability information of the suppliers is outdated. The initial supplier assessment process based on questionnaires continuously gets updated information of the supplier's capability of manufacturing equipment and inspection and test ability.

The simplified PPAP process is a starting point for Waters to make transformational changes to its supply chain process. Suppliers and Waters clear the discrepancy at early stage. Waters gains more visibility to the supplier's capability. It is easier for Waters to reassess the suppliers if problems happen. The trust relationship is built through the

PPAP process. The successful implementation of PPAP for all product parts is able to eliminate most of the inspection activities at Waters, which is the vision of Waters Vice President of Operations.

The process of requiring FAIR and inspection report from suppliers makes use of supplier's resource to control the product quality. The formal supplier feedback process helps the supplier to improve on their quality performance. The problems are solved at the root causes instead of just one time solution and firefighting happens again next time.

Other than the benefits, some of the obstacles have to be considered when implementing the process at Waters. Several of the process require cross functional team to work together. However, due to the culture of the company, it is hard to make people work together towards one goal. Waters has a very traditional culture, and the employees tend to work and think the way they are used to. It may be hard for them to make changes. The knowledge level and skill level among the employee varies, even under the same function. Some of the processes are new to the employees. It is necessary to have learning sessions among the employees for experience sharing and improve the overall employee skill level.

Chapter 6 Process Summary and Future Works

6.1 Process Summary

A new supplier selection and supplier management process was designed in this project. The goal of the project is to improve the supply chain process and thus have better quality parts from the suppliers. This is achieved by a series of processes from early evaluation on supplier capability to feedback to suppliers and all the processes in between. In the new process, the suppliers are evaluated in three main aspects that are requirements understanding, manufacturing capability and capability for providing PPAP documents. The early evaluation of the suppliers at quotation stage gives more visibility to the supplier's ability to satisfy Waters' requirements. Agreement on the requirements and clarification of problems can also be achieved at this stage. A structured supplier selection process based on AHP is designed. The selection process incorporates the opinions of multiple functional groups in the decision making process. The process aids the buyer in selecting the optimal supplier based on multiple criteria. A simplified PPAP process is suggested for easy implementation at Waters. The process builds trust in the supplier's manufacturing and process control ability. The successful implementation of the PPAP process requires cross functional corporation, which is a challenge at Waters. A formal process is established to require FAIR and inspection report from suppliers. The process builds trust in supplier's inspection and makes use of the supplier's inspection resources, which could save the large investment in the inspection activities at Waters. Finally, the supplier feedback process forms the closed loop supplier management

process. It ensures the corrective actions are taken by the suppliers and the supplier does not deliver nonconformance parts in the following shipments.

6.2 Future Works

There are some observations at Waters that are not addressed in the project. These areas can be improved in the future works.

In the product development process, the supplier involvement is very limited. The best practice companies are all starting to involve supplier early in the product development process. Supplier's knowledge is used to improve the design and drive cost saving as well. Future work can explore the way to involve suppliers early at Waters new product development. One example is to involve supplier early for DFx process. The possible benefit of early involvement of suppliers for DFx is to identify the possibilities to simplify the design, to reduce cost and to have higher manufacturability, because as the design process develops, the cost to change the design grows as shown in Figure 14.

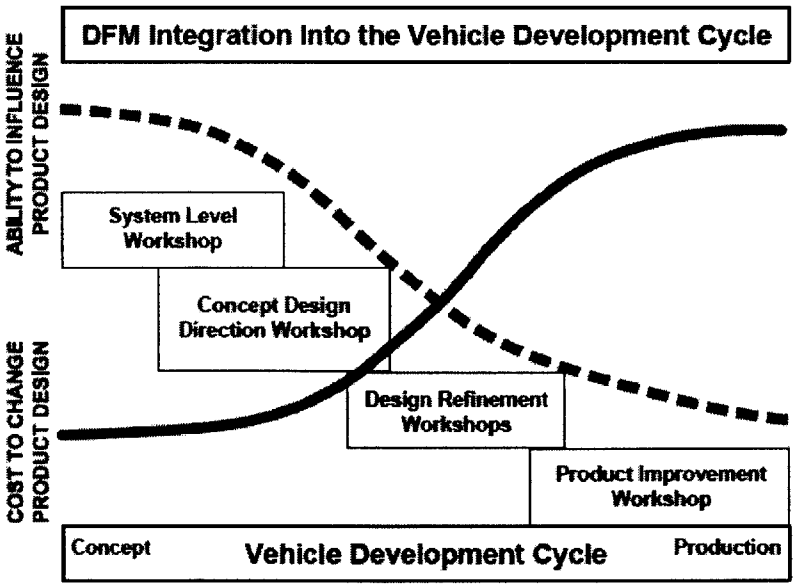

Figure 14: DFM integration into product development [18]

As discussed in Section 2.3, the other possible area for improvement is to track the true cost of poor supplier quality. The total true cost can help make supplier selection decision based on true cost. By tracing the true cost of poor supplier quality, the non-value added process can be identified. Thus, the total cost can be used to identify the improvement areas for the poor suppliers. On the other hand, it can also be used as a benchmark to reward the suppliers that have significantly reduced total cost.

