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# Suppliers Evaluation and Selection: A Comprehensive Model to Minimize the Risk Associated with Quality and Delivery

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To the Graduate Council:

I am submitting herewith a dissertation written by Ammar Mohamed Aamer entitled "Suppliers Evaluation and Selection: A Comprehensive Model to Minimize the Risk Associated with Quality and Delivery." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Industrial Engineering.

Rapinder Sawhney, Major Professor

We have read this dissertation and recommend its acceptance:

Kenneth Kirby, Dukwon Kim, Ramón V. León

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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# SUPPLIERS EVALUATION AND SELECTION:
# A COMPREHENSIVE MODELTO MINIMIZE THE RISK
# ASSOCIATED WITH QUALITY AND DELIVERY

A Dissertation Presented
For the Doctor of Philosophy Degree
The University of Tennessee, Knoxville

**Ammar Mohamed Aamer**
**December 2005**

**DEDICATION**

To My Wife,
Nesrine Abdulah El-Zine

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# ABSTRACT

This research focuses on one of the main steps in outsourcing, supplier evaluation and selection. The main contributions of this research were twofold. First, best practices in the supplier's value stream were identified that directly or indirectly impact a supplier's quality and delivery. Second, a comprehensive supplier evaluation and selection model was developed based on the value stream concept to minimize the risk associated with two very critical supplier-selection factors, quality and on-time delivery.

A survey was conducted to identify best practices. The outcome of the survey was used to develop a computer based supplier evaluation model, which could be used in conjunction with other existing supplier selection factors, such as price and others, to select suppliers.

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# CHAPTER 1

# INTRODUCTION

## Introduction to the Study

This research focuses on outsourcing in Supply Chain Management (SCM). Specifically, the research addresses one of the main steps in outsourcing, supplier evaluation and selection. The main contributions of this research were twofold. First, best practices in the supplier's value stream were identified that directly or indirectly impact a supplier's quality and delivery. Second, a comprehensive supplier evaluation and selection model was developed based on the value stream concept to minimize the risk associated with two very critical supplier-selection factors, quality and on-time delivery. The outcome of the proposed model could be used in conjunction with other existing supplier selection factors, such as price and others, to select among suppliers. The first chapter of this study presents the background of the study, specifies the problem of the study, and describes its significance.

## The Background of the Study

A common strategy in today's business is to continue doing what you do best then outsource what you do worst or know least about. This is called the core competency. Making a strategic outsourcing decision is no easy task. There are several factors, parameters, and considerations a company has to take into account to ensure that outsourcing is the right decision. Outsourcing is defined as the strategic use of outside resources, such as human resources, to perform activities traditionally handled by internal staff and resource [67]. Outsourcing has actually been practiced for years. Different business processes have been outsourced such as Human Resources, Maintenance activities, and most recently Information Technology.

A recent study by Maurice F. Greaver II [59] demonstrated that the outsourcing trend has started in the automobile industry. In the early ages of car manufacturing, mass production dictated that manufacturers produce their own components, but it became difficult for manufacturers to be flexible enough to keep up with the tremendous variation in customer requirements without relying on outside sources.

However, after the Toyota innovation of Just in Time concepts and the increasing customer requirements, the outsourcing trend increased exponentially. Japanese manufacturers had to seek alternatives, such as outsourcing the production of non-core components to their suppliers, to meet the customer demand variation [59]. A non-core component could be a component that other manufacturers have succeeded in producing with better quality and lower cost.

The Japanese competition in the automobile industry drove the American companies to react and follow a similar strategy. A recent study by Croon et al. examined how American car manufacturers responded in the seventies and eighties. The Big Three (Chrysler Corporation, Ford and General Motors) switched to long-term contracts with preferred suppliers and forged supplier relationships that valued more than just the lowest bid [60].

Following this trend, the American textile industry has heavily embraced production outsourcing. According to an American Textile Manufacturers Institute study, 257 US textile plants have closed from 1997 to 2003 [65]. Similarly, the electronics Original Equipment Manufacturers (OEM) have been placing a great deal of emphasis on outsourcing production. A recent study by the Electronics Industry Market Research and Knowledge Network examined the electronics industry, and its $104.95 billion dollar market. Researchers estimate 55% of the industry uses outsource manufacturing, compared to 45% that uses in-house manufacturing. These numbers are expected to diverge even further for 2004, to 73% outsource manufacturing, and only 27% in-house manufacturing as depicted in Figure 1.

A number of other industries, such as the pharmaceutical and biotechnology industries, have embraced the idea of production outsourcing for strategic and economical reasons. Industry Week reports that start-ups and pharmaceutical

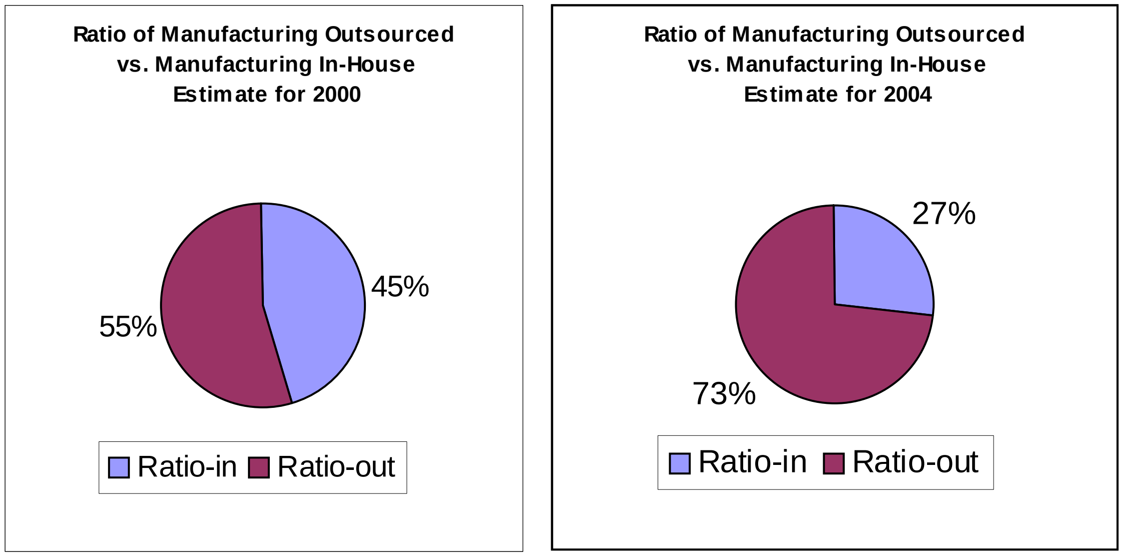


Figure 1: Ratio of Electronics Manufacturing Outsourced vs. In-House for 2000 & 2004 [66]

giants alike are turning to contract drug-development firms to handle production for clinical trials and recently to make drugs for the commercial market [55].

There are three main steps in outsourcing [61]:

1. Supplier evaluation and selection
2. Supplier management
3. Supplier development

### Supplier Evaluation and Selection

The supplier evaluation and selection process is a critical component of outsourcing because of the suppliers' large role in the entire supply chain success. Historically, suppliers have been selected and evaluated based on multiple criteria that reported in the history of purchasing management. These criteria could be broken into different categories related to the supplier's overall performance. Some of the main categories, as reported by Ellram, are financial issues, organizational culture and strategy issues, and technology issues [62].

There have been some studies that presented multiple criteria in selecting suppliers such as Dickson's 23 criteria, which are widely used in supplier selection. Table1 presents Dickson's supplier selection evaluation criteria.

In most cases, production outsourcing has helped organizations reduce cost and increase efficiency. However, if not executed appropriately, production outsourcing could undermine an organizations' productivity: "once you start transferring production lines to a contract manufacturer, there is often little or no time to respond to unforeseen issues, such as quality problems, supplier shortages or inflexible lead times around the world" [57]. In the short run, production outsourcing may seem to be a very economical and cost effective decision, but production outsourcing could potentially do a company more harm than good, especially if the extremely important suppliers' criteria are overlooked, such as quality and on-time delivery.  For instance, Boeing lost over 1 billion US dollars because of part shortages in the production of Boeing's 747 and 737 airplanes [109].

Table 1: Dickson 23 Supplier Evaluation Criteria [63]

| Rank | Factor | Mean Rating | Evaluation |
|---|---|---|---|
| 1 | Quality | 3.508 | Extreme Importance |
| 2 | Delivery | 3.417 | |
| 3 | Performance history | 2.998 | |
| 4 | Warranties and claim policies | 2.849 | |
| 5 | Production facilities and capacity | 2.775 | Considerable importance |
| 6 | Price | 2.758 | |
| 7 | Technical capability | 2.545 | |
| 8 | Financial position | 2.514 | |
| 9 | Procedural compliance | 2.488 | |
| 10 | Communication system | 2.426 | |
| 11 | Reputation and position in industry | 2.412 | |
| 12 | Desire for business | 2.256 | |
| 13 | Management and organization | 2.216 | |
| 14 | Operating controls | 2.211 | |
| 15 | Repair service | 2.187 | Average importance |
| 16 | Attitude | 2.120 | |
| 17 | Impression | 2.054 | |
| 18 | Packaging ability | 2.009 | |
| 19 | Labor relations record | 2.003 | |
| 20 | Geographical location | 1.872 | |
| 21 | Amount of past business | 1.597 | |
| 22 | Training aids | 1.537 | |
| 23 | Reciprocal arrangements | .610 | Slight importance |

It is very critical, for a purchasing company, to be able to predict the unexpected outsourcing issues of quality and on-time delivery. According to the popular press, there have been some indications that production outsourcing organizations are faced with unexpected outsourcing issues in the long run such as quality and on-time delivery problems. After great success in the short run, “companies that have been most aggressive in ridding themselves of their factories have been confronted with a host of unpredicted problems...This wasn't supposed to happen, say analysts with Booz-Allen & Hamilton's Global Operations Practice based in San Francisco " [56].

The primary question a buying company should ask is what the potential operational risks of production outsourcing in the long run are.  The more reliable the supplier is the less negative effects on the production system there are. Thus, supplier evaluation and selection is a critical step in production outsourcing. Reliable suppliers equal reliable production flow. Presumably, in production outsourcing a company’s production system is at the mercy of its supplier: “Because of increased dependence, how key suppliers perform in terms of quality, delivery, costs, and service affects the buying company’s performance” [109].

**Problem Statement**

More often than not, a supplier selection is based on the lowest bid, and in some cases on unsystematic and incomprehensive subjective evaluation and interviews. Therefore, it becomes too late to proactively avoid supplier issues or divest production flow of their symptoms. If causes of the suppliers' quality and delivery issues are accounted for early in the supplier evaluation and selection process, the associated risk could be minimized. The general question this study attempts to answer is this: is there a more comprehensive and effective supplier evaluation and selection model that minimizes the risk associated with quality and delivery? The general question subsumes several related questions:

1. What are the best practices in the supplier's value stream that affect suppliers' quality?
2. What are the best practices in the supplier's value stream that affect suppliers' on-time delivery?
3. Which best practices contribute the most to the suppliers' quality conformance?
4. Which best practices contribute the most to the suppliers' on-time delivery conformance?

## Professional Significance of the Study

It is hoped that this research would make a contribution to the existing knowledge of supplier evaluation and selection models and provide results of value to practitioners. Although there have been many supplier evaluation and selection models reported in the literature, there have been no models reported in the literature that comprehensively evaluate suppliers' factors from a value stream perspective.

## Organization of the Study

This study is organized into 5 chapters including the introduction--Chapter 1. Chapter 2 presents a thorough analysis of the supplier evaluation and selection literature. It also explains the difference between this study and the literature. Chapter 3 presents the methodology used in this study. Chapter 4 presents the results and the discussion of the study. It also presents the proposed model and its implementation. Chapter 5 concludes the study and its limitations with future research recommendations.

## Summary

Overall, evaluating and selecting suppliers based only on purchasing ratings can lead to a poor decision. This study develops a more comprehensive supplier evaluation and selection model that takes into account the best practices that are related to the most critical supplier selection factors in the supplier's value stream, quality and on-time delivery. The comprehensive model deals with supplier selection and evaluation from a supply chain perspective not a purchasing perspective. Figure 2 summarizes the focus of this study, as it relates to SCM.

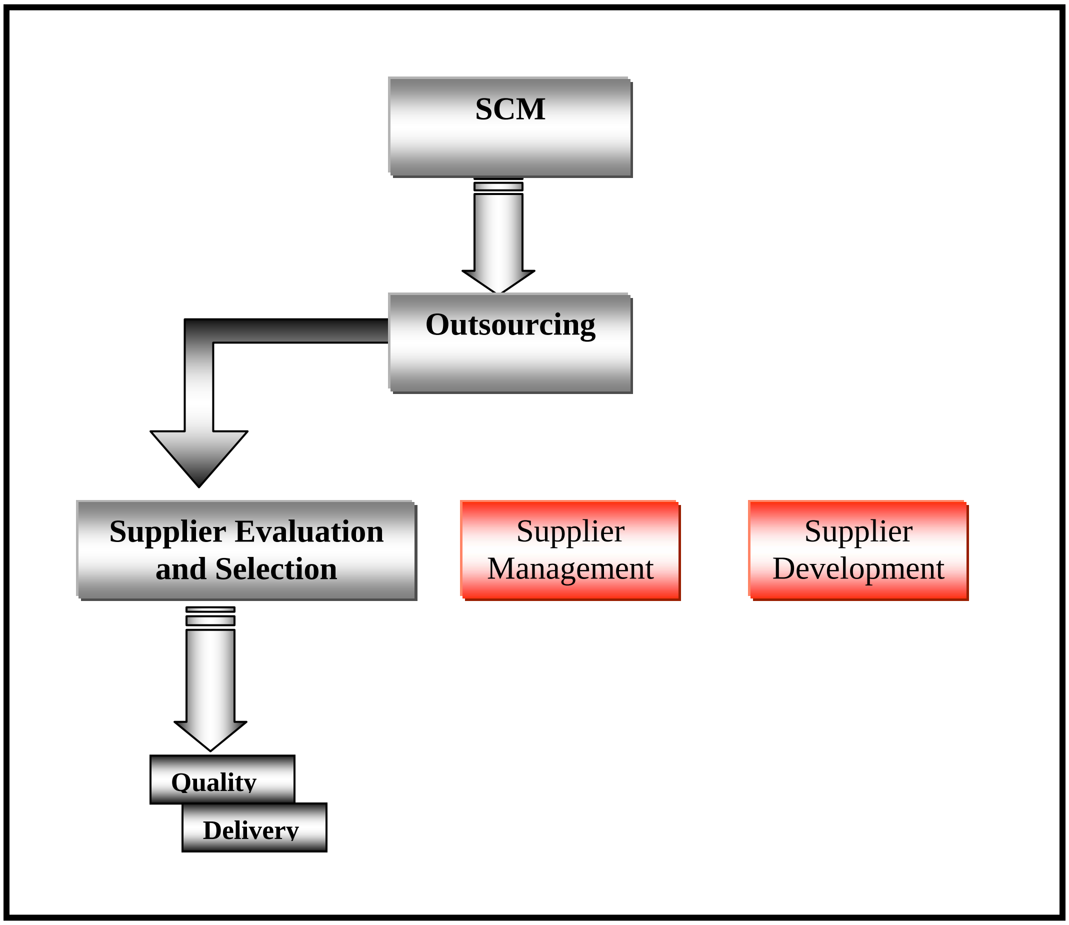


Figure 2: Roadmap of the Study

# CHAPTER 2

## OVERVIEW OF SUPPLIER EVALUATION AND SELECTION

A large body of literature on supplier evaluation and selection provides a basis for the present study. This chapter explains and summarizes the extensive search process in reviewing the supplier evaluation and selection methods in the literature. The main focus of this chapter is to present what has been done and what has not been done in the literature. It is left up to the reader to seek further details of each study.

### Search Process

The following review was developed through a systematic approach. Studies were selected from previous literature searches such as Boer et al., who conducted the most recent search in 2001 [68]. Additionally, more up to date studies were reviewed.

### Empirical Research

This study categorizes the supplier evaluation and selection empirical studies into three main categories based solely on each study's content: rating, mathematical, and hybrid methods. Figure 3 depicts the categorization of the supplier evaluation and selection methods. If it focuses on a supplier

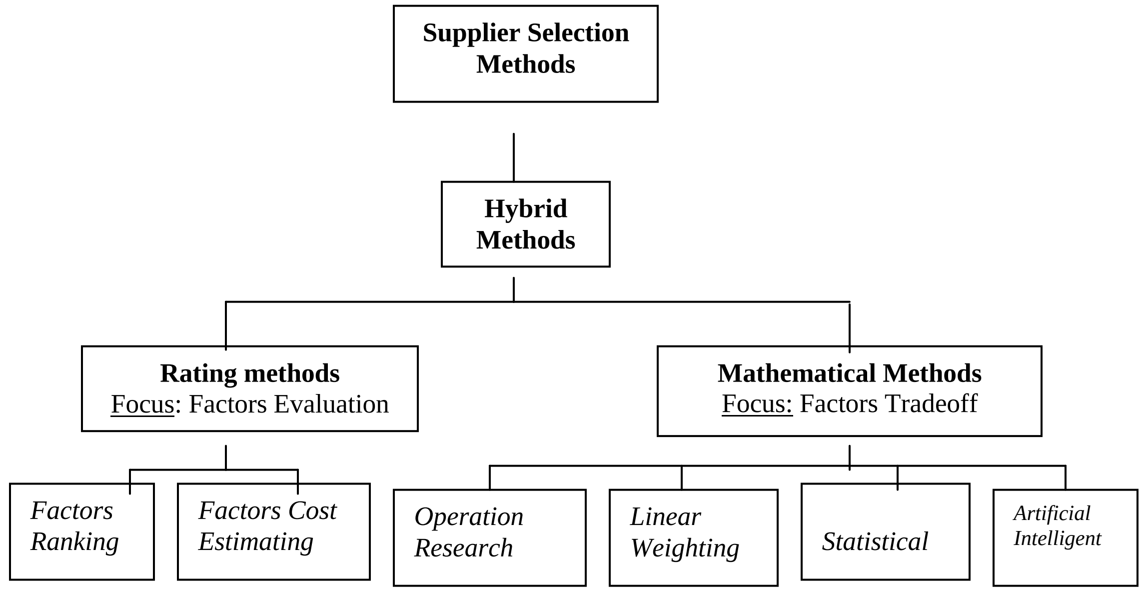


Figure 3: Supplier Selection Categories

performance evaluation, the study is listed under the rating methods; otherwise it is listed under the mathematical methods. However, if it integrates both the performance evaluation and criteria tradeoffs, the study is listed under the hybrid methods.

Rating methods encompasses two subcategories, criteria ranking and cost methods. The mathematical category encompasses four subcategories: operation research, linear weighting, statistical, and artificial Intelligence methods. This chapter lists each of the supplier selection and evaluation studies chronologically as they relate to each category and subcategory.

## Supplier Selection Methods

This section presents the three main supplier selection categories and their subcategories.

### 1. Rating Methods

Rating methods employ subjective weights or dollar values to evaluate and select suppliers. Factors such as quality and delivery are subjectively evaluated, rated, and ranked. A supplier, then, is compared to other suppliers and selected. Rating methods are broken into two subcategories: criteria ranking and cost methods.

#### 1.1. Factors Ranking

Factors ranking subjectively weights and ranks suppliers' selection factors. The main strength of subjective weighting of factors is its capability to evaluate suppliers' performance through an unsophisticated evaluation process. Factors ranking methods are generally conducted through different mechanisms such as plant visits, interviews, and audits. For example, a buying company team member subjectively evaluates and rate supplier's performance factors. After basic mathematical calculations, a number is assigned to each supplier. Accordingly, the buying company team ranks each supplier from high to low.

Factors ranking is the most popular method in supplier evaluation and selection. Authors have differed on how to apply factors ranking. Some of the studies rate factors by assigning simple subjective weights to each factor. For instance, Gregory used a simple weighted factor matrix approach to select suppliers. Gregory identified five major evaluation criteria and their subjective weight: proposal responsiveness, technical, quality, cost, and general. Logically the supplier with a higher score would be selected over others [1]. Similarly, Timmerman presented a simple approach to evaluate suppliers through the use of linear averaging, which is based on assigning weight to different suppliers' selection criteria such as quality and delivery [2].

Taking the factors ranking a step further, Thompson presented a modified traditional weighted supplier evaluation model. Unlike previous models, this model addresses the uncertainty associated with supplier factors through the use of Monte Carlo simulation. In essence, a purchaser has to determine high and low values for each supplier, and the computer will generate random numbers. Then the model calculates the sum of the weighted numbers. This number would be replicated thousands of times to form a frequency distribution for each vendor to be used as a base to compare suppliers [3, 4].

Several authors have improved the suppliers' factors ranking by using new techniques. Ghobadian et al. proposed a computerized model for suppliers' rating based on existing and developed methods in the area of a supplier's rating. The model breaks down the rating techniques into two categories:

qualitative techniques and quantitative techniques [5]. By the same token, Vokurka et al. presented a new method to rate suppliers based on an expert system [36].

More comprehensive approaches to evaluate and rank suppliers were presented in the literature, which evaluates the supplier's capability in different business areas. Barbarosoglu presented suppliers' assessment with an addition of new rating factors. The approach delineates the assessment criteria into three categories. The first category is performance assessment, which includes quality, cost, and delivery. The second category is business structure and manufacturing capability assessment, which looks at financial and technical capability. The third category is quality system assessment, which is a subjective supplier quality assessment that addresses various quality issues in a manufacturing plant. After assigning an importance rating to each category and subcategory, a supplier is evaluated and selected based on the highest score [7].

Moreover, Muralidharan et al [13] elaborated on the two most critical factors, quality and delivery. Authors rate quality based on inspection methods, percentage rejections, following TQM and JIT practices, and product performance. Also, the authors rate delivery based on speed, dependability, transport cost, and flexibility in delivery schedules. However, Garriz et al. [15] presented a more comprehensive ranking method. The evaluation process takes into account engineering technical capability, project management expertise, material planning and production scheduling, production technology and capability, commitment to continuous improvement and cost reduction, quality system and use of quality tools, business structure, and management commitment to quality and teamwork.

Nonetheless, the preceding methods are very comprehensive in terms of the different areas they evaluate but less comprehensive in the questionnaires themselves. The questionnaires are very generic and open ended, meaning that there are no set standards. Every assessor has a different perspective and different rating.

### 1.2 Factors Cost Estimating

Cost methods supplement the factors ranking by assigning a dollar value to selected and significant factors. For this reason, cost methods are easily communicated to executives, who will ultimately make decisions.

Very few authors have employed cost analysis in their supplier factors evaluation. Monczka et al. [22] is one of the few authors that have elaborated on using cost methods in selecting a supplier. Monczka’s cost method evaluates suppliers based on different factors, such as quality and delivery. The method assigns dollars per time spent, or lost, due to quality or delivery problems.

However, Smytka et al. [6] presented a more in depth analysis of the cost of suppliers' quality than Monczka. Smytka's model decomposes the cost of a supplier's quality into more appropriate subcategories such as rejects, shutdown, rework, and scrap. Also, Chen et al. [12] presented a different cost model, which bases the supplier selection on the critical factor of quality. Chen's model allocates costs to the defective shipments and the cost of quality. The model tracks the cost of quality in the entire organization from purchasing, production, design engineering, production supporting, and sales.

Another approach to the factors cost estimating is Activity Based Costing analysis (ABC). ABC accounts for all direct and indirect activities' cost. Degraeve et al. [8, 9] focuses on selecting an optimal number of qualified suppliers using ABC information. Similarly Dogan et al. [93] presented a supplier selection model using an ABC methodology, but considered fuzzy factors. Both models use the purchasing process costs to minimize the total cost of ownership (TCO). According to Degraeve, TCO quantifies all costs associated with the purchasing processes throughout the entire value chain of the firm. Compared to other cost methods, Degraeve's approach goes beyond the purchasing price to consider all costs over each item's entire life, such as costs related to service, quality, delivery, administration, communication, failure, maintenance, and others.

Most of the cost studies consider the cost of quality but at an aggregate level. For example, a production quality cost is calculated by considering the average amount of lost time due to a quality problem. There is not an emphasis on the detailed cost of quality issue as it relates to the entire organization value stream. The majority of the cost methods presented in this section measure performance cost and do not predict performance cost.

Overall, rating methods have evolved significantly. Despite their popularity, they are still biased methods because of the subjectivity involved in the evaluation process. The majority of the presented rating methods fail to adequately evaluate and predict suppliers' quantitative factors such as quality and delivery. There are other subtle activities and functions that contribute to quality and delivery. This study attempts to define these latent activities and functions in the entire supplier value stream to adequately evaluate or predict quality and delivery.

**2. Mathematical Methods**

Studies under mathematical methods do not incorporate performance evaluation, but they examine suppliers' criteria interactions and tradeoffs. There are 4 mathematical subcategories in this study; operation research, linear weighting, statistical, and artificial intelligence methods.

## 2.1. Operation Research

Operation Research (OR) methods optimize the interactions and tradeoffs among different factors of interest, which allow the buyer to make an effective supplier-selection decision. Several optimization methods such as goal programming, linear programming, heuristic, mixed integer and data envelopment analysis have been applied in the area of supplier evaluation and selection. The following sections present the different supplier evaluation and selection studies as they relate to each OR-method subcategory.

**Goal Programming:**

Few authors have applied the goal programming methods in the supplier evaluation and selection area. Bufa et al. [19] and Karpak et al. [42] presented models that schedule purchases from several suppliers based on goal programming. One of the fallbacks of goal programming is its lack to consider qualitative factors. To overcome this issue Cebi et al. [80] integrated goal programming and the Analytical Hierarchy Process (AHP), which considers both qualitative and quantitative factors.

**Linear Programming:**

A few linear programming studies exist in the supplier selection literature. Pan [23] presented a simple linear model to select among suppliers. However, Ghoudsypour et al. [41] presented a more comprehensive model, which integrates AHP and linear programming. Ghoudsypour considers the AHP method to incorporate the tangible and intangible supplier selection factors in the model. A similar approach was taken by Subramanian et al. [48] when they integrated the Multi Attribute Utility Theory (MAUT) with linear programming to account for the uncertainty in the suppliers' performance.

**Heuristic Programming:**

Heuristic programming is another OR area that is used in the supplier selection literature. Benton [24] presented a simple heuristic programming model. The model considers quantity discounts for multiple items, multiple suppliers and resource limitations. Akinc [29] presented another heuristic model that reduces the number of suppliers, and considers cost, delivery, and quality. Tempelmeier [49] presented a heuristic solution method for the dynamic order sizing and supplier selection problem. Ganeshan et al. [43] presented a more comprehensive approach yet simple heuristic model.

**Mixed Integer Programming:**

The majority of the studies presented in the supplier evaluation and selection literature use mixed integer programming. Weber et al. [26] presented a Multi-Objective-Program (MOP) method based on the mixed integer programming. Weber's model looks at the tradeoffs between different factors, but in a just in time (JIT) environment. The model establishes the appropriate order quantities.

A different approach was taken by Chaudhry [27] when the author presented a linear and mixed binary integer-programming model. Chaudhry's model presents a price break for a single product over a single planning period. Rosenthal et al. [35] illustrated an extended pure purchasing method. Rosenthal's model presented a mixed integer linear program method to minimize total purchasing cost. The strength of Rosenthal's method lies in considering buying from different suppliers with different discounted order quantity, different quality level, and different capacity levels.

To strengthen the mixed-integer models even more, authors integrated approaches to supplier selection using other research areas. For example, Degraeve et al. [11] integrated a mixed integer programming with the activity based costing (ABC). Degraeve' s model uses multi period, multi item, and multi-vendor mathematical model [11]. Kumara et al. [72] integrated the fuzzy theory with mixed integer programming. Kumara's model considers some of the parameters being fuzzy. Also, Feng et al. [81] presented a stochastic integer programming model. Feng integrated the Tagouchi's loss function and process capability indices with mixed integrate model. Feng's model is one of the very few models that address the quality problems from a production perspective.

Recent mixed integer programming studies in the literature consider more complex constraints in the models such as inventory, lot sizes, and quantity discount. For instance, Basnet et al. [87] presented a mixed integer programming model taking into consideration a multi-period inventory lot sizing scenario; Crama et al. [89] presented a mixed integer model taking into consideration total quantity discounts and alternative product recipes; Ghodsypour et al. [94] presented a mixed-integer nonlinear programming model to select suppliers and assign appropriate quantity to each selected suppliers with additional constraints of multiple sourcing, multiple criteria, and suppliers capacity; and Dahel et al. [97] presented a multi-objective mixed integer model that considers the quantity to allocate to each selected supplier in a multiple product, discounts, and multiple-supplier competitive sourcing. These models only differ in the factors considered in the analysis, but they are still similar to the preceding models in terms of the use of mixed integer programming.

**Data Envelopment Analysis:**

One of the most recent OR areas that is used in the supplier selection studies is Data Envelopment Analysis (DEA). Weber et al. [37] demonstrated the use of DEA for measuring vendor performance and efficiency. Weber's model presents a graphical analysis to help buyers choose among different suppliers. A few years later, Weber et al. [40, 46] integrated a mathematical model with DEA to select between suppliers. Liu et al. [44] extended Weber's research and evaluated different suppliers for an individual product using DEA. Liu's model estimates the overall performance of suppliers in order to be able to reduce the number of suppliers.

Besides, Zhu [82] presented a supplier selection model based on the DEA, which is similar to Talluri's model [76] with an objective to maximize efficiency rather than minimizing efficiency. Also, models are presented in the supplier selection literature by Current et al. [33] and Dulmin et al. [92]. Current presented a model to demonstrate the similarity between supplier selection models and facility location problems. Current's model reduces the number of existing suppliers [33]. Dulmin's model ranks alternatives and analyzes relationships between factors.

### 2.2. Linear Weighting

Linear weighting methods utilize simple weighting algorithms to rank suppliers performance factors subjectively, such as quality and delivery. Linear weighting studies are characterized in this research as mathematical because they do not evaluate factors but weight factors. Many studies use linear weighting methods in the supplier selection process because of their uncomplicated execution process and the use of both qualitative and quantitative factors.

One of the most applied weighting methods is Analytical Hierarchy Process (AHP). Narasimhan [18] and Nydick et al. [25] demonstrated the applicability of AHP when selecting suppliers. Finnman et al. [50] applied AHP based on supplier chain risk management. The model integrates decision tree analysis and AHP, which selects the lowest risk suppliers.

Vendor performance rating is another application area of the linear weighting methods. Vendor permanence methods evaluate and rate suppliers' factors. Soukup [20] presented a vendor performance matrix methodology to compare a vendor's performance based on different scenarios. Also, Grando et al. [38] presented another vendor performance matrix to evaluate suppliers based on services, quality, cost, and availability. Grando et al. uses a weighting system to assign criteria values, and then constructs a service vendor rating (SVR) to select suppliers [38]. However, Li et al. [39] proposed an alternative to the vendor performance index used in supplier selection. Li et al. proposes a fuzzy bag method and a new measure called standardized unit-less unit (SUR) to select between suppliers. Additionally, Willis et al. [30] presented a modified version of the dimensional analysis model. Basically, the model compares the criteria ratio, such as quality, between two suppliers, and then the company selects a high ratio supplier based on the model.

Even though many organizations and researchers use linear weighting methods, linear weighting methods are still considered biased because of their excessive subjectivity. The linear weighting methods process relies heavily on human judgment to weight different suppliers' factors.

## 2.3. Statistical

Statistical studies incorporate uncertainty; there are not many articles in the literature that utilize statistics in the supplier selection process. This study's comprehensive-literature search reveals three studies only of supplier evaluation and selection that use statistical methods.

The very first statistical study in the literature is presented by Hinkle et al. [17]. Hinkle et al. presented an overview of using cluster analysis when selecting suppliers. The method basically clusters suppliers' factors, and then selects the best supplier. A different statistical model was presented by Ronen et al. [21]. Ronen used statistical distributions to develop a decision support system (DSS). The DSS focuses on lead-time management. The model optimizes the order time for each supplied item, and then chooses the supplier whose minimal cost is the global minimum for a specific item. The decision support system is management of when to order items from suppliers in order to meet a due date. The third study is presented by Petroni et al. [45]. Petroni et al. presented a multivariate-statistical method. The method evaluates existing suppliers' performance, meaning that a company keeps the supplier that meets the company's requirement.

## 2.4. Artificial Intelligence

Artificial Intelligence [AI] methods incorporate the ‘if’ scenario when dealing with different factors. Very few researchers have applied artificial inelegance to the area of supplier selection.

Siying et al. [77] and Choy et al. [47] presented intelligent supplier selection models based on Neural Network [NN]. Subsequently, Choy et al. [73, 74, and 75] presented a series of studies dealing with supplier selection using the application of AI techniques. In particular, the authors used an AI technique called Critical Based Reasoning (CBR). CBR is a subset of an AI application Knowledge-based management (KBS), which utilizes past experience to solve problems. Similarly, Humphreys et al. [96] presented a supplier selection model using CBR, which takes into account environmental factors. Valluri [78] presented an AI model that employed an agent based modeling to select suppliers.

The AI methods presented in this section are constrained to qualitative factors. That is, if a supplier’s evaluation contain quantitative factor, such as percentage of defects, a different method would have to be integrated with AI to address the quantitative factors. AI methods incorporate very generic criteria such as technical capability, quality assessment, and organization profile.

The supplier evaluation and selection methods under the mathematical category have addressed supplier selection factors tradeoffs successfully. However, most of the proposed methods are constrained to existing suppliers and underestimate the suppliers' impact on the production system. For example, a mathematical model considers excessive inventory or safety stock to overcome a supplier's quality or delivery problem, meaning a supplier problem is solved by another manufacturing efficiency problem. Thus, instead of fixing a problem with another problem, suppliers' performances need to be evaluated and predicted before the final selection process.

### 3. Hybrid Methods

Studies under Hybrid methods encompass both suppliers' rating and mathematical methods. The strength of Hybrid models lay in combining the better of the two methods by evaluating and optimizing factors. A few hybrid studies are found in the literature review where factors are first evaluated and then integrated with a mathematical model to study the factors tradeoffs.

Talluri et al. [76] presented a framework to select suppliers based on Data Envelopment Analysis methodology. Barla et al. [71] presented a supplier selection using a multi attribute selection model in a lean environment. Also, Tam et al. [79], Kahraman et al. [88], and Wang et al. [90] evaluated very generic factors (such as delivery reliability, flexibility & responsiveness, cost, and assets) and employed the AHP method.

Other authors such as Kwong et al. [83] and Choy et al. [84, 85, 86] used AI as their mathematical models and extended the suppliers' evaluation to incorporate other functions of the value stream such as delivery, shipment quality, product price, customer service, quality, development, and organizational culture. A different approach was taken by Degraeve et al. [11, 95], who presented a mixed integer model based on data collected from the total cost of ownership. The authors evaluated and quantified suppliers' factors then examined the factors tradeoffs.

The studies presented in this section were very generic for the two critical factors, quality and on time delivery. Table 2 references the supplier evaluation and selection studies presented in this chapter. Also, Table 2 references the studies that included evaluation of quality or/and delivery in their models. The following section discusses the shortcoming of the presented studies in terms of quality and delivery evaluation.

Table 2: Chronological Summary of the Literature Review

| | | | **Supplier Selection Methods** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Rating methods** | | **Mathematical Methods** | | | | | **Selection Criteria** | |
| | **Article** | **Year** | Factors Ranking | Factors Costing | Operation Research | Linear Weighting | Statistical | Artificial Intelligence | Hybrid Methods | Delivery | Quality |
| 1 | Hinkle et al. | 1969 | | | | | X | | | | |
| 2 | Narasimhan | 1983 | | | | X | | | | | |
| 3 | Bufa et al. | 1983 | | | X | | | | | | |
| 4 | Gregory, R.E. | 1986 | X | | | | | | | | |
| 5 | Timmerman | 1986 | X | | | | | | | | |
| 6 | Soukup | 1987 | | | | X | | | | | |
| 7 | Ronen et al. | 1988 | | | | | X | | | X | |
| 8 | Monczka | 1988 | | X | | | | | | X | X |
| 9 | Pan | 1989 | | | X | | | | | | |
| 10 | Thompson, K. | 1990 | X | | | | | | | | |
| 11 | Thompson, K. | 1991 | X | | | | | | | | |
| 12 | Benton | 1991 | | | X | | | | | | |
| 13 | Nydick et al. | 1992 | | | | X | | | | | |
| 14 | Ghobadian et al. | 1993 | X | | | | | | | | |
| 15 | Smytka et al. | 1993 | | X | | | | | | X | X |
| 16 | Weber et al. | 1993 | | | X | | | | | | |
| 17 | Chaudhry | 1993 | | | X | | | | | | |
| 18 | Weber et al. | 1993 | | | X | | | | | | |
| 19 | Akinc | 1993 | | | X | | | | | | |
| 20 | Willis et al. | 1993 | | | | X | | | | | |
| 21 | Sadrian et al. | 1994 | | | X | | | | | | |
| 22 | Current et al. | 1994 | | | X | | | | | | |
| 23 | Min | 1994 | | | | X | | | | | |
| 24 | Rosenthal et al. | 1995 | | | X | | | | | | |
| 25 | Vokurka et al. | 1996 | X | | | | | | | | |
| 26 | Weber et al. | 1996 | | | X | | | | | | |
| 27 | Grando et al. | 1996 | | | | X | | | | X | X |
| 28 | Barbarosoglu et al. | 1997 | X | | | | | | | X | X |
| 29 | Li et al. | 1997 | | | | X | | | | | |
| 30 | Siying et al. | 1997 | | | | | | X | | | |
| 31 | Degraeve et al. | 1998 | | X | | | | | | | |

Table 2: Continued

| | | | Supplier Selection Methods | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Rating methods | | Mathematical Methods | | | | | Selection Criteria | |
| | Article | Year | Factors Ranking | Factors Costing | Operation Research | Linear Weighting | Statistical | Artificial Intelligence | Hybrid Methods | Delivery | Quality |
| 32 | Weber et al. | 1998 | | | X | | | | | | |
| 33 | Ghoudsypour et al. | 1998 | | | X | | | | | | |
| 34 | Degraeve et al. | 1999 | | X | | | | | | | |
| 35 | Karpak et al. | 1999 | | | X | | | | | | |
| 36 | Ganeshan et al. | 1999 | | | X | | | | | | |
| 37 | Degraeve et al. | 2000 | X | | | | | | | | |
| 38 | Degraeve et al. | 2000 | X | | X | | | | X | X | X |
| 39 | Liu et al. | 2000 | | | X | | | | | | |
| 40 | Petroni et al. | 2000 | | | | | X | | | | |
| 41 | Weber et al. | 2000 | | | X | | | | | | |
| 42 | Subramanian et al. | 2001 | | | X | | | | | | |
| 43 | Tempelmeier | 2001 | | | X | | | | | | |
| 45 | Tam et al. | 2001 | | | | | | | X | X | X |
| 46 | Feng et al . | 2001 | | | X | | | | | | X |
| 47 | Ghodsypour et al. | 2001 | | | X | | | | | | |
| 48 | Chen et al. | 2002 | | X | | | | | | | X |
| 49 | Muralidharan et al. | 2002 | X | | | | | | | | |
| 50 | Simpson et al. | 2002 | X | | | | | | | | |
| 51 | Garriz et al. | 2002 | X | | | | | | | | X |
| 52 | Okes et al. | 2002 | X | | | | | | | | |
| 53 | [a]Choy et al. | 2002 | | | | | | X | | | |
| 54 | Finnman et al. | 2002 | | | | X | | | | X | |
| 55 | Kwong et al. | 2002 | | | | | | | X | | |
| 56 | [b]Choy et al. | 2002 | | | | | | X | | X | X |
| 57 | Barla | 2003 | | | | | | | X | X | X |
| 58 | [a]Choy et al. | 2003 | | | | | | X | | X | X |
| 59 | [b,c,d]Choy et al. | 2003 | | | | | | | X | X | X |
| 60 | Kahraman et al. | 2003 | | | | | | | X | X | X |

Table 2: Continued

| | | | Supplier Selection Methods | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Rating methods | | Mathematical Methods | | | | | Selection Criteria | |
| | **Article** | **Year** | Factors Ranking | Factors Costing | Operation Research | Linear Weighting | Statistical | Artificial Intelligence | Hybrid Methods | Delivery | Quality |
| 61 | Cebi et al. | 2003 | | | X | | | | | | |
| 62 | Valluria et al. | 2003 | | | | | | X | | | |
| 63 | Dulmin et al. | 2003 | | | X | | | | | | |
| 64 | Humphreys et al. | 2003 | | | | | | X | | | |
| 65 | Dahel | 2003 | | | X | | | | | | |
| 66 | Dogan et al. | 2003 | | X | | | | | | X | X |
| 67 | Talluri et al. | 2004 | | | | | | | X | X | X |
| 68 | Wang et al. | 2004 | | | | | | | X | X | |
| 69 | Degraeve et al. | 2004 | | | | | | | X | | |
| 70 | Choy et al. | 2004 | | | | | | X | | | |
| 71 | Zhu | 2004 | | | X | | | | | | |
| 72 | Kumara et al. | 2004 | | | X | | | | | | |
| 73 | Crama et al. | 2004 | | | X | | | | | | |
| 74 | Crama | 2004 | | | X | | | | | | |
| 75 | Basnet et al. | 2005 | | | X | | | | | | |

## Literature Review Summary

This section discusses the studies that are related to two of the most critical suppliers' selection criteria, quality and delivery. The majority of the studies presented in the supplier evaluation & selection literature focused on the selection and overlooked the evaluation of suppliers. The presented studies occasionally focused on how to better evaluate and measure the suppliers' criteria. Table 2 references the studies that addressed quality and delivery. According to Table 2, only 19 out of 75 reviewed studies touched on either supplier's quality or delivery. However, the studies that considered either quality or delivery or even both utilized pre-evaluated values. For example, a study used percent of defective parts or on time delivery values without presenting how these values were evaluated. The following section presents the quality related studies, delivery related studies, and both quality and delivery related studies as they were listed in Table 2.