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Appendix I PPAP documents

	Document	Short Description
1	Part Submission Warrant	Summary of the PPAP package
2	Design Records & Bubbled Drawings	Design drawings with dimensions bubbled
3	Approved Engineering Change	Drawing specifications that authorize the supplier to deviate or change any part of the instructions from the design record.
4	Customer Engineering Approvals	Includes any documents relating to temporary deviation and any supporting evidence of parts sent to the customer before the PPAP
5	DFMEA	This is only applicable when the supplier has the design responsibility
6	Process Flow Diagram	Clarifies all the manufacturing process from material receiving to product shipment
7	PFMEA	Considers all the possible failures of the production process for the part in question
8	Control Plan	Any control operations in the process. It should mirror the PFEMA and address the CTQ
9	Measurement System Analysis	Record all tools and instruments used to measure or check the raw materials and finished parts
10	Dimensional Results	100% inspection of the sample parts
11	Records of Material/Performance Tests	A summary of all tests that have been performed on the part, lists all material certifications
12	Initial Sample Inspection Report	Report for material samples which is initially inspected before prototype made
13	Initial Process Studies	Study of the repeatability of the process
14	Qualified Laboratory Documentation	If testing is performed in a supplier's internal lab, they must provide a copy of their quality certification
15	Appearance Approval Report	This is produced from the appearance approval inspection process
16	Sample Production Parts	A number of pictures can be included of the sample part from the same production run that has been

		analyzed throughout the PPAP
17	Master Sample	This sample MUST be signed by the customer and the supplier when the sample part meets all the design requirements and extra customer requirements.
18	Checking Aids	When special tools are used they should be photographed, documented and included in this section, and this should also include the calibration records of the tools and the dimensional report from the tools.
19	Customer Specific Requirements	Any specially required document by the customer

Appendix II Supplier Quotation Questionnaire

Supplier Quotation Questionnaire

Supplier		Supplier Contact Person	
Waters Part No.		Waters Buyer	
Part Rev		Waters SQE	
Due date		Waters Manufacturing Engineer	

Instructions:

1. All questions should be answered. If the question is not applicable, please indicate N/A.

2. The questionnaire should be returned to Waters buyers within required days by the buyer.

3. In section 2, please provide information based on your current capability to make this specific part. In section 3, please identify if you are able to provide the required PPAP document for this part if given the business.

Section 1 Design and Drawing Review

Questions	**Yes/No/N.A**	**Comments**
1. Do you have the quotation level drawing?		
2. Do you have the necessary files, eg CAD model?		
3. Do you understand all engineering specifications?		
4. Do you have the engineering change document?		
5. Do you have the Design FMEA?		
6. Are all dimensions and tolerances manufacturable?		
7. Are all dimensions and tolerances measurable?		
8. Can you meet the requirements in the notes?		

Note: For question 6, 7 and 8, if the answer is yes, please provide the manufacturing machine and measurement machine information in Section 2, or attach any information that proves you can meet the requirements. If the answer is No, please fill the DFM form for all the specifications that are not manufacturable or not measurable, or the requirement (eg, critical clean, labeling, finishing...) that you cannot meet.

Section 2 Manufacturing

1. Please provide information of the machines that are available to make this part?

Equipment Type	Equipment model	Complexity Level	Other Comments

2. Please provide information of the measurement tools/machines that are available for measuring the specifications for this part?

Equipment Type	Equipment model	Complexity Level	Other Comments

3. Have you manufactured the similar types of product before? Yes___ No___

4. Do you have reliable material source for this part? Yes___ No___

5. Can you provide certificate of compliance of the material? Yes___ No___

6. Can you provide electronic copy of the FAIR before shipment and hard copy of the FAIR with the shipment? Yes___ No___

7. Other special requirement for this part by Design Engineer

Section 3 PPAP

1. Have you done PPAP before with Waters or other customer? Yes__ No__

2. Would you be able to provide the planning PPAP documents at quotation for this part? Please provide the documents if the answer is Yes. Please also indicate whether you can provide the required PPAP in production?

	Item	Required for quotation (Yes/No)	If you can provide the planning docs for quotation (Yes/No)	Required for production (Yes/No)	If you can provide in production stage (Yes/No)
Mandatory for Quotation	Process Flow Diagram	Yes		Yes	
	Process FMEA	Yes		Yes	
	Control Plan	Yes		Yes	
	Packaging & Labeling Standards	Yes		Yes	
	Test/Inspection Planning	Yes			
Engineer specific requirement for this part					
Others	Part Submission Warrant			Yes	
	Design Records				
	Approved Engineering Change				
	Customer Engineering Approvals				
	DFMEA				
	Measurement System Analysis				
	Dimensional Results			Yes	
	Records of				

	Material				
	Initial Sample Inspection Report				
	Initial Process Studies			Yes	
	Qualified Laboratory Documentation				
	Appearance Approval Report				
	Sample Production Parts			Yes	
	Master Sample				
	Checking Aids				
	Specific Requirements				

THE FOLLOWING SECTION IS FOR WATERS USE

Based on the returned questionnaire and the documents provided by the suppliers, Manufacturing Engineer and SQE give a capability score. A guideline for giving the score is shown in the following picture.

Grade	Very dissatisfied	Poor	Acceptable	Good	Very satisfied
	←				→
Scores	0/1	2/3	5	7/8	9/10

Overall capability score	
Justifications	
Manufacturing Engineer	
SQE	

Appendix III Measurement Correlation Report

Measurement Correlation Report

Supplier				Supplier Contact			
Part No.				Waters SQE			
Part Rev							
Part Description				Waters Inspector			
No.	Specification	Supplier		Waters		Supplier Action	Waters Action
		Method	Result	Method	Result		
Comment						Waters Sign Off	