### Quality Related Studies:

Few authors mentioned quality directly or indirectly in their studies. Feng et al. (2001) addressed suppliers' quality by considering the concept of concurrent engineering. The authors focused on developing a model to achieve quality through integrating manufacturing cost, quality loss cost, assembly yield, and process capability index. The study stressed the importance of considering tolerance design in selecting suppliers. Nonetheless, the model was still limited to design tolerances to achieve good quality. It did not present how to evaluate suppliers' quality.

Chen et al. (2002) evaluated quality from a cost of quality perspective. The authors used five costs of quality categories: prevention cost, appraisal cost, internal failure cost, external failure cost, and consequential costs of failure. These costs were tracked throughout a supplier's entire organization: purchasing, production, design engineering, production supporting, and sales. This model looked at evaluating the cost of suppliers' quality not the quality of suppliers.

Gariz et al. (2002) presented more detailed suppliers' criteria evaluation than other presented studies. The study touched on several value stream elements but from a macro level. The authors presented questionnaires to evaluate suppliers based on engineering technical capability, project management expertise, material planning and production scheduling, production technology and capability, commitment to continuous improvement and cost reduction, use of quality tools, business structure, and management commitment to quality and teamwork. Clearly, the quality evaluation focused more on the management aspect of suppliers' quality rather than conformance to quality.

**Delivery Related Studies:**

Three of the presented studies focused on the suppliers' delivery criteria. Ronen et al. (1988) assumed known lead-time in their model based on historical data. The study focused on determining when to place orders to hit the due date. Hence, no delivery evaluation was presented.

Finnman (2002) developed a supplier selection model considering the risk of several parameters. One of the parameters in the model was the suppliers' logistics complexity, which was described as a poor optimization of the suppliers' logistic network. The study focused on the selection model development rather than the suppliers' delivery evaluation.

Wang et al. (2004) presented very general parameters to evaluate delivery: delivery performance, fill rate, order fulfilment lead-time, and perfect order fulfilment. Similarly, the study focused on the selection rather than the evaluation of suppliers.

**Quality and Delivery Related Studies:**

More studies focused on both quality and delivery. Monczka et al. (1988) assigned cost to suppliers' performance parameters. Quality and delivery were among the parameters in the model. The authors used very simple evaluation measurements for both quality and delivery. Quality was evaluated by number of scraped parts. Meanwhile, delivery was evaluated by on-time delivery, where 5 days early and two days beyond deadline were considered on-time. No specific details were presented in how to evaluate each factor. The study focused more on how to select a supplier given the quality and delivery values.

Smytka et al. (1993) presented a cost evaluation to both quality and delivery. The study assigned dollar value to the activities associated with the resolutions of non-conformances. In addition, delivery was evaluated based on the cost associated with transportation and delivery expediting. The model was very limited in the parameters that evaluated suppliers' quality and delivery.

Grando et al. (1996) presented supplier evaluation metrics. Quality was evaluated based on 4 criteria: number of returned or waste units/ units supplied, physical or performance measurements carried out when goods entered the plant, replacement guarantees, and certification. Delivery was evaluated based on average delivery time, schedule average delay, and average gap between goods ordered and goods delivered. This study did not add anything to previous quality and delivery evaluation.

Barbarosoglu et al. (1997) also presented limited suppliers evaluation metrics. Suppliers' quality evaluation was based on 4 parameters: rejection rate, lot certification, sorting effort, and defective acceptance. Delivery was also evaluated using compliance with quantity, compliance with due dates, and compliance with packaging standards.

Degraeve et al. (2000) presented an activity based costing evaluation of quality and delivery. The authors associated cost with quality audit, quality problems set up and defects cost, inventory holding cost, and transportation cost. Nothing very specific was presented on how to evaluate rather than capturing the cost of both quality and transportation.

Tam et al.  (2001) reported an actual case study of selecting suppliers in the telecommunication industry. Thus, quality and delivery evaluation were geared toward telecommunication practices not manufacturing practices.

Choy et al. (2002, 2003) presented a series of articles in the area of Artificial Intelligence. The authors included delivery and quality as input of the supplier selection criteria in the intelligent model. However, very generic referral to quality and delivery was presented. For example, quality was referred to as rejection from customers, rejection in production line, and rejection in incoming quality. Also delivery was referred to as compliance with quantity and compliance with due date. The data used in the model did not evaluate the suppliers. Again, the study focused more on the model that the evaluation itself.

Barla et al. (2003) presented a case study using an OR model. The authors claimed the importance of quality and quick response parameters. However, the model did not present any clarification of how the quality and delivery criteria were evaluated other than the quality and delivery performance were generally rated using a scale of 0 to 100.

Kahraman et al. (2003) also focused on developing a mathematical model more than evaluating criteria. The authors mentioned that quality and delivery criteria were an important part of the model, but just like most of the models the focus was more on how to use the value rather than how to evaluate the quality and delivery. Very general statements were made about quality being measured by ISO 9000 and end user criteria.

Dogan et al. (2003) used value such as delayed delivery and quality trouble in the model. No specific details on how to evaluate. The study used predetermined values and implemented a fuzzy logic and ABC costing.

Talluri et al. (2004) presented a framework to select suppliers. The study presented steps of categories for suppliers' evaluation. Questionnaires were sent to suppliers to rate themselves between 0 and 1. Not enough details were presented in terms of what types of questionnaires were asked to evaluate both quality and delivery.

The studies presented here did not elaborate on the evaluation steps. Most of them were very generic in evaluating quality and delivery. Gariz's assessment was the only study to address suppliers' selection from a value stream perspective. However, the assessment was not geared toward quality and delivery criteria. It was an overall evaluation to the suppliers and it was still very limited in the parameters and the areas it assessed. The most common parameters found in Gariz's assessment and the reviewed literatures fall under the following quality and delivery categories:

- Quality management system [ISO 9000]
- Quality planning and assurance processes
- Quality performance [such as PPM, Cpk]

- Quality reliability [warranty cost, failure frequency, customer compliant and serviceability]
- Quality problem solving methods
- Quality safety parts management
- Logistics system evaluation
- Delivery precision [on-time percentage]

However, the literature lack an effective and comprehensive model for suppliers' quality and delivery evaluation that takes into account the entire supplier value stream practices. Simpson et al. presented a result of survey to find the different evaluation methods or factors considered across industry. The survey proved the lack of predictive measures of suppliers' selection process [14]. The majority of the presented methods in the literature fall short to adequately and comprehensively evaluate suppliers' quantitative factors such as quality and delivery. Only a few direct practices of the two factors quality and delivery are considered in the evaluation models. Indeed, there are other subtle direct and indirect activities that contribute to quality and delivery conformance. This study attempted to define these latent activities in the entire supplier value stream to ultimately minimize the risk associated with suppliers' quality and delivery.

In more details, this study addressed the risk associated with underestimating the two most critical factors. To overcome this issue and minimize the associated risk, this study considered a holistic approach to evaluating suppliers' quality and delivery conformance. The study addressed the possible practices in the entire organization to examine their impact on products' conformance.

The rationale of this study was that the preceding most common evaluation practices overlooked the latent quality and delivery activities, which could have tremendous impact on a product conformance. For instance, how the purchasing department selects vendors has to do tremendously with a product quality and delivery conformance. If defective materials are bought, scraps and defects are produced.  This study attempts to reveal the most overlooked value stream practices and prove their implication on quality and delivery conformance, and apply the practices into a model to evaluate suppliers' quality and delivery to minimize the risk associated when selecting suppliers.

# CHAPTER 3

# RESEARCH METHODOLOGY

This chapter explains the method used in conducting the study. The method was broken down into four main phases: general approach, methodology, data collection, and data analysis.

## General Approach

The general approach of this study was based on the suppliers' product value stream. Figure 4 depicts the overall approach to this study where quality and delivery were evaluated and predicted based on 7 value stream elements, 39 sub-elements and their associated 205 best practices. The following section explains the general approach in detail.

To answer the research questions of what best practices in the supplier's value stream affected and contributed to the suppliers' quality and on-time delivery conformance, an examination of the supplier value stream was required. To examine a supplier value stream and identify direct and indirect activities associated with a product quality and delivery, a product was tracked throughout the value stream. A product went through several transformations from receiving the raw material all the way to shipping the final product to customers.

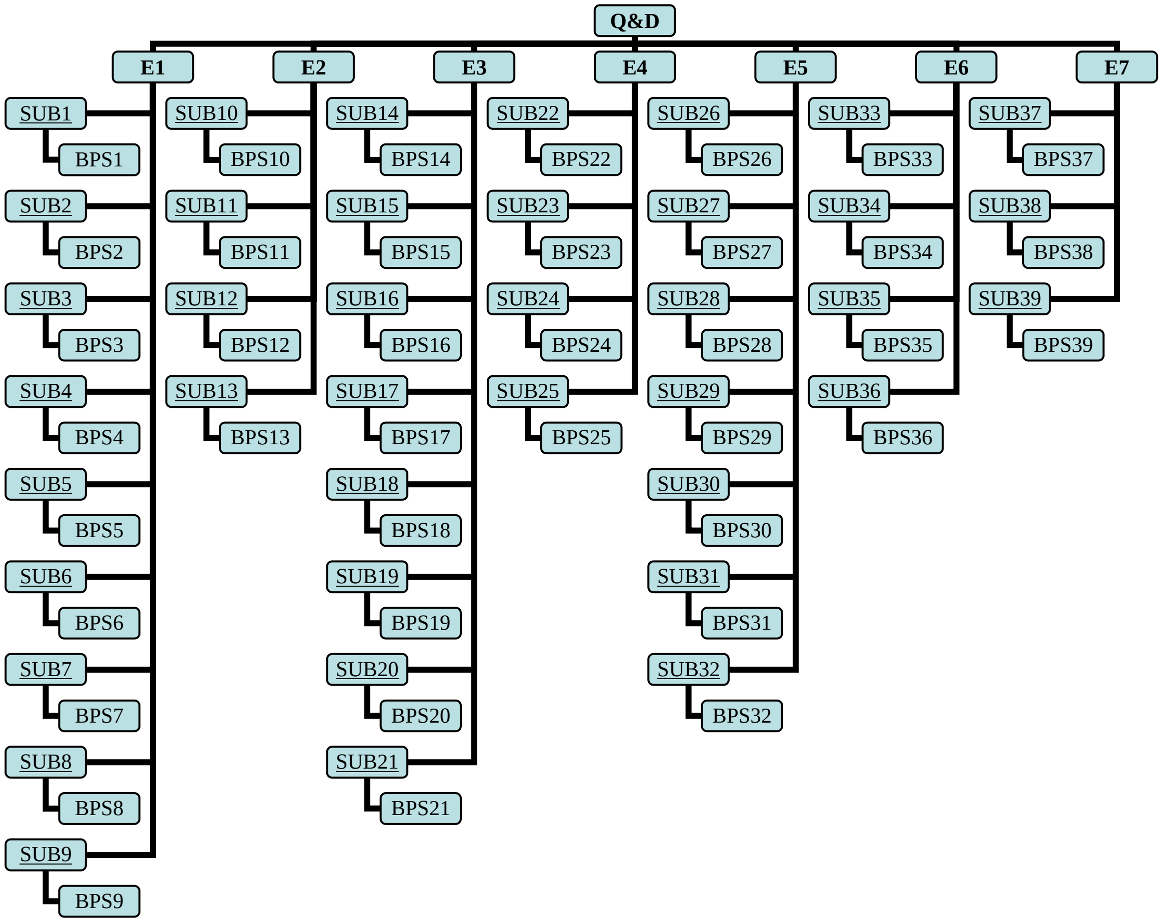


Figure 4: General Approach of the Study. (Q: Quality, D: Delivery, E: Value Stream Element, SUB: Sub-element, BPS: Best practices of sub-element).

Each step of the product flow had associated activities that impacted the final product's quality and delivery. The product order flow encompassed material and information flow as illustrated in Figures 5&6. Figure 5 depicts an example of a typical value stream map. A value stream map is a visual tool that helps one to see and understand the flow of material and information as a product makes its way through the value stream [100]. A value stream map places more emphasis on the production process activities.  Meanwhile, what we call a control stream map places more emphasis on the supporting functions activities, such as purchasing and customer service activities.  Figure 6 depicts an example of a control stream map, where a detailed breakdown of a product order flow activities are illustrated as an order made its way through the sales and the engineering department. According to the literature, a typical manufacturer value stream consists of the following 7 major elements [100]:

1. Customer service/sales
2. Purchasing
3. Production planning and control
4. Manufacturing engineering
5. Shop floor and quality control
6. Receiving
7. Shipping

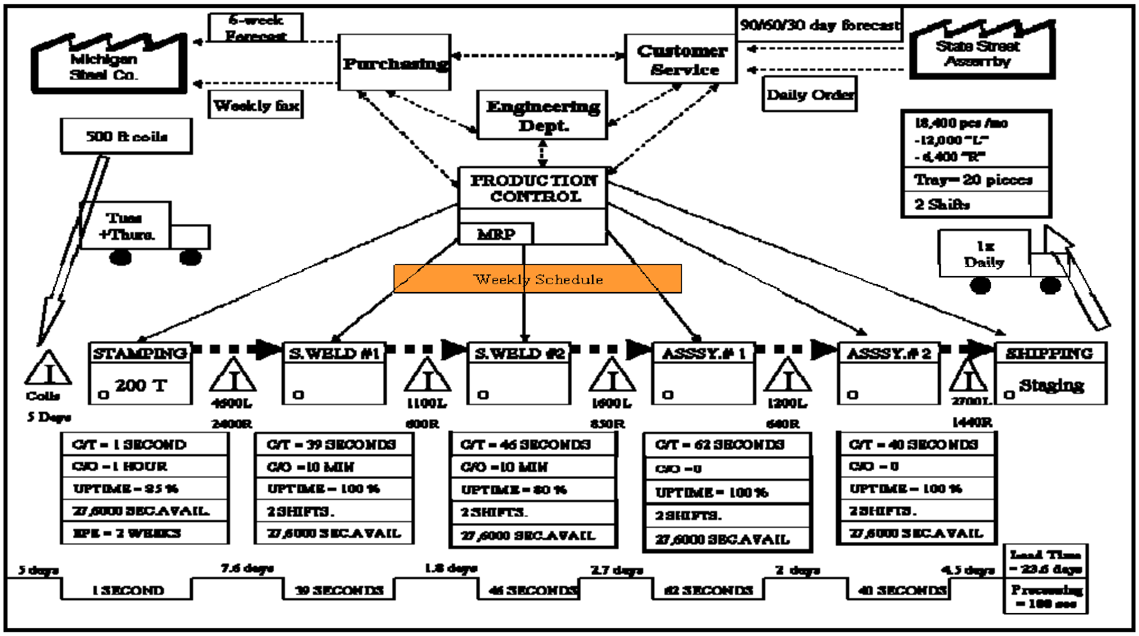


Figure 5: Example of a Value Stream Map [100]

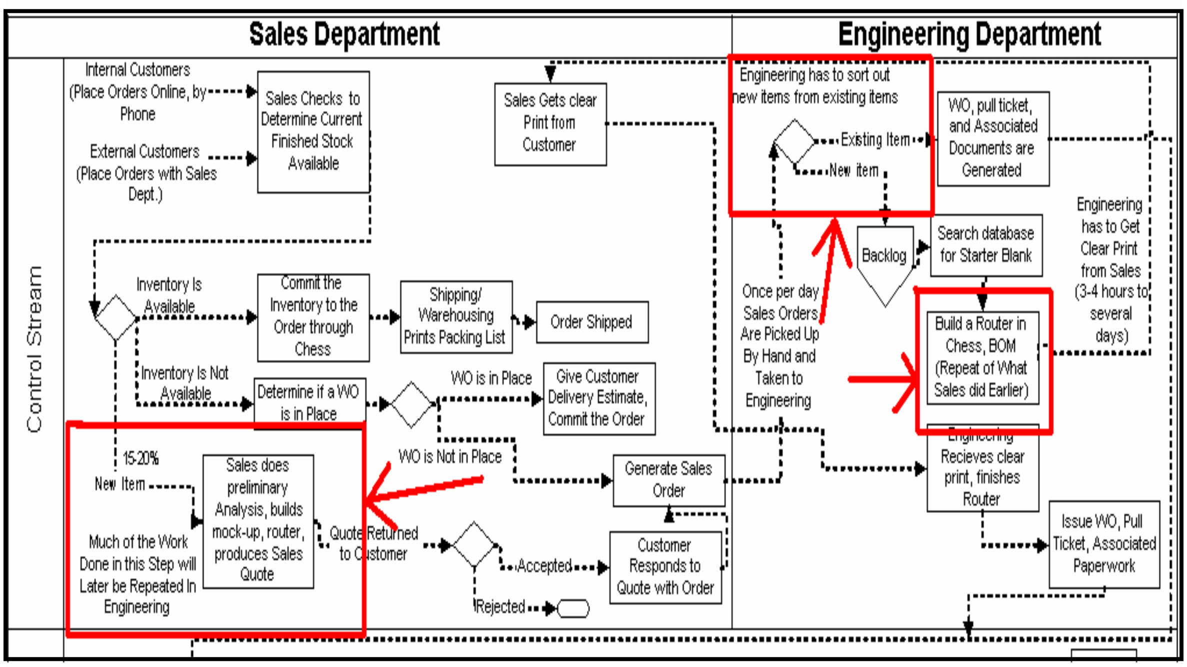


Figure 6: Example of a Control Stream Map

Each one of the 7 value stream elements contributed to the product's quality and delivery because every product had to pass through them directly or indirectly. Some of the elements had direct and clear contribution to quality and delivery conformance while others had indirect contribution. For example, in Figures 5& 6 a time delay in customer service/sales paper work processing caused a delay in the product's release. Also, a miscommunication of product specifications impacted product quality. In Purchasing, inaccurate records of parts inventory affected the time to release a product. Also, purchasing low quality raw material impacted the final product quality. In Production planning and control, miscalculation of customers' requirements and executing the orders contributed to product's quality and delivery. In manufacturing and engineering, poor design contributed to poor quality and delivery. In shop floor and quality control, poor flow and poor quality practices resulted in poor quality and delayed product release. In receiving, poor handling and misallocation of received parts contributed to low quality and delivery conformance. In Shipping, packing and packaging affected the products quality and delivery.

There are several subtle value stream practices and activities that contributed to the suppliers' quality and delivery. A regressive search approach was conducted to compile a list of possible best practices within each of the 7 value stream elements. Several practical and academic sources were used to gather and categorize the best practices. Table 3 reports the different academic and

Table 3: Academic and Practitioners' Literature Sources

| Number | Bibliography Number | Book and Best practices sources |
|---|---|---|
| 1 | 101 | Bender, Paul S. Design and Operation of Customer Service Systems. AMACOM, New York 1976. |
| 2 | 102 | Aljian, George. Purchasing Handbook. 3rd edition New York, McGraw-Hill 1973. |
| 3 | 103 | Greene, James H. Production and Inventory Control Systems and Decisions. Richard D. IRWIN, INC. Homewood, Illinois, 1974. |
| 4 | 104 | Wage, Herbert W. Manufacturing Engineering. McGraw-HILL Book Company, INC. New York, 1963. |
| 5 | 105 | Ertas, Atila and Jesse C. Jones. The Engineering Design Process. John Wiley & Sons, Inc. 1993. |
| 6 | 106 | Jenkins, Creed H. Complete Guide to Modern Warehouse Management. Prentice Hall. Englewood Cliffs, New Jersey 1990. |
| 7 | 107 | Greene, James H. Production and Inventory Control Handbook. Third Edition, McGraw-Hill 1997. |
| 8 | 108 | Robeson, James F. and William C. Copacino. The Logistics Handbook. The free press, New York 1994. |
| 9 | 109 | Malcolm Baldridge National Quality Award criteria (MBNQAC). Park, Seungwook, Janet L. Hartley, and Darryl Wilson. Quality management practices and their relationship to buyer's supplier ratings: a study in the Korean automotive industry. Journal of Operations Management, 2001, 695-712. |
| 10 | 110 | Master Global Materials Management Operations Guidelines / Logistics Evaluation (MMOG-LE). Automative Industry Action Group. http://www.aiag.org |
| 11 | 111 | APICS supplier evaluation model. ExcelSCM from APICS mag 10-02. www.apics.org |

practitioners' literature sources for the value stream elements, sub-elements and their associated best practices.

Each academic and practitioner source was examined thoroughly. Consequently, a list of sub-elements for each value stream element was created. There were a total of 39 sub-elements. For instance, customer service/sales was broken down into 6 sub-elements: order processing, information, exchange, technical services, customer service planning, after delivery services, and reliability.  Table 4 reports the sub-elements as they relate to the 7 value stream elements.

Sources were also examined thoroughly to extract best practices within each sub-element. Initial examination of the sources revealed a total of 350 best practices. However, not every single one of the best practice was very important to either quality or delivery. Hence, the compiled list was sent to 7 different value stream mangers to screen and confirm the classification of each sub-element and best practices.  A rating scale from 1 to 10 was used to indicate whether managers think that the listed best practice contributed to quality or delivery. One means that the practice was not important and 10 means the practice was extremely important to the value stream mangers.  After refining the data received from the managers, 145 best practices were excluded from the list because of their weak association with quality or delivery. Best practices with a rating lower than a cutting point of 3 were excluded from the list. Consequently, the list of best practices for all the 7 value stream elements was reduced from

Table 4: The 7 Value Stream Elements and their Sub-elements

| | Value Stream Element | Sub-Elements |
|---|---|---|
| **1** | **Customer Service/Sales** | 1.1. Order Processing |
| | | 1.2. Information Exchange |
| | | 1.3. Technical Services |
| | | 1.4. Customer Services Planning |
| | | 1.5. After Delivery Services |
| | | 1.6. Reliability |
| | | 1.7. Sales Forecasting |
| | | 1.8. Order Entry |
| | | 1.9. Claims and Credits |
| **2** | **Purchasing** | 2.1. Database |
| | | 2.2. Procurement Process |
| | | 2.3. Material management |
| | | 2.4. Procurement Decision |
| **3** | **Production Planning and Control** | 3.1. Engineering Data control |
| | | 3.2. Inventory control |
| | | 3.3. Requirements planning |
| | | 3.4. Capacity planning |
| | | 3.5 .Operation scheduling |
| | | 3.6 .Shop floor control |
| | | 3.7. Purchasing |
| | | 3.8. Quality Management |
| **4** | **Manufacturing Engineering Department** | 4.1. Production Planning |
| | | 4.2.Product Design |
| | | 4.3.Tooling Design |
| | | 4.4. Documentation |
| **5** | **Shop Floor and Quality Control** | 5.1. Order Review and release |
| | | 5.2. Detailed scheduling (Lean Manufacturing) |
| | | 5.3. Maintenance |
| | | 5.4. Quality/Prevention |
| | | 5.5. Quality/Appraisal |
| | | 5.6. Quality/Failure |
| | | 5.7. Efficiency |
| **6** | **Receiving** | 6.1. Receiving |
| | | 6.2. Storing |
| | | 6.3. Incoming Material Inspection |
| | | 6.4. Space Planning |
| **7** | **Shipping** | 7.1. Picking/Packaging and labeling |
| | | 7.2. Shipping |
| | | 7.3. Transportation |

305 to 205 best practices. Table 5 presents a detailed example of the best practices under each of the customer service's sub-element. There are two separate lists of practices for both quality and on-time delivery (See appendix B for a detailed list of the best practices).

## Methodology

Because this study was empirical, a survey was the most appropriate empirical data collection method. However, a single survey with 205 best practices related questions would have been highly unlikely filled out by any one of the suppliers. Such survey would have required the suppliers to spend hours to fill out. Hence, a fewer number of questions were sought. Hence the 205 best practices were combined into 39 different categories. Each category represents a value stream sub-element. Table 6 reports the combined best practices into their 39 sub-elements.

### Criteria for Combining Best Practices:

The list of the 205 best practices was given to 7 practitioners in each value stream area separately. Then, it was determined that to ensure a valid response rate and get a generalized rating on all value stream elements, a combined list of best practices under their sub-element was sufficient. Hence the 205 best practices were combined into 39 different categories. Each category represents a value stream sub-element. Table 6 reports the combined best practices into their 39 sub-elements.

Table 5: Example List of Possible Customer Service/Sales Best Practices

| **1- Customer Service/ Sales** | |
|---|---|
| **Sub-Elements** | **Best Practices** |
| **1.1. Order processing** | Adequate procedure exists to generate order assembly and shipping documents |
| | Customer Service monitor the performance of production planning and inventory control operations |
| | Customer Service Manage the quality control operations |
| | When expediting customer orders, Customer Service supervises the proper execution of special customer requirements, such as periodic deliveries and packaging requirements |
| | Procedure exist for editing customer orders |
| | Customer Service monitor the performance of warehousing and transportation operations |
| **1.2. Information exchange** | Procedures exist to communicate products specifications with customers and production |
| | collect performance feedback data from customer |
| **1.3. Technical services** | Customer Service offers technical assistance to customers |
| | Customer Service offers testing and laboratory services |
| **1.4. Customer service planning and control** | Customer Service identifies deviations between standards and actual and their causes |
| | Customer Service initiates corrective actions to minimize deviations between standards and actual |
| **1.5. After delivery services** | Customer Service manages preventive inspection operations |
| | Customer Service monitors the maintenance and repair operations for customers |
| **1.6. Reliability** | A positive trend exists concerning the following reliability problems: |
| | Warranty Cost |
| | Failure Frequency |
| | Customer complaints |
| | Serviceability |

Table 6: Combined Best Practices

| Value Stream Element | Sub-element | Combined Best Practices |
|---|---|---|
| **1. Sales /Customer Service** | ORDERP ROCESSING | Generate assembly and shipping documents; execute special customer requirements, and monitor the performance of warehousing and transportation operations |
| | INFORMATION EXCHANGE | Communicate product specification and performance feedback with customers and production |
| | TECHNICAL SERVICES | Provide technical assistance to customers ( testing and laboratory services) |
| | CUSTOMER SERVICE PLANNING AND CONTROL | Identify deviations between standards and actual and their causes, and initiate corrective actions to minimize deviations between standards and actual |
| | AFTER DELIVERY SERVICES | Monitor the maintenance and repair operations for customers |
| | RELIABILITY | Track Warranty Cost, Customer complaints, Serviceability |
| | SALES FORECASTING | Forecast short-term sales |
| | ORDER ENTRY | Standardize procedures to enter and trace orders |
| | CLAIMS AND CREDITS | Handle credit and claim efficiently |
| **2. Purchasing** | DATABASE | Ensure availability of parts-history records, specifications files, standards files, and vendor records |
| | PROCUREMENT PROCESS | Study suppliers capability of meeting all specifications; evaluate suppliers according to the quality control and delivery standards |
| | MATERIAL MANAGEMENT | Control transferring materials; minimize excess stock and obsolescence; improve inventory turnover; standardize packages and containers, and report material commitments periodically |
| | PROCUREMENT DECISION | Conduct make-buy analyses based on quality and delivery; visit supplier plants; consider long term relationships with suppliers, and consider involving suppliers in new product development |
| **3. Production Planning and Control** | ENGINEERING DATA CONTROL | Continuously update Engineering drawings changes, production specifications changes, and standard routings work center sequences. |
| | INVENTORY CONTROL | Maintain accurate Bill of Material (BOM) records; compare inventory to schedule, and supply information to all appropriate persons. |

Table 6: Continued

| Value Stream Element | Sub-element | Combined Best Practices |
|---|---|---|
| | REQUIREMENTS PLANNING | Receive the expected customer requirements daily for production operating plans; plan components requirements accurately, and utilize efficient lot size policy. |
| | CAPACITY PLANNING | Plan load and load leveling of work orders efficiently; review and compare resources versus customer requirements. |
| | OPERATION SCHEDULING | Estimate manpower and machine requirements based on schedules; run operations based on rate based order management*; assign start and finish job dates accurately; assign priority rules, and analyze queue time |
| | SHOP FLOOR CONTROL | Control shortage in labor, and standardize procedure to expedite orders |
| | PURCHASING | Communicate with suppliers regarding orders and delivery requirements |
| | QUALITY MANAGEMENT | Comply with ISO/QS 9000 |
| **4. Manufacturing Engineering** | PRODUCTION PLANNING | Reproduce and forward complete drawings and Bills of Material (BOM) to production control; determine raw material accurately, and associate finishing route sheets with every work order |
| | PRODUCT DESIGN | Utilize the Design for Manufacturability (DFM) and Design for Assembly (DFA) concepts when designing a product |
| | TOOLING DESIGN | Plan for new products and tool availability, and track tool's lifecycle |
| | DOCUMENTATION | Document review process for proposed engineering changes, physical material flow, and delivery |
| **5. Shop Floor and Quality Control** | ORDER REVIEW AND RELEASE | Associate routing sheets with items including: how to machine and/or fabricate the item, description of the activity or process, sequence of the work, tooling required for each operation, type of labor required, and where the work is to be performed. |
| | DETAILED SCHEDULING | Apply lean production system: 5S, standard work flow, method sheet, mistake proofing, flow cells, visual control, mixed model production, pull production scheduling, and cross training. |

Table 6: Continued

| Value Stream Element | Sub-element | Combined Best Practices |
|---|---|---|
| | MAINTENANCE | Schedule lubrication and inspection; periodic overhaul of tools and equipment; measure the OEE; track breakdown production losses, and plan maintenance activities. |
| | QUALITYP REVENTION | Validate design using failure prevention analysis; test and calibrate; use SPC; conduct capability analysis; track PPM, and train operators on quality and reliability. |
| | QUALITY APPRAISAL | Conduct Inspection & testing of incoming materials and final products; audit quality, and calibrate & gauge equipments. |
| | QUALITY FAILURE | Control internal scrap and rework. |
| | EFFICIENCY | Calculate and track contact time versus lead time. |
| **6. Receiving** | RECEIVING | Utilize visual controls, un-palletize or containerize incoming materials appropriately; unload in a logical and orderly fashion, and compare shipping documents with actual goods received |
| | STORING | Utilize efficient material tracking system; control the storage environment; ensure parts have sufficient protection; record inventory for all materials until they are released for shipment, and minimize handling and transportation |
| | INCOMING MATERIAL INSPECTION | Identify unacceptable goods upon receipt; track discrepancies of incoming material, and identify all storage locations accurately |
| | SPACE PLANNING | Clear doorways, passageways, and ramps to allow ease of movement of the product handled; utilize the right material handling equipments for the right products |
| **7. Shipping** | PICKING PACKAGING AND LABELING | Locate materials easily for packaging; define standard packaging; allocate and monitor all packing material, and consider engineering problems in packaging |
| | SHIPPING | Ensure what is being shipped is what the customer ordered; optimize transportation, and dock operations; detect discrepancies automatically in quantity shipped |
| | TRANSPORTATION | Follow-up transportation quality and delivery issues; select logistics provider based on flexibility and quality parameters; ensure the product is delivered to the customer damage-free; supply the scheduling function with information on in-bound transportation modes and associated transit times |

Each sub-element had a list of best practices. The main contents of the best practices were combined into a single question, which revolved around how to lower the negative impact of each sub-element on a product quality and delivery. For example, information exchange was originally evaluated using the following 2 best practices:

1. Procedures exist to *communicate product specifications* with customers and production
2. Customer Service/Sales collects *performance feedback* data from customer.

The preceding 2 best practices were then combined into a single question without losing their underlined contexts. One question was asked instead of asking 2 different questions about information exchange: “Communicate product specification and performance feedback with customers and production”. Similarly, after delivery services had 2 best practices:

1. Customer Service manages *preventive inspection operations*
2. Customer Service monitors the maintenance and repair operations for customers

These 2 best practices were also combined into one question without losing their underlined contexts: “Monitor the maintenance and repair operations for customers”

Nonetheless, there are some instances where there could be a conflicting response for a specified sub-element. For example, in Production planning and control, requirements planning sub-element included three related best-practices, where the rating could be 7 for one best practice and 1 for the other two:

1. Receive the expected customer requirements daily for production operating plans

2. Plan components requirements accurately

3. Utilize efficient lot size policy

We assumed here that the respondents did not rate this sub-element as a high emphasis but rather as an average emphasis of the three best practices. For instance, if the respondents rating for “Receive the expected customer requirements daily for production operating plans;” was 7, and the rating for “plan components requirements accurately” was 1, and the rating for “utilize efficient lot size policy” was 1, then the respondent used the generalized assessment of the level of emphasis for this question, which was the average of the three ratings (7+1+1/3 = 3).

This issue does not impact the main objective of this research since the proposed model considered only the generalized average of the three best practices rather than each single practice rating.

In addition, the following guidelines were considered in combining the best practices and writing the questions to maximize the survey reliability and validity before the data was initially collected [112]:

- The respondents should consistently understand the questions.
- The questions should consistently be administered to respondents.
- A respondent should understand what an adequate answer is to a question.
- All respondents should have access to the information needed to answer accurately.

Validity focuses on whether a question actually measures what it is supposed to measure [113]. Validity of the survey was tested using the internal consistency approach, which focuses on measuring several indicators of similar phenomena and evaluating their consistency. SPSS Data Entry 4.0 was used to create the survey, which provided the reliability procedure to estimate internal consistency reliability. In addition, a pre-testing of the survey was conducted to correct any possible mistakes prior to the data collection process.

## Data Collection

A survey was conducted and administered over the Internet. The internet was used to expedite the process of collecting the data. According to the literature, surveys have associated advantages and disadvantages. The survey advantage lies in its ability to validate empirical studies. Unlike face to face interviews, surveys might have low response rate, which could be remedied by using a good communication language and persuasion techniques. Also, survey respondents may tend to interpret questions out of their contextual information, and it would be impossible to have verbal exchange with the respondents [98, 99, and 114]. A few approaches may be used to overcome the disadvantages such as encouraging, language, clear explanation of terms and open line of communication through emails.

To ensure its legibility and contents, the survey was tested by 20 industry practitioners and academic participants. The participants were given the survey's web link and were asked to fill it out. As a result of the initial test, some modifications were made to the survey. Modifications were cosmetics, definition of terms, and moving of best practices around.

The survey was distributed through e-mails to a number of suppliers for a construction equipment manufacturer. The entire first tier suppliers to a major construction equipment manufacturer represented the population of this study. A total of 369 active suppliers were solicited for responses. The survey was communicated to all suppliers through an email. Detailed directions to complete the survey were provided to participants (see appendix A for a copy of the email).

To ensure a sound and valid feedback from the suppliers, a few critical steps were taken into consideration:

1. The email was sent by the manufacturer's supplier development and control manager.
2. An incentive to fill out the survey was communicated to the suppliers by sending the survey results to them.
3. A weekly follow up email was sent (see appendix A for a copy).
4. Ensured that the suppliers knew their answers were protected. The answers of the survey were protected by sending the responses directly to the University of Tennessee for the analyses. The manufacturer had no control over the data.

The email targeted quality and logistics mangers, and general mangers. For each question, the survey participants were asked to rate the degree of emphasis placed on the best practices in the 7 value stream element and their sub-elements. Likert scale of 1-7, as illustrated in Figure 7, was used because scales of five points or more are reasonably reliable. As the number of categories increases, the use of these techniques is more justified [113].

| **Element** | No emphasis | | | | | | Extreme emphasis |
|---|---|---|---|---|---|---|---|
| Customer Service | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

Figure 7: Survey Likert scale

## Research Hypotheses

In this study, Quality and delivery were considered functions of the 7 value stream elements. Each value stream element was considered a function of its sub-element, and each sub-element was considered a function of its best practices. The focus of this study was to identify significant best practices that contributed to the supplier's quality and delivery conformance. Thus, the best practices were considered the dependent variables, and suppliers' conformance to quality and delivery were considered the independent variable as illustrated in Table 7. Table 7 presents a summary of hypotheses, variables, and statistical tests.

*Quality (Delivery) Prediction = F (Significant Best Practices)*

*Best Practices Significance = F (suppliers conformance to quality and delivery)*

Table 7: Summary of Hypotheses, Variables, and Statistical Tests

| Hypotheses | Dependent Variables | Independent Variables | Analytical Techniques |
|---|---|---|---|
| Classification of suppliers' quality conformance suggests significant practices across the value stream | 39 combined practices (sub-elements) across the product value stream | Classification of Suppliers conformance to quality | Kruskal-Wallis non-parametric test. |
| High quality conformance suppliers place more emphasis on significant best practices than medium and low quality conformance suppliers. | | Classification of Suppliers conformance to quality | |
| Classification of suppliers' on-time conformance suggests significant practices across the value stream | | Classification of Suppliers conformance to delivery | |
| High on-time conformance suppliers place more emphasis on significant best practices than medium and low quality conformance suppliers. | | Classification of Suppliers conformance to delivery | |

The heavy construction equipment assembler collected suppliers' data for both quality and delivery performances. Quality performance data included the number of received parts not approved in part per million, and after sales defective parts. Delivery performance data included percent of total number of orders delivered in right time, percent of total number of order delivered earlier or later than dispatch data, percent of the total orders delivered with the right or partial quantity.

To group this study's independent variables (classification of suppliers' conformance), the supplier process development and control manager at the heavy equipment manufacturer was asked to classify the suppliers into different groups based on the company's record. A one year worth of suppliers quality and delivery performance data was collected from the company's database. The suppliers' performance data suggested 4 groupings for each of the quality and delivery performance: Excellent, High, Acceptable, and Low. Excellent suppliers' quality and delivery conformance represented the top 25% of all the suppliers. Meanwhile, High, Acceptable and Low suppliers quality and delivery conformance represented Less than the top 25% and more than the lower 50%, less than the top 50% and more than the lower 25% of the suppliers, and bottom 25% of the suppliers respectively. Table 8 illustrates the breakdown of the independent variables.

Table 8: Breakdown of the Independent Variables

| Independent variable | Grouping | Criteria |
|---|---|---|
| Conformance to quality | Excellent conformance to quality | Top 25% of the suppliers |
| | High conformance to quality | Less than the top 25% and more than the lower 50% of the suppliers |
| | Acceptable conformance to quality | Less than the top 50% and more than the lower 25% of the suppliers |
| | Low conformance to quality | Bottom 25% of the suppliers |
| Conformance to delivery | Excellent conformance to delivery | Top 25% of the suppliers |
| | High conformance to delivery | Less than the top 25% and more than the lower 50% of the suppliers |
| | Medium conformance to delivery | Less than the top 50% and more than the lower 25% of the suppliers |
| | Low conformance to delivery | Bottom 25% of the suppliers |

## Data Analysis

Since the survey responses were based on a Likert scale, the responses were considered ordinal scale. The response scale measured the degree of difference not the amount of difference. For example, the interval of 1 between 3 and 4 or 5 and 6 is not necessary the same across all the participants responses. Furthermore, to compare multiple samples, the appropriate method would have been the analysis of variance (ANOVA). However, because the data collected was ordinal scaled, the normality assumption was not met. Therefore, it was recommended to use Kruskal-Wallis nonparametric test for the ordinal scale data (115,116).

Kruskal-Wallis nonparametric test is used to compare multiple independent samples to determine whether or not the variables of interest differ between two or more groups when the analysis of variance (ANOVA) assumption of normality is not met. In this study, variables of interests were the 39 sub-elements and their combined best practices, and the groups were the classifications of suppliers' quality and delivery performances.

The Kruskal-Wallis test statistics is represented by the following equation (116), where $n_i$ (i = 1, 2, ..., k) represent the sample sizes for each of the k groups and $R_i$ = the sum of the ranks for group i:

$$H = \frac{12}{n(n+1)} \sum_{i=1}^{k} \frac{R_i^{\ 2}}{ni} - 3(n+1)$$

The Kruskal test estimates the probability of group mean rank using a Chi-square statistics with a k-1 degree of freedom. The Kruskal-Wallis hypothesis tests that all populations have identical distribution functions, and the alternative hypothesis is that at least two of the samples differ only with respect to location (median) (116).

The null hypothesis is rejected when the test statistics H falls in the critical region H> $\chi_{\alpha}^{2}$ at the $\alpha$ significant level or the p-value is less than the $\alpha$ significance level.

# CHAPTER 4

## RESULTS AND DISCUSSION

As stated in chapter one, the study reported here identified the significant best practices that affect both suppliers' quality and delivery conformance. The significant best practices were used to develop a model to minimize the risk associated in selecting suppliers. This chapter is organized in terms of the four hypotheses listed in the third chapter. It reports the results of the conducted statistical analyses. First, it presents a descriptive statistics about the survey results; then, it discuses the hypotheses analyses. Finally, it presents the proposed model and its application.

### Descriptive Analysis

A total of 175 survey responses were received, which accounted for a 47.4 % response rate. This rate is compared highly to similar empirical studies (109, 117, 118, 119, and 114). However, thirteen responses were excluded form the analysis because they lacked complete suppliers information. The company's name and location were needed to cross reference the suppliers name with the quality and delivery performance in the company's database.

Table 9 reports the number of respondents by quality grouping. Fifty four of the respondents were excellent conformance suppliers. High, Acceptable, and Low

Table 9: Frequency of Respondents by Quality Conformance Grouping

| | Quality Conformance Grouping | |
|---|---|---|
| | Count | Percentage |
| Excellent | 88 | 54.3% |
| High | 24 | 14.9% |
| Acceptable | 18 | 11% |
| Very Low | 32 | 19.8 % |

Table 10: Frequency of Respondents by Delivery Conformance Grouping

| | Delivery Performance Grouping | |
|---|---|---|
| | Count | Percentage |
| Excellent | 17 | 10.6% |
| High | 18 | 11% |
| Acceptable | 39 | 24% |
| Very Low | 87 | 54% |

quality conformance suppliers accounted for 14.9 %, 11%, and 19.8% respectively.

Table 10 reports the number of respondents by delivery grouping. Excellent suppliers accounted for the lowest respondents' percentage of 10.6%. Meanwhile, the highest respondents' percentages of 54% accounted for the lowest delivery conformance suppliers. High and acceptable grouping accounted for 11% and 24% respectively.

Table 11: Frequency of Respondents by Location

| | Location | |
|---|---|---|
| | Count | Percentage |
| USA/Canada | 86 | 53% |
| International | 76 | 47% |

Table 11 reports the number of respondents by location. Forty seven percent of the respondents were international suppliers from different continents such as South America, Asia, and Europe. The rest of the respondents were North American suppliers, which accounted for the higher percentage of 53%.

It is important to note that the low percentage of excellent delivery conformance compared to high quality conformance. This difference was due to the long shipment lead time. Forty seven percent of the suppliers were foreigner suppliers; this contributed to the low percentage of excellent suppliers due to shipment issues and new USA custom regulations.

Table 12 in Appendix E reports the actual survey responses for randomly selected suppliers. A total of 5 suppliers were selected randomly to respond to the survey twice by two different people. This random selection was conducted to test the responses' reliability and validity. Comparison of the 5 randomly selected suppliers showed a strong consensus, which justifies the selection of only 5 suppliers. Appendix E presents the analysis results for the selected responses.

Two samples Paired t-test was conducted to compare the suppliers' responses. In all five cases, the P-value was significantly higher than 5 %. This result indicated that there was no significant difference between both of the same supplier's responses for each of the five randomly selected suppliers. This affirms the responses reliability and validity.

**Relation between Suppliers' Quality Conformance and Best Practices**

H1: Classification of suppliers' quality conformance suggests significant best practices across the value stream

H2: High quality conformance suppliers place more emphasis on best practices than low quality conformance suppliers

Kruskal-Wallis test was used to test the first hypothesis (H1) as well as the second hypothesis (H2). Tables 13 and 14 report the initial Kruskal-Wallis test output for H1 and H2. Table 13 presents the Chi-Square value, degrees of freedom (df), and the P-values (Asymp. Sig.) for each best practice sub-element by quality grouping. Each significant sub-element with a P-value less than 5% was highlighted in all the proceeding Kruskal-Wallis tables. Recall from chapter 3 that the best practices were combined into 39 survey questionnaires. Each question was categorized by one of the 39 value stream sub-elements. For instance, order processing was a sub-element of the customer service element in the supplier value stream, which encompassed a compilation of several order-

Table 13: Kruskal-Wallis Test for Best-practices' Sub-elements across the Value Stream by Quality Grouping

Test Statistics [a,b]

| | Chi-Square | df | Asymp. Sig. |
|---|---|---|---|
| ORDERP ROCESSING | 1.856 | 3 | 0.6028 |
| INFORMATION EXCHANGE | 12.075 | 3 | 0.0071 |
| TECHNICAL SERVICES | 5.32 | 3 | 0.1498 |
| CUSTOMER SERVICE PLANNING ANDCONTROL | 10.739 | 3 | 0.0132 |
| AFTERDELIVERYSERVICES | 11.748 | 3 | 0.0083 |
| RELIABILITY | 16.009 | 3 | 0.0011 |
| DATABASE | 4.106 | 3 | 0.2502 |
| PROCUREMENT PROCESS | 15.983 | 3 | 0.0011 |
| MATERIAL MANAGEMENT | 9.385 | 3 | 0.0246 |
| PROCUREMENT DECISION | 8.561 | 3 | 0.0357 |
| ENGINEERING DATA CONTROL | 9.987 | 3 | 0.0187 |
| INVENTORY CONTROL | 15.524 | 3 | 0.0014 |
| REQUIREMENTS PLANNING | 16.379 | 3 | 0.0009 |
| CAPACITY PLANNING | 16.96 | 3 | 0.0007 |
| OPERATION SCHEDULING | 8.598 | 3 | 0.0351 |
| SHOP FLOOR CONTROL | 4.212 | 3 | 0.2395 |
| PURCHASING | 2.686 | 3 | 0.4426 |
| QUALITY MANAGEMENT | 7.318 | 3 | 0.0624 |
| PRODUCTION PLANNING | 6.256 | 3 | 0.0998 |
| PRODUCT DESIGN | 3.479 | 3 | 0.3235 |
| TOOLING DESIGN | 7.071 | 3 | 0.0697 |
| DOCUMENTATION | 5.839 | 3 | 0.1197 |
| ORDER REVIEW AND RELEASE | 3.371 | 3 | 0.3378 |
| DETAILED SCHEDULING | 11.204 | 3 | 0.0107 |
| MAINTENANCE | 7.174 | 3 | 0.0666 |
| QUALITYP REVENTION | 6.771 | 3 | 0.0796 |
| QUALITY APPRAISAL | 3.738 | 3 | 0.2911 |
| RECEIVING | 10.683 | 3 | 0.0136 |
| STORING | 16.795 | 3 | 0.0008 |
| INCOMING MATERIAL INSPECTION | 10.174 | 3 | 0.0171 |
| SPACE PLANNING | 3.503 | 3 | 0.3204 |
| PICKING PACKAGING AND LABELING | 10.929 | 3 | 0.0121 |
| SHIPPING | 5.054 | 3 | 0.1679 |
| TRANSPORTATION | 8.321 | 3 | 0.0398 |

a. Kruskal Wallis Test
b. Grouping Variable: Quality Grouping

Table 14: Average Ranks of Best-practices' Sub-elements by Quality Grouping

| | Quality Level | N | Mean Rank |
|---|---|---|---|
| ORDERP ROCESSING | Very Low | 30 | 76.92 |
| | Acceptable | 18 | 81.81 |
| | High | 24 | 91.04 |
| | Excellent | 87 | 77.64 |
| | Total | 159 | |
| INFORMATION EXCHANGE | Very Low | 30 | 82.87 |
| | Acceptable | 18 | 94.17 |
| | High | 24 | 102.04 |
| | Excellent | 87 | 70 |
| | Total | 159 | |
| TECHNICAL SERVICES | Very Low | 30 | 77.13 |
| | Acceptable | 18 | 99.44 |
| | High | 24 | 87.85 |
| | Excellent | 87 | 74.8 |
| | Total | 159 | |
| CUSTOMERSERVICEPLANNINGANDCONTROL | Very Low | 30 | 64.47 |
| | Acceptable | 18 | 96.08 |
| | High | 24 | 98.77 |
| | Excellent | 86 | 75.9 |
| | Total | 158 | |
| AFTER DELIVERY SERVICES | Very Low | 30 | 56.4 |
| | Acceptable | 18 | 95.5 |
| | High | 24 | 90.92 |
| | Excellent | 86 | 81.02 |
| | Total | 158 | |
| RELIABILITY | Very Low | 30 | 58.3 |
| | Acceptable | 18 | 108.11 |
| | High | 24 | 92.17 |
| | Excellent | 86 | 77.37 |
| | Total | 158 | |
| DATABASE | Very Low | 29 | 69.38 |
| | Acceptable | 18 | 95.81 |
| | High | 24 | 83.27 |
| | Excellent | 87 | 78.46 |
| | Total | 158 | |

Table 14: Continued

| | Quality Level | N | Mean Rank |
|---|---|---|---|
| PROCUREMENT PROCESS | Very Low | 29 | 70.31 |
| | Acceptable | 18 | 107.64 |
| | High | 24 | 98.94 |
| | Excellent | 87 | 71.38 |
| | Total | 158 | |
| MATERIAL MANAGEMENT | Very Low | 29 | 70.34 |
| | Acceptable | 18 | 106.47 |
| | High | 24 | 86.81 |
| | Excellent | 87 | 74.95 |
| | Total | 158 | |
| PROCUREMENT DECISION | Very Low | 29 | 70.1 |
| | Acceptable | 18 | 80.67 |
| | High | 24 | 102.52 |
| | Excellent | 86 | 75.09 |
| | Total | 157 | |
| ENGINEERING DATA CONTROL | Very Low | 29 | 59.76 |
| | Acceptable | 18 | 98.83 |
| | High | 24 | 87.9 |
| | Excellent | 86 | 78.85 |
| | Total | 157 | |
| INVENTORY CONTROL | Very Low | 29 | 62.83 |
| | Acceptable | 18 | 112.75 |
| | High | 24 | 88.19 |
| | Excellent | 87 | 75.78 |
| | Total | 158 | |
| REQUIREMENTS PLANNING | Very Low | 29 | 81.47 |
| | Acceptable | 18 | 106.33 |
| | High | 24 | 96.42 |
| | Excellent | 86 | 67.59 |
| | Total | 157 | |
| CAPACITY PLANNING | Very Low | 28 | 79.29 |
| | Acceptable | 18 | 104.89 |
| | High | 24 | 99.88 |
| | Excellent | 87 | 67.79 |
| | Total | 157 | |

Table 14: Continued

| | Quality Level | N | Mean Rank |
|---|---|---|---|
| OPERATION SCHEDULING | Very Low | 29 | 77.69 |
| | Acceptable | 18 | 94.78 |
| | High | 24 | 96.46 |
| | Excellent | 86 | 71.27 |
| | Total | 157 | |
| SHOP FLOOR CONTROL | Very Low | 29 | 67.81 |
| | Acceptable | 18 | 92.83 |
| | High | 24 | 86.75 |
| | Excellent | 87 | 78.64 |
| | Total | 158 | |
| PURCHASING | Very Low | 28 | 71.07 |
| | Acceptable | 18 | 73.14 |
| | High | 24 | 89.92 |
| | Excellent | 87 | 79.75 |
| | Total | 157 | |
| QUALITY MANAGEMENT | Very Low | 30 | 70.82 |
| | Acceptable | 18 | 100.17 |
| | High | 24 | 86.94 |
| | Excellent | 84 | 74.19 |
| | Total | 156 | |
| PRODUCTION PLANNING | Very Low | 30 | 69.3 |
| | Acceptable | 18 | 99.33 |
| | High | 23 | 86.72 |
| | Excellent | 86 | 76.06 |
| | Total | 157 | |
| PRODUCT DESIGN | Very Low | 29 | 68.72 |
| | Acceptable | 18 | 79.5 |
| | High | 24 | 88.88 |
| | Excellent | 79 | 73.01 |
| | Total | 150 | |
| TOOLING DESIGN | Very Low | 30 | 88.33 |
| | Acceptable | 18 | 85.06 |
| | High | 24 | 94.25 |
| | Excellent | 86 | 71.14 |
| | Total | 158 | |

Table 14: Continued

| | Quality Level | N | Mean Rank |
|---|---|---|---|
| DOCUMENTATION | Very Low | 30 | 76.57 |
| | Acceptable | 17 | 97.29 |
| | High | 24 | 89.81 |
| | Excellent | 86 | 73.22 |
| | Total | 157 | |
| ORDER REVIEW AND RELEASE | Very Low | 31 | 66.73 |
| | Acceptable | 17 | 85.21 |
| | High | 24 | 85.54 |
| | Excellent | 86 | 81.29 |
| | Total | 158 | |
| DETAILED SCHEDULING | Very Low | 31 | 80.35 |
| | Acceptable | 17 | 87.35 |
| | High | 24 | 103.21 |
| | Excellent | 85 | 70 |
| | Total | 157 | |
| MAINTENANCE | Very Low | 31 | 64.6 |
| | Acceptable | 16 | 95.88 |
| | High | 24 | 90.58 |
| | Excellent | 86 | 77.82 |
| | Total | 157 | |
| QUALITYP REVENTION | Very Low | 31 | 79.48 |
| | Acceptable | 17 | 98.09 |
| | High | 24 | 91.52 |
| | Excellent | 86 | 72.48 |
| | Total | 158 | |
| QUALITY APPRAISAL | Very Low | 31 | 71.19 |
| | Acceptable | 17 | 96.24 |
| | High | 24 | 75.77 |
| | Excellent | 84 | 78.39 |
| | Total | 156 | |
| RECEIVING | Very Low | 30 | 61.8 |
| | Acceptable | 18 | 104.33 |
| | High | 24 | 84.81 |
| | Excellent | 86 | 78.99 |
| | Total | 158 | |

Table 14: Continued

| | Quality Level | N | Mean Rank |
|---|---|---|---|
| STORING | Very Low | 30 | 64.92 |
| | Acceptable | 18 | 114.39 |
| | High | 24 | 88.56 |
| | Excellent | 85 | 73.78 |
| | Total | 157 | |
| INCOMING MATERIAL INSPECTION | Very Low | 30 | 67.97 |
| | Acceptable | 18 | 101.72 |
| | High | 24 | 92.79 |
| | Excellent | 85 | 74.19 |
| | Total | 157 | |
| SPACE PLANNING | Very Low | 30 | 71.1 |
| | Acceptable | 18 | 95.78 |
| | High | 24 | 80.46 |
| | Excellent | 86 | 78.76 |
| | Total | 158 | |
| PICKING PACKAGING AND LABELING | Very Low | 29 | 62.64 |
| | Acceptable | 18 | 103.89 |
| | High | 24 | 85.31 |
| | Excellent | 84 | 75.67 |
| | Total | 155 | |
| SHIPPING | Very Low | 29 | 71.33 |
| | Acceptable | 18 | 89.28 |
| | High | 24 | 91.5 |
| | Excellent | 84 | 74.03 |
| | Total | 155 | |
| TRANSPORTATION | Very Low | 29 | 64.69 |
| | Acceptable | 18 | 96.11 |
| | High | 22 | 91.93 |
| | Excellent | 86 | 75.13 |
| | Total | 155 | |

processing best practices. See Appendix B for a detailed list of the best practices underneath the elements and sub-elements of the supplier value stream.

A total of 34 quality related sub-elements were analyzed. According to Table 13, a total of 23 quality sub-elements were found statistically significant. Significant sub-elements were highlighted in all the tables. Meanwhile, Table 14 presents the mean rank for each quality grouping. The mean rank adjusts for the difference in the number of samples in all quality grouping. Thus, the mean rank should be equal for all quality grouping by sub-element if and only if the groups were only randomly different. However, when testing the mean rank for each sub-element, excellent-quality suppliers were found to place less emphasis than high quality but both place higher emphasis than low quality suppliers. The main reason for such output was how the manufacturer's database recorded the suppliers' quality data. It was found out that some suppliers were classified as excellent suppliers because there were no defective parts received during the selected time period of this study. It appeared that these suppliers did not supply at all or supplied very insignificant number of orders. Hence, these suppliers were excluded from the analysis and a rerun of the data was conducted.

It is worth noting here that because the way defective Parts Per Million (PPM) was calculated, different suppliers could end up with the same PPM value for a specific time period (i.e. one year). PPM was calculated by dividing the total number of defective parts received by the total number of parts received, and then multiplied the resulted ratio by one million. However, having the same PPM for two or more suppliers does not necessarily mean that the two suppliers have similar quality conformance.

Table 15 and 16 in Appendix C present the results for the data rerun. Table 15 reports the rerun for the Kruskal-Wallis test for the quality sub-elements. Twenty two out of the 34 quality sub-elements were found significant across the value stream with a P-value less than 5%. Also, Table 16 shows that higher quality conformance mean rank is greater than low quality conformance mean rank, which indicated that high quality conformance suppliers placed more emphasis on best practices than low quality conformance suppliers.

**Discussion of the Results:**

According to the survey analysis results, 22 quality sub-elements of combined best practices were significantly different among suppliers (P<5%). The following quality sub-elements were found insignificant:

- Order processing
- Information exchange
- Technical services
- Requirements planning
- Capacity planning

- Operation scheduling
- Production design
- Tooling design
- Documentation
- Detailed scheduling
- Quality prevention

However, insignificant sub-elements only meant that all the surveyed suppliers placed close or similar emphasis on these best practices. Only the listed significant best practices' sub-elements distinguished a high quality supplier from unacceptable supplier.

Based on the Kruskal-Wallis test, the two Hypotheses 1 and 2 were proved to be true. Significant practices were found among suppliers. Also, the test proved that higher quality suppliers placed more emphasis on the best practices than low quality suppliers. The following is a list of the significant sub-elements as they relate to each of the 7 value stream elements. A detailed list of each category and sub-element best practices is presented in Appendix B:

1- Customer Service/ Sales
    - Customer service planning and control
    - After delivery services
    - Reliability

2- Purchasing

- Database
- Procurement Process
- Material management
- Procurement Decision

3- Production Planning and Control

- Engineering Data control
- Inventory control
- Shop floor control
- Purchasing
- Quality Management

4- Manufacturing Engineering Department

- Production Planning

5- Shop Floor & Quality Control

- Order Review and release
- Maintenance
- Quality/Appraisal

6- Receiving

- Receiving
- Storing
- Incoming Material Inspection
- Space Planning

7- Shipping

- Picking/Packaging and labeling
- Shipping
- Transportation

**Relation between Suppliers' On-time Conformance and Best Practices**

H3: Classification of suppliers' on-time conformance suggests significant practices across the value stream

H4: High on-time conformance suppliers place more emphasis on best practices than low quality conformance suppliers.

Kruskal-Wallis test was also used to test the third (H3) and fourth (H4) hypotheses. Table 17 in Appendix C reports the output of the initial Kruskal-Wallis test for H3. It presents the P-values for the delivery sub-elements. Expectedly, only three sub-elements were found to be significant. As previously stated, suppliers who did not deliver or deliver very insignificant amount of products were removed from the analysis and the Kruskal-Wallis test was conducted again.

Table 18 reports the results of the rerun of the Kruskal-Wallis test. A total of 37 delivery related sub-elements were analyzed. According to Table 18, a total of 34 sub-elements were found very significant with an alpha significant level of less than 5%. Meanwhile, Table 19 presents the mean ranks for each delivery grouping. The mean rank adjust for the difference in the number of samples in all delivery groups. Thus, the mean rank should be equal for all delivery groups by best-practices sub-element if and only if the groups were only randomly different. However, when testing the mean rank for sub-element, as shown in Table 19, excellent delivery placed more emphasis than low delivery because higher delivery conformance mean rank was higher than low delivery conformance mean rank. This indicated that high delivery conformance suppliers placed more emphasis on best practices than low delivery conformance suppliers.

Nonetheless, because of the low sample size in the two higher delivery categories (excellent and high), it was determined to reclassify the suppliers into three categories only to balance out the sample size and vary the outcome of the significant practices. Tables 20 and 21 in Appendix C present the results of the analysis with only 3 delivery groupings: high, acceptable, and very low. Table 20 confirmed the results of Table 18 that a total of 34 best-practices categories were found very significant. Also, Table 21 confirmed the finding of Table 19 that excellent delivery suppliers' placed more emphasis than low delivery because

Table 18: Rerun of Kruskal-Wallis Test for Best-practices' Sub-elements across the Value Stream by Suppliers' Delivery Grouping (4 Groupings)

Test Statistics[a,b]

| | Chi-Square | df | Asymp. Sig. |
|---|---|---|---|
| ORDERP ROCESSING | 17.8526 | 3 | 0.00047 |
| INFORMATION EXCHANGE | 11.64974 | 3 | 0.00868 |
| TECHNICAL SERVICES | 16.77474 | 3 | 0.00079 |
| CUSTOMER SERVICE PLANNING AND CONTROL | 9.109419 | 3 | 0.02787 |
| AFTERDELIVERYSERVICES | 8.837877 | 3 | 0.03153 |
| SALES FORECASTING | 4.836465 | 3 | 0.18417 |
| ORDER ENTRY | 18.02278 | 3 | 0.00044 |
| CLAIMS AND CREDITS | 23.5982 | 3 | 0.00003 |
| DATABASE | 11.85019 | 3 | 0.00791 |
| PROCUREMENT PROCESS | 9.902659 | 3 | 0.01941 |
| MATERIAL MANAGEMENT | 22.35346 | 3 | 0.00006 |
| PROCUREMENT DECISION | 10.94876 | 3 | 0.01201 |
| ENGINEERING DATA CONTROL | 14.38621 | 3 | 0.00242 |
| INVENTORY CONTROL | 9.359713 | 3 | 0.02487 |
| REQUIREMENTS PLANNING | 11.68812 | 3 | 0.00853 |
| CAPACITY PLANNING | 18.06021 | 3 | 0.00043 |
| OPERATION SCHEDULING | 13.96134 | 3 | 0.00296 |
| SHOP FLOOR CONTROL | 8.312775 | 3 | 0.03997 |
| PURCHASING | 10.53792 | 3 | 0.01451 |
| PRODUCTION PLANNING | 3.451429 | 3 | 0.32712 |
| PRODUCT DESIGN | 12.23498 | 3 | 0.00662 |
| TOOLING DESIGN | 16.28269 | 3 | 0.00099 |
| DOCUMENTATION | 14.04738 | 3 | 0.00284 |
| ORDER REVIEW AND RELEASE | 9.976038 | 3 | 0.01877 |
| DETAILED SCHEDULING | 9.708777 | 3 | 0.02121 |
| MAINTENANCE | 14.9557 | 3 | 0.00185 |
| QUALITYP REVENTION | 13.69822 | 3 | 0.00335 |
| QUALITY APPRAISAL | 7.880365 | 3 | 0.04855 |
| QUALITY FAILURE | 10.74837 | 3 | 0.01317 |
| EFFICIENCY | 4.608665 | 3 | 0.20280 |
| RECEIVING | 13.20437 | 3 | 0.00421 |
| STORING | 17.88268 | 3 | 0.00047 |
| INCOMING MATERIAL INSPECTION | 10.05543 | 3 | 0.01810 |
| SPACE PLANNING | 18.59176 | 3 | 0.00033 |
| PICKING PACKAGING AND LABELING | 22.84288 | 3 | 0.00004 |
| SHIPPING | 19.31386 | 3 | 0.00024 |
| TRANSPORTATION | 16.85667 | 3 | 0.00076 |

a. Kruskal Wallis Test
b. Grouping Variable: Delivery Grouping

Table 19: Average Ranks of Best-practices' Sub-elements by Delivery Grouping (4 Groupings)

| | Delivery Level | N | Mean Rank |
|---|---|---|---|
| ORDERP ROCESSING | Very Low | 41 | 39.94 |
| | Acceptable | 38 | 55.78 |
| | High | 15 | 72.8 |
| | Excellent | 12 | 68.5 |
| | Total | 106 | |
| INFORMATION EXCHANGE | Very Low | 41 | 43.48 |
| | Acceptable | 38 | 53.88 |
| | High | 15 | 71.9 |
| | Excellent | 12 | 63.54 |
| | Total | 106 | |
| TECHNICAL SERVICES | Very Low | 41 | 41.46 |
| | Acceptable | 38 | 56.3 |
| | High | 15 | 78.03 |
| | Excellent | 12 | 55.08 |
| | Total | 106 | |
| CUSTOMER SERVICE PLANNING AND CONTROL | Very Low | 41 | 44.12 |
| | Acceptable | 38 | 54.24 |
| | High | 15 | 66.33 |
| | Excellent | 12 | 67.17 |
| | Total | 106 | |
| AFTERDELIVERYSERVICES | Very Low | 41 | 44.17 |
| | Acceptable | 38 | 62.58 |
| | High | 15 | 61.17 |
| | Excellent | 12 | 47.04 |
| | Total | 106 | |
| SALES FORECASTING | Very Low | 41 | 46.48 |
| | Acceptable | 38 | 57.61 |
| | High | 15 | 52.6 |
| | Excellent | 12 | 65.63 |
| | Total | 106 | |
| ORDER ENTRY | Very Low | 41 | 44.11 |
| | Acceptable | 38 | 49.24 |
| | High | 15 | 78.97 |
| | Excellent | 12 | 67.25 |
| | Total | 106 | |

Table 19: Continued

| | Delivery Level | N | Mean Rank |
|---|---|---|---|
| CLAIMS AND CREDITS | Very Low | 40 | 37.35 |
| | Acceptable | 38 | 59.62 |
| | High | 15 | 77.83 |
| | Excellent | 12 | 53.17 |
| | Total | 105 | |
| DATABASE | Very Low | 40 | 43.86 |
| | Acceptable | 38 | 52.67 |
| | High | 16 | 63.94 |
| | Excellent | 12 | 74.33 |
| | Total | 106 | |
| PROCUREMENT PROCESS | Very Low | 40 | 42.79 |
| | Acceptable | 38 | 56.01 |
| | High | 16 | 64.25 |
| | Excellent | 12 | 66.92 |
| | Total | 106 | |
| MATERIAL MANAGEMENT | Very Low | 40 | 37.14 |
| | Acceptable | 38 | 58.29 |
| | High | 16 | 67.5 |
| | Excellent | 12 | 74.21 |
| | Total | 106 | |
| PROCUREMENT DECISION | Very Low | 40 | 42.24 |
| | Acceptable | 37 | 55.04 |
| | High | 16 | 69.06 |
| | Excellent | 12 | 61.17 |
| | Total | 105 | |
| ENGINEERING DATA CONTROL | Very Low | 40 | 43.14 |
| | Acceptable | 38 | 57.28 |
| | High | 16 | 50.91 |
| | Excellent | 12 | 79.54 |
| | Total | 106 | |
| INVENTORY CONTROL | Very Low | 40 | 43.94 |
| | Acceptable | 38 | 58.37 |
| | High | 16 | 52.31 |
| | Excellent | 12 | 71.54 |
| | Total | 106 | |

Table 19: Continued

| | Delivery Level | N | Mean Rank |
|---|---|---|---|
| REQUIREMENTS PLANNING | Very Low | 40 | 41.18 |
| | Acceptable | 38 | 56.63 |
| | High | 16 | 65.97 |
| | Excellent | 11 | 64.59 |
| | Total | 105 | |
| CAPACITY PLANNING | Very Low | 40 | 40.34 |
| | Acceptable | 37 | 52.72 |
| | High | 16 | 71.88 |
| | Excellent | 12 | 70.92 |
| | Total | 105 | |
| OPERATION SCHEDULING | Very Low | 40 | 39.86 |
| | Acceptable | 38 | 57.66 |
| | High | 15 | 67.8 |
| | Excellent | 12 | 63.54 |
| | Total | 105 | |
| SHOP FLOOR CONTROL | Very Low | 40 | 44.74 |
| | Acceptable | 38 | 55.22 |
| | High | 16 | 57.41 |
| | Excellent | 12 | 72.04 |
| | Total | 106 | |
| PURCHASING | Very Low | 40 | 44.79 |
| | Acceptable | 38 | 51.71 |
| | High | 16 | 66.69 |
| | Excellent | 12 | 70.63 |
| | Total | 106 | |
| PRODUCTION PLANNING | Very Low | 41 | 48.15 |
| | Acceptable | 38 | 54.54 |
| | High | 16 | 60.56 |
| | Excellent | 12 | 63.54 |
| | Total | 107 | |
| PRODUCT DESIGN | Very Low | 40 | 39.59 |
| | Acceptable | 34 | 62.07 |
| | High | 16 | 50.22 |
| | Excellent | 11 | 59.41 |
| | Total | 101 | |

Table 19: Continued

| | Delivery Level | N | Mean Rank |
|---|---|---|---|
| TOOLING DESIGN | Very Low | 41 | 41.71 |
| | Acceptable | 38 | 54.8 |
| | High | 16 | 74.66 |
| | Excellent | 12 | 65.92 |
| | Total | 107 | |
| DOCUMENTATION | Very Low | 41 | 42.2 |
| | Acceptable | 38 | 55.29 |
| | High | 16 | 72.56 |
| | Excellent | 12 | 65.5 |
| | Total | 107 | |
| ORDER REVIEW AND RELEASE | Very Low | 41 | 45.74 |
| | Acceptable | 37 | 54.39 |
| | High | 16 | 53.78 |
| | Excellent | 12 | 76.88 |
| | Total | 106 | |
| DETAILED SCHEDULING | Very Low | 41 | 42.85 |
| | Acceptable | 37 | 55.16 |
| | High | 16 | 66.25 |
| | Excellent | 11 | 64.27 |
| | Total | 105 | |
| MAINTENANCE | Very Low | 41 | 42.82 |
| | Acceptable | 37 | 55.86 |
| | High | 16 | 55.19 |
| | Excellent | 12 | 80.46 |
| | Total | 106 | |
| QUALITYP REVENTION | Very Low | 41 | 40.85 |
| | Acceptable | 37 | 57.12 |
| | High | 16 | 66.03 |
| | Excellent | 12 | 68.83 |
| | Total | 106 | |
| QUALITY APPRAISAL | Very Low | 40 | 48.75 |
| | Acceptable | 37 | 48.14 |
| | High | 16 | 56.94 |
| | Excellent | 11 | 74.36 |
| | Total | 104 | |

Table 19: Continued

| | | | |
|---|---|---|---|
| QUALITY FAILURE | Very Low | 40 | 43.58 |
| | Acceptable | 37 | 52.89 |
| | High | 16 | 62.03 |
| | Excellent | 12 | 72.71 |
| | Total | 105 | |
| EFFICIENCY | Very Low | 40 | 46.16 |
| | Acceptable | 37 | 54.96 |
| | High | 16 | 55.84 |
| | Excellent | 12 | 65.96 |
| | Total | 105 | |
| RECEIVING | Very Low | 40 | 44.56 |
| | Acceptable | 38 | 51.68 |
| | High | 16 | 61.19 |
| | Excellent | 12 | 78.79 |
| | Total | 106 | |
| STORING | Very Low | 40 | 39.15 |
| | Acceptable | 38 | 56.54 |
| | High | 16 | 62.94 |
| | Excellent | 11 | 76.68 |
| | Total | 105 | |
| INCOMING MATERIAL INSPECTION | Very Low | 40 | 42.03 |
| | Acceptable | 37 | 56.59 |
| | High | 16 | 62.94 |
| | Excellent | 12 | 65.25 |
| | Total | 105 | |
| SPACE PLANNING | Very Low | 40 | 38.05 |
| | Acceptable | 38 | 60.18 |
| | High | 16 | 62.19 |
| | Excellent | 12 | 72.25 |
| | Total | 106 | |
| PICKING PACKAGING AND LABELING | Very Low | 39 | 35.82 |
| | Acceptable | 38 | 62.24 |
| | High | 16 | 55.38 |
| | Excellent | 11 | 73.82 |
| | Total | 104 | |

Table 19: Continued

| | Delivery Level | N | Mean Rank |
|---|---|---|---|
| SHIPPING | Very Low | 38 | 36.17 |
| | Acceptable | 37 | 59.91 |
| | High | 16 | 58.94 |
| | Excellent | 12 | 68.5 |
| | Total | 103 | |
| TRANSPORTATION | Very Low | 40 | 39.35 |
| | Acceptable | 36 | 55.21 |
| | High | 16 | 62.69 |
| | Excellent | 12 | 74.63 |
| | Total | 104 | |

higher delivery conformance mean rank was higher than low delivery conformance mean rank.

**Discussion of the Results:**

According to the survey analysis, 34 sub-elements of combined delivery best practices were significantly different among suppliers (P<5%). The following sub-elements were found insignificant:

- Sales Forecasting
- Production Planning
- Efficiency

Hypothesis 3 and 4 were proved to be true. Significant sub-elements of delivery best practices were found among the different suppliers based on their delivery conformance using the Kruskal-Wallis test. In addition, the Kruskal-Wallis test proved that higher delivery performance suppliers placed significant emphasis on the majority of the best practices. The following is a list of the sub-element of the significant best practices that distinguish a high delivery performance supplier from a low delivery performance supplier. A detailed list of each category and sub-element best practices is presented in Appendix B:

1- Customer Service/ Sales

- Order processing
- Order entry
- Information exchange
- Claims and credits
- Technical services
- Customer service planning and control
- After delivery services

2- Purchasing

- Database
- Procurement Process
- Material management
- Procurement Decision

3- Production Planning and Control

- Engineering Data control

- Inventory control
- Requirements planning
- Capacity planning
- Operation scheduling
- Shop floor control
- Purchasing

4- Manufacturing Engineering Department

- Product Design
- Tooling Design
- Documentation

5- Shop Floor and Quality Control

- Order Review and release
- Detailed scheduling (Lean Manufacturing)
- Maintenance
- Quality/Prevention
- Quality/Appraisal
- Quality/Failure

6- Receiving

- Receiving

- Storing
- Incoming Material Inspection
- Space Planning

7- Shipping

- Picking/Packaging and labeling
- Shipping
- Transportation

## The Proposed Model

A computerized model was developed to evaluate and predict supplier's quality and delivery performance based on the Kruskal-Wallis test outcome. Microsoft Excel was the platform used to develop the model. Significant best practices for each value stream element were the basis of the proposed model. Figures 8 and 9 depict an overall flow of the quality and delivery models. Both figures follow the same steps from bottom up. The following section presents a detailed explanation of the model. It is important to note that the mathematical calculations of the proposed model were derived from a model developed by Automotive Industry Action Group [110], which is a model used by the Automotive industry and heavy manufacturer equipments. Appendix D presents the full details of the proposed-model calculations

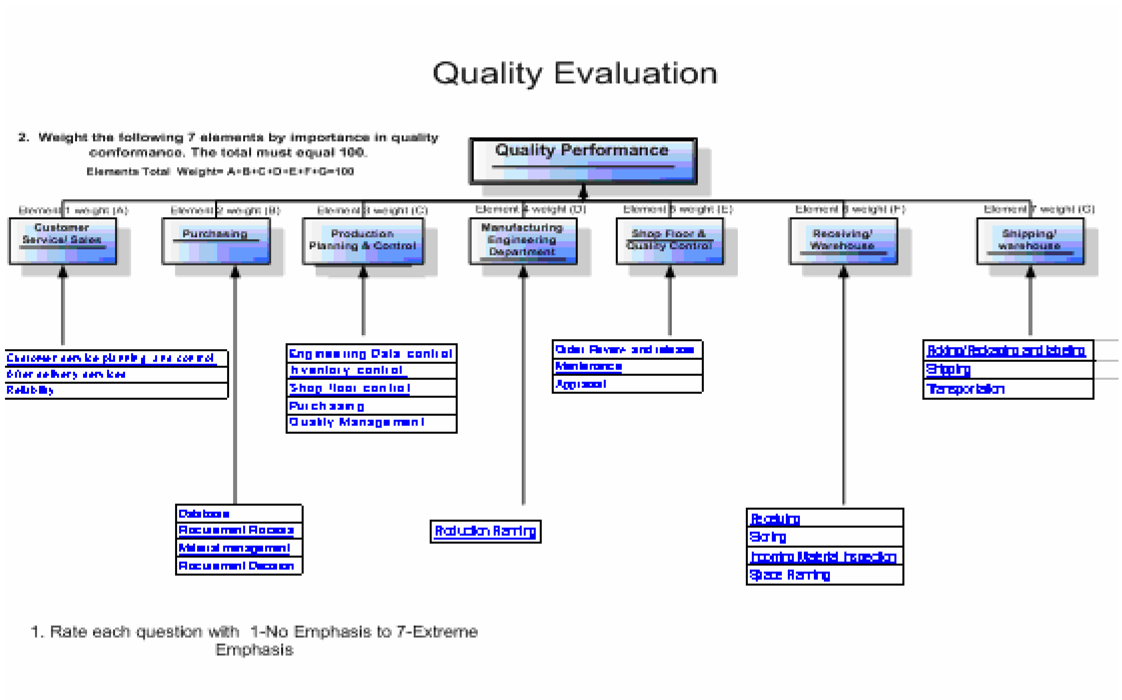


Figure 8: Overview of the Main Components of the Quality Evaluation Model

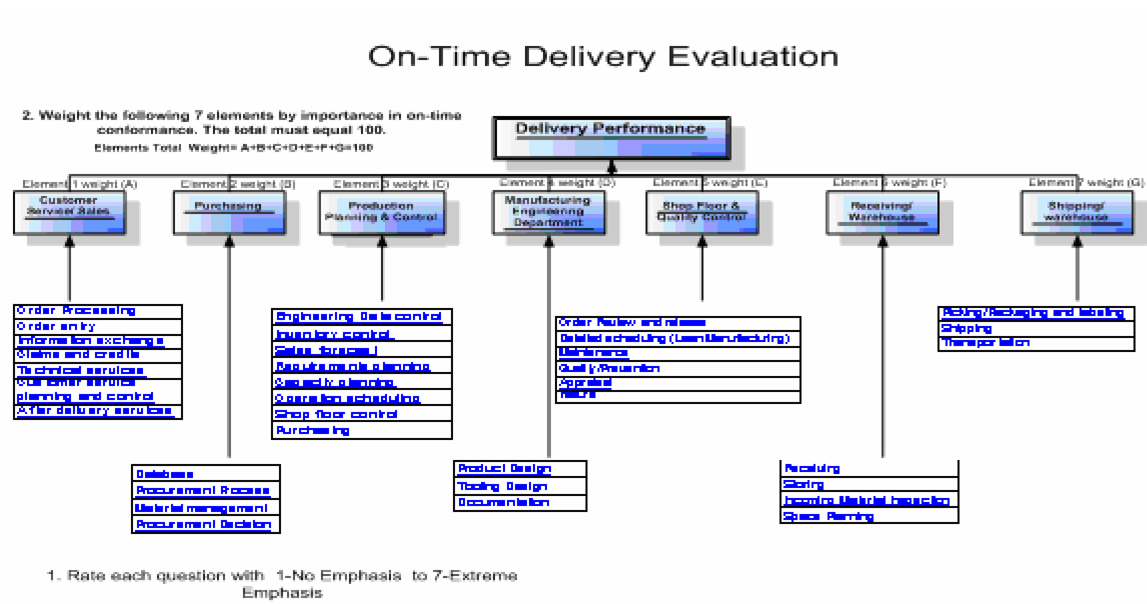


Figure 9: Overview of the Main Components of the On-time Evaluation Model

**Steps of the Proposed Model:**

Figure 10 presents an example of the detailed quality and delivery score calculations. Each value stream element was delineated to its significant sub-elements and their associated combined best practices based on the outcome of the previous analyses.  For example, in Figure 10, Customer services/sales was broken down into its 3 significant quality sub-elements and their associated best practices: customer service planning and control, after delivery services, and reliability.

**Step 1**

Each combined-best practice, under the question column in Figure 10, was assigned a score between 1 and 7. One meant practices were not applied, and seven meant an extreme emphasis was placed on the best practice. Each question's score was automatically transferred to column A in a separate worksheet.

**Step 2**

The score for all questions was totaled in column A. Column B was the maximum attainable score for each question, 7 points maximum. Column C was the result of dividing the total of column A by the total column B, which was the sub-element final score. The resulted final score for each sub-element was copied to column D to form a summary Table.

**Score Summary**

| | Element | (D) Score | (E) Weight (100) | (F) Element Final Score |
|---|---|---|---|---|
| 1 | Customer Service/Sales | 57.14% | 13.2 | 7.54 |
| 2 | Purchasing | 82.14% | 13.5 | 11.09 |
| 3 | Production Planning and Control | 77.14% | 14.6 | 11.26 |
| 4 | Manufacturing Engineering Department | 71.43% | 13.6 | 9.71 |
| 5 | Shop Floor & Quality Control | 95.24% | 15.1 | 14.38 |
| 6 | Receiving/ Warehouse | 100.00% | 15.2 | 15.20 |
| 7 | Shipping/ warehouse | 95.24% | 14.8 | 14.10 |
| | | | Quality Score (Out of 100) | 83.29 |

Step 3

Step 2

| | Element | Sub-Element | (A) Questions Score (1-7) | (B) Max. Score | (C) Element Score |
|---|---|---|---|---|---|
| 1 | Customer Service/Sales | 1.4. Customer Services Planning | 6 | 7 | 57.14% |
| | | 1.5. After Delivery Services | 1 | 7 | |
| | | 1.6. Reliability | 5 | 7 | |
| | | Total | 12 | 21 | |

Step 1

| Value Stream Element | Sub-element | Question | Score (1-7) |
|---|---|---|---|
| 1. Sales /Customer Service | 1.4. Customer Services Planning | Identify deviations between standards and actual and their causes, and initiate corrective actions to minimize deviations between standards and actual | 6 |
| | 1.5. After Delivery Services | Monitor the maintenance and repair operations for customers | 1 |
| | 1.6. Reliability | Track Warranty Cost, Customer complaints, Serviceability | 5 |

Figure 10: Overview of the Calculation for the Main Components of the Quality Evaluation Model

**Step 3**

Each value stream element was weighted for its important as it related to either quality or on-time delivery in column E. For example, production planning and control was not equally important as customer service/sales or purchasing to quality. Similarly, shipping was more important than customer service/sales to on-time delivery. Each value stream element was weighed out of 100 based on its importance to either quality or delivery. In this study, the Kruskal-Wallis test average mean rank results was used to calculate the weights based on the level of emphasis placed on each element as it related to either quality or delivery, See Appendix F for the weights calculation. Finally, column F was the result of multiplying column D and column E to get the weighted score for each value stream element and ultimately get the final quality and delivery score out of 100.

## Application of the Proposed Model

The Heavy Equipment Manufacturer Company (HEMC) like other companies had its own supplier evaluation and selection model. Hence, every supplier was evaluated and selected based on the company's specific metrics. Quality and delivery were two of the metrics used in the company's evaluation model. A score was calculated for each metric including quality and delivery for each potential supplier.  The company used the most common quality and delivery evaluation format or questionnaires as follow:

- Quality management system [ISO 9000]

- Quality planning and assurance processes
- Quality performance [ such as PPM, CpK]
- Quality reliability [warranty cost, failure frequency, customer compliant and serviceability]
- Quality problem solving methods
- Quality safety parts management
- Logistics system evaluation
- Delivery precision [ on time percentage]

Only 65 of the surveyed suppliers had their quality scores reported and 60 had their delivery score reported on the company's database. Tables 22 and 23 in Appendix G report the HEMC initial quality and delivery evaluation scores for the selected suppliers as well as the actual performance. Clearly, there was a discrepancy between the initial evaluation and the performance of each supplier due to the misevaluation of quality and delivery in the first place. Both Tables also include the proposed model score of quality and delivery for each selected supplier.

The proposed model was applied to each of the 65 suppliers. Each value stream element was evaluated by rating the significant best practices. A score between 1 and 7 was assigned to each supplier based on their responses. Table 22 presents the actual quality performance in PPM, HEMC model quality score, and the proposed model quality score.

Since the actual quality performance had a different measurement unit than the HEMC and the proposed model, it was recommended to conduct a correlation test on the HEMC column and a 2-saplme t test on the 2 columns. A correlation test was conducted between the first two columns of Table 22 to test whether the HEMC model score was representative of the actual suppliers' performance. If the HEMC evaluation model score was representative, one would expect a strong negative correlation between both actual performance and the score. As the score increased the quality performance increased and the PPM score should have decreased. The correlation test revealed insignificant correlation between the two columns. The correlation test resulted in "r" value of -0.083 and a Pearson correlation P-Value of 0.511 indicating a poor correlation. However, a much stronger correlation was found between the suppliers' actual performance and the proposed model. The correlation test resulted in a better "r" value of -0.378 and a Pearson correlation P-Value of 0.002 indicting that there was enough statistical data to reject the hypothesis of no correlation exist. In addition, a 2-sample t test was conducted between HEMC model and the proposed model. The test indicated a significant difference between both columns with a P-Value of 0.005 indicating strong statistical evidence to reject the hypothesis of equal means. Thus, the proposed model was proven to be much closer to the actual performance and better than the HEMC model (traditional model), see Appendix G for the analyses results.

Table 23 compares both HEMC and proposed models results and the actual delivery performance. Since all the three columns had the same measurement units, it was recommended to conduct a 2-saplme t test on the 3 columns. First, a 2-sample t test was run between actual delivery performance and HEMC model score. The test revealed a significant different between both columns with a P-value of 0.0001. Second, a 2-sample t test was conducted between the proposed model scores and the actual suppliers' performance. The t-test resulted in a P-value of 0.084.The results indicated that both columns are not statistically different. However, when both traditional and proposed model were compared using also a 2-sample t test, a P-value of 0.002 resulted indicating a statistical significant difference between both columns. All in all, the statistical results proved that the proposed model was much closer than the HEMC (traditional model) to the actual suppliers' delivery performance. See appendix G for the test results.

# <u>CHAPTER 5</u>

## SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This chapter restates the research problem and reviews the major methods used in the study. The major section of this chapter summarizes the results, discusses the study limitations, and recommends future research.

### Summary and Conclusion of the Research

The main purpose of this research was to develop a comprehensive and effective supplier evaluation and selection model. Several questions were answered to achieve the research goal. These questions as stated in the first chapter were as follow:

- What are the best practices in the supplier's value stream that affect suppliers' quality?
- What are the best practices in the supplier's value stream that affect suppliers' on-time delivery?
- Which best practices contribute the most to the suppliers' quality conformance?
- Which best practices contribute the most to the suppliers' on-time delivery conformance?

A survey instrument was developed to address the preceding questions. The survey encompassed best practices that impacted the suppliers' quality and delivery performance. A compiled list of 39 questions was sent to 369 heavy equipment manufacturer first tier suppliers. The survey was solicited through an email sent by the supplier product development and control manager. A weekly follow up email was also sent to ensure a high response rate. A high response rate of 43.7% was attained.

Four hypotheses were tested: Classification of suppliers' quality conformance suggests significant practices across the value stream (H1), High quality conformance suppliers place more emphasis on significant best practices than medium and low quality conformance suppliers (H2), Classification of suppliers' on-time conformance suggests significant practices across the value stream (H3), and High on-time conformance suppliers place more emphasis on significant best practices than medium and low quality conformance suppliers (H4).

All the hypotheses were statistically proved to be true. The nonparametric test of Kruskal-Wallis was used to test the 4 hypotheses. The hypotheses stated that suppliers place different emphasis on the value stream best practices, which denoted best practices across the value stream. Also, the hypotheses state that higher quality and delivery suppliers placed more emphasis on the best practices than lower quality and delivery suppliers.

Twenty two sub-elements of the quality best practices were found to be very significant where higher quality suppliers placed more emphasis on the best practices. Also, a total of 34 Delivery sub-elements of best practices were found to be very significant where higher delivery suppliers placed more emphasis on the best practices.

Two quality and delivery models were developed and applied. The statistical results revealed that the proposed models were a better evaluation tool than the traditional models and much closer to the actual suppliers' performance.

In conclusion, the main value of this study was not only to identify the best practices within the supplier value stream but to apply them. The identified best practices within their sub-elements were the platform for the proposed model. This proposed model will serve as a tool to practitioners to evaluate the two most critical factors, quality and delivery, more effectively. This tool will minimize the risk associated with selecting suppliers by reducing the uncertainty of suppliers' performance.

## Study Limitations

There were some limitations to this study. One limitation was the scope of the study. The study focused mainly on the heavy manufacturer industry. However, one can claim that the proposed model can be applied in the automotive industry because of the similarities in the heavy manufacturers and automotive industry supply chain.

Another limitation of this study was communication. As stated in chapter four that 47% of the suppliers were from other contents such as South America, Asia, and Europe. The assumption was that the survey was filled by people who are fluent in English, which was the language of the survey.

In addition, a limitation was in reducing the number of best practices in the survey from 204 to 39. It was determined that to ensure a valid response rate and get a generalized rating on all value stream elements, a combined list of best practices under their sub-element was sufficient. Hence the 205 best practices were combined into 39 different categories.

## Recommendations for Research

This study provides a general feedback of the best practice within each element and sub-element by combining sub-element's practices into one survey. Even though this study provided a valuable insight into the significant impact of value stream activities on the suppliers' quality and delivery conformance, a further research is needed in.  A study is needed to identify best practices at a lower level than the sub-elements level. That is to have several surveys designated to each value stream element.  For example, a separate survey is needed for purchasing with 29 questions. Each question is related to a single best practice. This will provide more in depth analysis of the best practices in the value stream that impact quality and delivery.

Further research is also needed to investigate the significant best practices that impact quality and delivery in industries other than heavy equipments manufacturers. With variant supply chains variant best practices exist. However, the main elements of the heavy equipment manufacturers' value stream might be similar to other industries. Thus, the only differences are in the daily activities.

In addition, a study is needed to consider the suppliers' effect on the customer production system to not only react but predict suppliers' conformance issues. To move toward becoming a world-class manufacturer, an organization ought to address the supplier's exacerbated impact on the production system before selecting a supplier. No clear evidence has shown any sign of addressing a supplier's impact on the production system. In particular, production-system data mining techniques could be utilized to identify factors such as productivity, asset utilization, inventory, set ups, lead time, lay out, quality, and schedule deviation.

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# APPENDICES

# Appendix A: Solicitation and Follow-up Emails

## Initial Solicitation Email

Dear XYZ Vendors,

Please find below a link to a value stream survey from XYZ Group and the University of Tennessee. We would like you to take 10 to 15 minutes out of your time and answer the questionnaires to help us understand what impacts the quality and delivery of a product.

The survey is broken up into 7 different value stream areas: Sales /Customer Service, Purchasing, Production Planning and Control, Manufacturing Engineering, Shop Floor and Quality Control, Receiving, and Shipping. Each value stream area has a list of practices, and you are asked to rate each area by indicating the level of emphasis placed on each practice.

Research question: what practices contribute the most to a product quality and delivery conformance?

Ammar Aamer is a Doctorial student who is the main coordinator of the survey. The main purpose of the survey is helping both XYZ and the Vendors pinpoint areas for improvements. Your response to the survey is strictly confidential. The data collection and the analysis will be conducted by the University of Tennessee. In return, you will receive a report of the research outcome when it is complete.

To complete the survey, please click on the web address below. If that does not work, please copy and paste the entire web address into the address field of your browser.

http://surveys.utk.edu/aamer/index.htm

I strongly encourage you to take a few minutes out of your time to fill out the survey. Your feedback is very important to us. Thank you for your input and support of this research.

Sincerely,

XXXXXXXX
Supplier Development Process and Control Manager

**Follow-up Email**

Dear XYZ Vendors,

This is a friendly reminder to please take a few minutes to fill out the value stream survey from XYZ Group and the University of Tennessee.

Our records indicate that you have not filled out the survey yet. When you fill out the survey, please make sure to click on the “Company Name” field and type your company’s name, so we can remove your email address from future reminders.

Your feedback is very important to us. If you have any questions, please contact me by email aamer@utk.edu or call (865) 974-9943.

Here's the survey link:

http://surveys.utk.edu/aamer/index.htm

Sincerely,
Ammar Aamer
The University of Tennessee
Coordinator of the value stream survey

# Appendix B: List of the Best Practices

## A. Quality Best Practices:

| 1- Customer Service/ Sales | |
|---|---|
| **Sub-Element** | **Best Practices** |
| **1.1. Order processing** | Adequate procedure exists to generate order assembly and shipping documents? |
| | Customer Service monitor the performance of production planning and inventory control operations |
| | Customer Service Manage the quality control operations |
| | When expediting customer orders, Customer Service supervises the proper execution of special customer requirements, such as periodic deliveries and packaging requirements |
| | Procedure exist for editing customer orders |
| | Customer Service monitor the performance of warehousing and transportation operations |
| **1.2. Information exchange** | Procedures exist to communicate products specifications with customers and production |
| | |
| | collect performance feedback data from customer |
| **1.3. Technical services** | Customer Service offers technical assistance to customers |
| | Customer Service offers testing and laboratory services |
| **1.4. Customer service planning and control** | Customer Service identifies deviations between standards and actual and their causes |
| | Customer Service initiates corrective actions to minimize deviations between standards and actual |
| **1.5. After delivery services** | Customer Service manages preventive inspection operations |
| | Customer Service monitors the maintenance and repair operations for customers |
| **1.6. Reliability** | A positive trend exists concerning the following reliability problems: |
| | Warranty Cost |
| | Failure Frequency |
| | Customer complaints |
| | Serviceability |

| 2- Purchasing | |
|---|---|
| **Sub-Element** | **Best Practices** |
| **2.1. Database** | Parts history records are available |
| | Specifications files are available |
| | Standards files are available |
| | Vendor records, including financial and performance are available |
| **2.2.Procurement Process** | |
| | Suppliers are capable of meeting all specification requirements |
| | Vendor specifications are established |

| | |
|---|---|
| | Suppliers are evaluated according to the quality control standards (purchasing are familiarized with these standards) |
| | Accurate analysis process exist of quotation/ or proposals |
| | Purchasing corresponds with suppliers |
| | Materials are checked upon receipt |
| | Buyer specifications are established |
| **2.3.Material management** | A control system exists to minimize excess stocks and obsolescence |
| | Accounting for returnable containers |
| | Inventory turnover is being improved |
| | Stocks control exists |
| | Packages and containers are standardized |
| | Periodic reports exist of commitments |
| | A control exists over transferring materials |
| **2.4.Procurement Decision** | Adequate procedures exist for make or buy studies |
| | New supply sources development exist |
| | Alternatives exist for materials and sources |
| | An efficient supplier plants visits and inspections process exist |
| | Strive to establish long term relationships with suppliers |
| | Suppliers are involved in new product development process |
| | Quality is number 1 criteria in selecting suppliers |
| | Rely on small number of high quality suppliers |
| | |

## *3- Production Planning and Control*

| Sub-Element | Best Practices |
|---|---|
| | |
| **3.1. Engineering Data control** | Engineering drawings/changes are kept up to date |
| | A continuous addition or removal exist of assembly components or quantities |
| | Production specifications changes are updated |
| | Standard routings/work center sequences are corrected and updated |
| **3.2. Inventory control** | |
| | There is a process in place to ensure accurate stock balance of all inventory types (i.e., finished goods, scrap) and that these stock balance figures are accurately updated in the organization's systems in a timely manner. |
| | The organization has a process that ensures the structure of the Bill of Material (BOM) records are maintained and are accurate. Any deviations are investigated and reflected accurately in perpetual inventory records. |
| | Records are maintained, compared to schedule, and information supplied to all appropriate persons, for evaluations of important material processes for the organization. |

| | |
|---|---|
| | The organization has a process to ensure physical inventory counts, when performed, are done accurately and reported in inventory records. These inventory counts are performed with an adequate frequency for every part, depending on volume value, waste percentage, etc. |
| | The organization has, and periodically evaluates, error reduction tools (i.e., visual controls, bar coding, elimination of manual entry), for part storage, part movement and accurate inventory records. |
| **3.3.Requirements planning** | |
| | Components requirements are planned correctly |
| | An efficient lot size policy exist |
| **3.4. Capacity planning** | An efficient planned load and load leveling exist of work orders |
| **3.5 Operation scheduling** | |
| | Manpower and machine requirements are estimated from schedules |
| **3.6 .Shop floor control** | Control of shortage in labor exists |
| | A systematic and efficient process exist to assign jobs to men and machines |
| | A standardized procedure exist to expedite orders |
| **3.7. Purchasing** | The order preparation process is error proofed |
| | An efficient internal transportations of material exist |
| | A good communication exists with suppliers regarding orders and delivery requirements |
| | No delay in purchase requisitions issuance |
| **3.8. Quality Management** | A good quality management system exists to coordinate planning and production |
| | management is committed to quality |
| | ISO/QS 9000 complied |

## *4- Manufacturing Engineering Department*

| Sub-Element | Best Practices |
|---|---|
| | |
| **4.1. Production Planning** | Complete drawings and bills of materials are being reproduces and forwarded to production control |
| | Needed raw material are being determined accurately |
| | Manufacturing Engineering studies the design, the manufacturing phases, the necessary drawings, and the bills of materials |
| | Clear prints from customer, and finishing route sheets are associated with every work order |
| | Necessary test specifications and operating instructions are submitted to the quality control |
| **4.2.Product Design** | A good communication exist of quotation request from contract administrator |
| | Definite procedures exist for the design of the of the product under consideration |
| | Designed similar product before |

| | |
|---|---|
| **4.3.Tooling Design** | A good planning exist for new products and tool availability |
| | There is a documented, implemented and periodically evaluated process, which tracks a tool's lifecycle (i.e., current status, rework history, ownership, authorizations, and BOM item link). |
| **4.4. Documentation** | There is a formal review process for proposed engineering changes to evaluate the impact on manufacturing operations, physical material flow and delivery. |
| | Process documents are associated with work orders |
| | A good database exist for starter blank to build router sheet in database for new items |

## *5- Shop Floor & Quality Control*

| Sub-Element | Best Practices |
|---|---|
| **5.1. Order Review and release** | Routing sheets are associated with items produced and include the following: |
| | How to machine and/or fabricate the item and a description of the activity or process |
| | Sequence of the work |
| | Tooling required for each operation |
| | Type of labor required |
| | Where the work is to be performed |
| **5.2. Detailed scheduling (Lean Manufacturing)** | An efficient process layout exist: |
| | 5S |
| | standard work flow |
| | method sheet |
| | mistake proofing |
| | cells |
| | visual control |
| | mixed model production |
| | pull production scheduling |
| | cross training |
| **5.3. Maintenance** | Scheduled lubrication and inspection exist |
| | Periodic overhaul exist of tools and equipment |
| | A good system exist to replace used parts with new or refurbished parts |
| | Measurement of the OEE exist: |
| | 80-85% (World Class) |
| | 50-70% (Typical) |
| | Breakdown production losses are tracked: |
| | < 1-2% (World Class) |
| | 5-10% (Typical) |
| | Planned Maintenance: |
| | >90% (World Class) |
| | 50-70% (Typical) |
| | Reactive Maintenance: |
| | <10% (World Class) |

| | |
|---|---|
| | 45-55% (Typical) |
| **5.4. Quality/Prevention** | Is the design Validated using the following: |
| | Failure prevention analysis |
| | Field tests |
| | Prototype build |
| | Design review |
| | Release and validation |
| | Failure mode analysis |
| | Test and calibration procedures |
| | Calibration equipment |
| | Product testing-design |
| | Product testing-production processes |
| | Inspect processes, prototype, and 1st art |
| | Analytical analysis |
| | SPC is used to control the production process |
| | Production processes are capable: |
| | >2 (World Class) |
| | >1.33 (Typical) |
| | PPM: |
| | 50-100 PPM (World Class) |
| | 500-5000 PPM (Typical) |
| | Waste/Scrap as a percentage of manufacturing cost: |
| | 0.1-0.2% (World Class) |
| | 1-3% (Typical) |
| | Quality problem are well managed via the following: |
| | Scrap/rework reduction |
| | Feedback of Q/R and failure information |
| | Warranty reduction |
| | Warranty charge back communication |
| | Products are properly packed and handled |
| | Operators are trained on quality and reliability |
| **5.5. Quality/Appraisal** | Inspection & testing exist: |
| | Inspection direct 100% |
| | Inspect direct less 100% |
| | Quality audits |
| | Material for inspection & test |
| | Receiving inspection & storage |
| | Lab accept testing receiving inspection |
| | Lab accept testing production area |
| | Outside lab services |
| | Field testing |
| | Reliability testing |
| | Inspection indirect |
| | Review test & inspection date |
| | Tools and equipments are calibrated and gauged continuously |

| *6- Receiving* | |
|---|---|
| **Sub-Element** | **Best Practices** |
| | |
| **6.1. Receiving** | Incoming materials are appropriately unpalletized or containerized |
| | Unloading mechanization exist |
| | Unloading occur in a logical and orderly fashion |
| | A planning function exists to allocate resources to ensure adequate capacity (personnel, equipment, maintenance and layout/space). |
| | All variables that affect the receiving activities are considered to balance the utilization of the docks and space (i.e., scheduling, fixed time slots). |
| | A procedure exists for the correction and follow-up of any discrepancies in the receipt of material (i.e., quality and quantity verification [including packaging]). The organization ensures that each receiving transaction has a unique identifier to support problem resolution. |
| **6.2. Storing** | Materials are properly stored |
| | An efficient tracking system exist for the location of the materials at all times |
| | The storage environment is appropriately controlled for material on hand, ensuring that all parts have sufficient protection. |
| | The organization has a process to safeguard easily damaged material and high theft material. |
| | Accurate inventory records exist for all materials until they are released for shipment |
| **6.3. Incoming Material Inspection** | Unacceptable goods are identified by quality control upon receipt |
| **6.4. Space Planning** | An efficient and safe layout exist |
| | The right material handling equipments are used for the right products |
| *7- Shipping* | |
| **Sub-Element** | **Best Practices** |
| | |
| **7.1. Order Processing** | A process exist for special loading and/or shipping instructions |
| **7.2. Picking/Packaging and labeling** | A sound storage function with good materials location system exist |
| | Inventory records are updated periodically |
| | A good information system exist |
| | Engineering Problems are considered in packaging: |
| | Compression strength for hard to store products |
| | Cushioning for fragile products |
| | shelf life for sensitive products |
| | Impact and vibration of filling packages |
| | packaging operations configurations |

| | |
|---|---|
| | A documented control system exists for the procurement, allocation and monitoring of all packing material (i.e., standard packaging & back-up packaging) and the responsibilities are clearly defined between partners. |
| | There is a documented procedure to control the return of empty packaging in quality and quantity. |
| | Packing material is considered and optimized as a part of the total Materials Planning and Logistics costs. |
| **7.3. Shipping** | Materials are consolidated and containerized appropriately |
| | A standardized procedure exist to ensure what is being shipped is what the customer ordered |
| **7.4. Space Planning** | An efficient plan exist for material handling maneuvering |
| | Doorways, passageways, and ramps allow ease of movement of the product handled |
| | Product storage methods exist to prevent product crushing and products falls |
| | Compatibility is investigated of material to be stored close together |
| | Products are properly protected from moisture, severe temperature, leakage, and staining |
| **7.5. Transportation** | |
| | Documented procedures for the follow-up of transportation issues relating to quality (damages), cost (normal, premium freight and detention/demurrage costs), and delivery (ordering and on-time performance) exists. |
| | A procedure exists for the correction and follow-up of any discrepancies in the receipt of material (i.e., quality and quantity verification [including packaging]). The organization ensures that each receiving transaction has a unique identifier to support problem resolution. |
| | A documented control system exists for the procurement, allocation and monitoring of all packing material (i.e., returnable containers, expendable packaging, dunnage, spacers). |
| | A documented and implemented process exists to ensure that returnable container inventory and their availability in quantity and quality is adequate to cover customer requirements. |
| | A documented, customer approved process exists in case of missing, damaged, dirty or otherwise unsuitable packaging. |
| | There is a process to notify the customer for each shipment when alternative or back-up packaging is used. |
| | A documented process for the storage of customer-supplied packaging is available and followed (i.e., suitable storage and cleaning facilities for returnable containers). |
| | For organization managed transportation the carrier/Lead Logistics Provider is selected and shall be assessed regarding logistics, flexibility and quality parameters. |
| | Appropriate equipment (i.e., bracing, banding) is used to ensure the product is delivered to the customer damage-free. |

| | |
|---|---|
| | Transportation planning is included from beginning of the products life cycle and the carrier/Lead Logistics Provider is involved as early as possible (i.e., product development process). |
| | The organization has a process to plan transportation capacity together with the carrier/Lead Logistics Provider in line with its own processes and their capacities. |
| | The organization has established documented contingency plans in the event of failure of transport, including quantified alternative methods of transport. |

## B. On-time Delivery Best Practices:

| ***1- Customer Service/ Sales*** | |
|---|---|
| **Sub-Element** | **Best Practices** |
| **1.1. Order processing** | Adequate procedure exists to generate order assembly and shipping documents? |
| | Customer Service monitor the performance of production planning and inventory control operations |
| | When expediting customer orders, Customer Service supervises the proper execution of special customer requirements, such as periodic deliveries and packaging requirements |
| | Customer Service monitor the performance of warehousing and transportation operations |
| **1.2. Sales forecasting** | A good short-term sales forecast exists |
| **1.3. Order entry** | |
| | Standardized procedures exist to trace orders |
| **1.4. Information exchange** | Sales and delivery terms are communicated with customer |
| | Procedures exist to communicate products specifications with customers and production |
| | There are agreed contingency plans established between both parties to maintain permanent communication during bottle-neck situations. |
| | The customers' goals regarding Materials Planning and Logistics performance are clearly defined (i.e., Customer delivery instructions/schedules), visualized and followed-up by the organization. |
| | A contact list exists containing name, function, method of communication (i.e., phone number, fax number, e-mail address, language spoken, etc…), hours of availability and deputies/back-ups for each Materials Planning and Logistics function from its customers. |
| | Electronically communicated delivery forecasts shall be received and processed without manual entry. |
| | Electronically communicated call off's (i.e., shipping schedules, sequenced shipping schedules) shall be received and processed without manual entry. |
| **1.5. Claims and credits** | Efficient Credit handling and claim are in place |
| **1.6. Technical services** | Customer Service offers technical assistance to customers |
| | Customer Service offers testing and laboratory services |
| **1.7. Customer service planning and control** | Customer Service identifies deviations between standards and actual and their causes |
| | Customer Service initiates corrective actions to minimize deviations between standards and actual |

| | |
|---|---|
| **1.8. After delivery services** | Customer Service manages preventive inspection operations |
| | Customer Service monitors the maintenance and repair operations for customers |
| ***2- Purchasing*** | |
| **Sub-Element** | **Best Practices** |
| **2.1. Database** | Parts history records are available |
| | Specifications files are available |
| | Standards files are available |
| | Vendor records, including financial and performance are available |
| **2.2. Procurement Process** | Following up exist for delivery, i.e. expediting and updating open-order status reports |
| | Modes of transportation and carrier are determined |
| | Accurate analysis process exist of quotation/ or proposals |
| | Efficient scheduling of purchases and deliveries |
| | Purchasing corresponds with suppliers |
| | Materials are checked upon receipt |
| | Efficient checking and approving of invoices |
| | Corresponding with suppliers |
| | Are suppliers being evaluated according to the delivery control standards (purchasing must familiarize themselves with these standards)? |
| **2.3. Material management** | A control system exists to minimize excess stocks and obsolescence |
| | Stocks control exists |
| | Packages and containers are standardized |
| | Periodic reports exist of commitments |
| | Inventory classifications exists |
| **2.4. Procurement Decision** | Adequate procedures exist for make or buy studies |
| | New supply sources development exist |
| | Alternatives exist for materials and sources |
| ***3- Production Planning and Control*** | |
| **Sub-Element** | **Best Practices** |
| | |
| **3.1. Engineering Data control** | Engineering drawings/changes are kept up to date |
| | A continuous addition or removal exist of assembly components or quantities |
| | Production specifications changes are updated |
| | Standard routings/work center sequences are corrected and updated |

| | |
|---|---|
| **3.2. Inventory control** | There is a process in place to ensure accurate stock balance of all inventory types (i.e., finished goods, scrap) and that these stock balance figures are accurately updated in the organization's systems in a timely manner. |
| | Efficient order policy exists |
| | The organization has a process that ensures the structure of the Bill of Material (BOM) records are maintained and are accurate. Any deviations are investigated and reflected accurately in perpetual inventory records. |
| | Records are maintained, compared to schedule, and information supplied to all appropriate persons, for evaluations of important material processes for the organization. |
| | The organization has a process to ensure physical inventory counts, when performed, are done accurately and reported in inventory records. These inventory counts are performed with an adequate frequency for every part, depending on volume value, waste percentage, etc. |
| | The organization has, and periodically evaluates, error reduction tools (i.e., visual controls, bar coding, elimination of manual entry), for part storage, part movement and accurate inventory records. |
| **3.3. Sales forecast** | Accurate sales forecast exists |
| **3.4. Requirements planning** | Components requirements are planned correctly |
| | An efficient lot size policy exist |
| | Customer schedule information shall be automatically integrated into the organization's releasing system to avoid manual transference of data |
| | MRP receives the expected customer requirements prior to the actual MRP run to calculate daily production operating plans. |
| | |
| **3.5. Capacity planning** | An efficient planned load and load leveling exist of work orders |
| | Accurate start dates calculations |
| | Comparison of resources versus customer requirements shall be reviewed upon receipt of forecast requirements, comparing every week of the forecast (i.e., from week 3 to month 6 of the planning horizon) sent by customers. |
| | Resources versus customer requirements shall be reviewed upon receipt of shipping requirements, comparing daily ship requirement (usually current week and week 2) sent by customers. |
| | There shall be a process in place to notify customers of any significant resource limitations in meeting the requirements. |
| **3.6. Operation scheduling** | Operations are run based on rate based order management |
| | Accurate assignment of start and finish job dates |

| | |
|---|---|
| | Priority rules exist |
| | Queue time analysis exists |
| | Tools are controlled |
| | Efficient planning of schedules and minimizing planning failures |
| | Manpower and machine requirements are estimated from schedules |
| | The scheduling system shall consider customer requirements when generating production schedules. |
| **3.7. Shop floor control** | Control of shortage in labor exists |
| | A systematic and efficient process exist to assign jobs to men and machines |
| | A standardized procedure exist to expedite orders |
| **3.8. Purchasing** | The order preparation process is error proofed |
| | An efficient internal transportations of material exist |
| | No delay in purchase requisitions issuance |
| ***4- Manufacturing Engineering Department*** | |
| **Sub-Element** | **Best Practices** |
| **4.1. Production Planning** | Complete drawings and bills of materials are being reproduces and forwarded to production control |
| | Needed raw material are being determined accurately |
| | Manufacturing Engineering studies the design, the manufacturing phases, the necessary drawings, and the bills of materials |
| | Clear prints from customer, and finishing route sheets are associated with every work order |
| | Necessary test specifications and operating instructions are submitted to the quality control |
| **4.2. Product Design** | A good communication exist of quotation request from contract administrator |
| | Definite procedures exist for the design of the of the product under consideration |
| **4.3. Tooling Design** | A good planning exist for new products and tool availability |
| | There is a documented, implemented and periodically evaluated process, which tracks a tool's lifecycle (i.e., current status, rework history, ownership, authorizations, BOM item link). |
| | There is a sub-process for evaluating tool disposition when related to past models or inactive parts. |
| | There is a sub-process, which tracks customer authorizations for reworking or disposing of tools. |
| **4.4. Documentation** | Process documents are associated with work orders |
| | A good database exist for starter blank to build router sheet in database for new items |

| | |
|---|---|
| | A formal engineering change/sign-off review shall exist to ensure that all changes which affect the materials planning and Logistics process are planned, performed and communicated in a synchronized manner, (i.e., process sign-off sheet with Bill of Material (BOM) review, routing changes, effective dates, notification to suppliers, scheduling, and shipping). |
| | There is a formal review process for proposed engineering changes to evaluate the impact on manufacturing operations, physical material flow and delivery. |
| | All affected parties are represented in the review (i.e., Materials, Engineering, Suppliers, and Customer) and the results are communicated to all affected parties. |
| | All affected personnel understand engineering change procedures internally, and at the supplier and customer facilities. These procedures are reviewed on a regular basis for effectiveness and potential process improvements. |
| | There is a process for ensuring that inbound material has adequate revision control, including labels with revision level if applicable, and all material personnel understand the process. |
| ***5- Shop Floor & Quality Control*** | |
| **Sub-Element** | **Best Practices** |
| | |
| **5.1. Order Review and release** | Routing sheets are associated with items produced and include the following: |
| | How to machine and/or fabricate the item and a description of the activity or process |
| | How much time is required to perform each operation |
| | Sequence of the work |
| | Tooling required for each operation |
| | Type of labor required |
| | Where the work is to be performed |
| **5.2. Detailed scheduling (Lean Manufacturing)** | An efficient process layout exist: |
| | 5S |
| | standard work flow |
| | method sheet |
| | mistake proofing |
| | cells |
| | visual control |
| | mixed model production |
| | pull production scheduling |
| | cross training |
| **5.3. Maintenance** | Scheduled lubrication and inspection exist |
| | Periodic overhaul exist of tools and equipment |

| | |
|---|---|
| | A good system exist to replace used parts with new or refurbished parts |
| | Measurement of the OEE exist: |
| | 80-85% (World Class) |
| | 50-70% (Typical) |
| | Breakdown production losses are tracked: |
| | < 1-2% (World Class) |
| | 5-10% (Typical) |
| | Planned Maintenance: |
| | >90% (World Class) |
| | 50-70% (Typical) |
| | Reactive Maintenance: |
| | <10% (World Class) |
| | 45-55% (Typical) |
| **5.4. Quality/Prevention** | Is the design Validated using the following: |
| | Failure prevention analysis |
| | Field tests |
| | Prototype build |
| | Design review |
| | Release and validation |
| | Failure mode analysis |
| | Test and calibration procedures |
| | Calibration equipment |
| | Product testing-design |
| | Product testing-production processes |
| | Inspect processes, prototype, and 1st art |
| | Analytical analysis |
| | SPC is used to control the production process |
| | Production processes are capable: |
| | >2 (World Class) |
| | >1.33 (Typical) |
| | PPM: |
| | 50-100 PPM (World Class) |
| | 500-5000 PPM (Typical) |
| | Waste/Scrap as a percentage of manufacturing cost: |
| | 0.1-0.2% (World Class) |
| | 1-3% (Typical) |
| | Quality problem are well managed via the following: |
| | Scrap/rework reduction |
| | Feedback of Q/R and failure information |
| | Warranty reduction |
| | Warranty charge back communication |
| | Products are properly packed and handled |
| | Operators are trained on quality and reliability |
| **5.5. Quality/Appraisal** | Inspection & testing exist: |
| | Inspection direct 100% |

| | |
|---|---|
| | Inspect direct less 100% |
| | Quality audits |
| | Material for inspection & test |
| | Receiving inspection & storage |
| | Lab accept testing receiving inspection |
| | Lab accept testing production area |
| | Outside lab services |
| | Field testing |
| | Reliability testing |
| | Inspection indirect |
| | Review test & inspection date |
| | Tools and equipments are calibrated and gauged continuously |
| **5.6 Quality/Failure** | Internal/Scrap: |
| | Vendor responsible |
| | Re-inspection |
| | Internal/Rework: |
| | Direct labor sorting |
| | Division responsible |
| | Vendor responsible |
| | External: |
| | Customer complaints |
| | User complaints |
| | Scrap-division responsible at assembly plant |
| | Salaries related to product reliability |
| | Product liability costs |
| | Field service |
| | Civil penalty for lack of due care |
| | Returned material process and repair |
| | Management and engineering |
| | Management and engineering |
| **5.6 Efficiency** | Contact Time / cycle time |

## *6- Receiving*

| **Sub-Element** | **Best Practices** |
|---|---|
| | |
| **6.1. Receiving** | Choices of receiving dock bays are specified in the purchase order |
| | Incoming materials are appropriately unpalletized or containerized |
| | Unloading mechanization exist |
| | Unloading occur in a logical and orderly fashion |
| | A planning function exists to allocate resources to ensure adequate capacity (personnel, equipment, maintenance and layout/space). |
| | All variables that affect the receiving activities are considered to balance the utilization of the docks and space (i.e., scheduling, fixed time slots). |

| | |
|---|---|
| | The organization ensures shipping labels are accurate and comply with the labeling standards. |
| | The organization compares shipping documents with actual goods received to ensure accuracy and compliance to organization's requirements/standards. |
| | A procedure exists for the correction and follow-up of any discrepancies in the receipt of material (i.e., quality and quantity verification [including packaging]). The organization ensures that each receiving transaction has a unique identifier to support problem resolution. |
| | The organization uses visual controls to assist the receiving process. |
| **6.2. Storing** | Materials are properly stored |
| | An efficient tracking system exist for the location of the materials at all times |
| | Accurate inventory records exist for all materials until they are released for shipment |
| | The organization has a process that facilitates management of all types of inventory, in-house and off-site. |
| | The organization has visual controls in place to support inventory management (designated storage, minimum and maximum levels). |
| | The storage environment is appropriately controlled for material on hand, ensuring that all parts have sufficient protection. |
| | The organization has a process to safeguard easily damaged material and high theft material. |
| | The organization's material flow is designed to support FIFO where applicable. |
| | The organization has a process to optimize the material flow for new and current parts and production processes. |
| | The organization's material flow is designed to facilitate accurate tracking. |
| | The organization's material flow is designed to minimize handling and transportation costs. |
| | There is a process in place to ensure accurate stock balance of all inventory types (i.e., finished goods, scrap) and that these stock balance figures are accurately updated in the organization's systems in a timely manner. |
| | The organization has a process that ensures the structure of the Bill of Material (BOM) records are maintained and are accurate. Any deviations are investigated and reflected accurately in perpetual inventory records. |
| | Records are maintained, compared to schedule, and information supplied to all appropriate persons, for evaluations of important material processes for the organization. |

| | |
|---|---|
| | The organization has a process to ensure physical inventory counts, when performed, are done accurately and reported in inventory records. These inventory counts are performed with an adequate frequency for every part, depending on volume value, waste percentage, etc. |
| | The organization has, and periodically evaluates, error reduction tools (i.e., visual controls, bar coding, elimination of manual entry), for part storage, part movement and accurate inventory records. |
| | The organization shall archive material records for the appropriate length of time (retention requirements). These records must be retrievable and readable. |
| **6.3. Incoming Material Inspection** | Unacceptable goods are identified by quality control upon receipt |
| | Discrepancies are tracked in the receiving tally against the carrier's bill of lading, the vendors packing list, and the purchase order recorded? |
| | Unacceptable goods are identified by quality control? |
| | The organization shall have a process to correctly identify all material, including in-process material and including direct marking when needed. |
| | The organization shall have a process to ensure part's labels are available at the appropriate time and are applied correctly. |
| | The organization shall have a process to clearly identify all storage locations accurately. |
| | The organization shall have a process to assure the appropriate identification of all unusable or damaged material (scrap, returns, rejections, etc…). |
| | Bar codes are used to identify and trace material where appropriate. |
| **6.4. Space Planning** | An efficient and safe layout exist |
| | The right material handling equipments are used for the right products |
| ***7- Shipping*** | |
| **Sub-Element** | **Best Practices** |
| **7.1. Order Processing** | Credit limit/terms are set |
| | Procedures to acknowledge receipt of customer orders exist |
| | A process is in place for special loading and/or shipping instructions |
| | Process exists to check the Compliance of warehouse with customer due dates? |
| | A process exists for releasing stocking locations and standard handling times to schedule picking and shipping |
| **7.2. Picking/Packaging and labeling** | A process exist for special loading and/or shipping instructions |
| | A sound storage function with good materials location |

| | |
|---|---|
| | system exist |
| | The organization shall have a process and supporting documentation to define standard packaging, (usually reusable container), and back-up packaging (usually expendable containers), and pack size before start of production (i.e., agreements about packaging type and rules for use with customer, involvement of all internal departments connected with the packaging process). |
| | Requirements for packaging development/specification is agreed and documented. |
| | The organization periodically audits shipments and conducts a physical review of packaging to ensure compliance with defined packaging requirements. |
| | Customer specific packaging should be developed for integration into the manufacturing process (i.e., max. use of transportation conveyance, transport optimization). |
| | Engineering Problems are considered in packaging: |
| | Compression strength for hard to store products |
| | Cushioning for fragile products |
| | shelf life for sensitive products |
| | Impact and vibration of filling packages |
| | packaging operations configurations |
| | A documented control system exists for the procurement, allocation and monitoring of all packing material (i.e., returnable containers, expendable packaging, dunnage, spacers). |
| | A documented and implemented process exists to ensure that returnable container inventory and their availability in quantity and quality is adequate to cover customer requirements. |
| | A documented, customer approved process exists in case of missing, damaged, dirty or otherwise unsuitable packaging. |
| | There is a process to notify the customer for each shipment when alternative or back-up packaging is used. |
| | A documented process for the storage of customer-supplied packaging is available and followed (i.e., suitable storage and cleaning facilities for returnable containers). |
| **7.3. Shipping** | Materials are consolidated and containerized appropriately |
| | A standardized procedure exist to ensure what is being shipped is what the customer ordered |
| | Spotting the carrier with good access to the staging area |
| | Care is taken to load the carrier in a way that facilities unloading the customer order |
| | The implemented and documented process to detect quantity shipped discrepancies is automated (i.e., scan based shipment and loading control systems). |
| | The organization ensures that any quantity-shipped disagreements with the customer are detected and reconciled in a timely manner without cost penalties to the customer. |

| | |
|---|---|
| | Dock operations (i.e., capacity of preparation areas, loading bays, limits of loading and unloading, rules of freight capacity, schedule of dispatch handling) are optimized, using scheduled window times and carrier on-time performance is tracked. |
| | The organization shall verify the data contents of shipping labels, **(the use of electronic based support systems such as RFID or scanning is mandatory for some customers)**, to assure consistency between container content, labels and documentation. |
| | The organization shall ensure that the data content of all ASN's is complete and accurate in accordance with customer requirements. |
| | All shipments, including documentation and labeling, shall be prepared to customer, industry and government standards and requirements (i.e., customs handling) including carrier routings. |
| | The shipment process shall ensure that each ASN is transmitted at the time of conveyance departure. |
| | There is a procedure describing the proper use of shipment quantity-determination equipment (i.e., scales, counters). |
| | All quantity-determination equipment is calibrated to a recognized standard at planned intervals. |
| | The inspection status and date for all quantity-determination equipment is clearly displayed on the equipment. |
| | An inspection schedule is created and one person has the responsibility of equipment calibration. |
| | Design and development responsibility is agreed between partners; packaging design requirements (i.e., standard packaging, pack size, back-up packaging) are documented in a detailed procedure and communicated to the supplier before the start of production and covers the entire product life cycle. |
| | Existing standards are used; returnable, reusable or recyclable containers are considered as a part of environmental guidelines. |
| | Optimization of transport, variety of packaging, material receiving, and handling until point of use is considered. |
| | A documented control system exists for the procurement, allocation and monitoring of all packing material (i.e., standard packaging & back-up packaging) and the responsibilities are clearly defined between partners. |
| | There is a documented procedure to control the return of empty packaging in quality and quantity. |
| | Packing material is considered and optimized as a part of the total Materials Planning and Logistics costs. |
| **7.4. Space Planning** | An efficient plan exist for material handling maneuvering |
| | Doorways, passageways, and ramps allow ease of movement of the product handled |
| | Product storage methods exist to prevent product crushing |

| | |
|---|---|
| | and products falls |
| | Compatibility is investigated of material to be stored close together |
| | Products are properly protected from moisture, severe temperature, leakage, and staining |
| **7.5. Transportation** | Transportation set-up is considered as part of the product development process, including transportation specification, (i.e., lead time), optimization and environmental consideration together with carriers and Lead Logistics providers. |
| | Documented procedures for the follow-up of transportation issues relating to quality (damages), cost (normal, premium freight and detention/demurrage costs), and delivery (ordering and on-time performance) exists. |
| | The organization tracks and traces in-bound material from time of supplier shipment through to receipt of material. |
| | Transportation function supplies the scheduling function with information on in-bound transportation modes and associated transit times (i.e., lead-time, window times). |
| | For organization managed transportation the carrier/Lead Logistics Provider is selected and shall be assessed regarding logistics, flexibility and quality parameters. |
| | Appropriate equipment (i.e., bracing, banding) is used to ensure the product is delivered to the customer damage-free. |
| | Transportation planning is included from beginning of the products life cycle and the carrier/Lead Logistics Provider is involved as early as possible (i.e., product development process). |
| | The organization has a process to plan transportation capacity together with the carrier/Lead Logistics Provider in line with its own processes and their capacities. |
| | The organization has established documented contingency plans in the event of failure of transport, including quantified alternative methods of transport. |
| | The organization regularly explores opportunities to reload inbound conveyances with outbound product. |
| | Disposition of all empty transportation capacities (both inbound and outbound) should be done on a daily basis to ensure that FIFO is occurring to minimize detention and demurrage related charges. |
| | The organization tracks and traces in-bound material from time of supplier shipment through to receipt of material. |
| | The organization ensures shipping labels are accurate and comply with the labeling standards. |

# Appendix C: Test Statistics Tables

Table 15: Rerun of the Kruskal-Wallis Test for Best-practices' Sub-elements across the Value Stream by Quality Grouping

Test Statistics[a,b]

| | Chi-Square | df | Asymp. Sig. |
|---|---|---|---|
| ORDERP ROCESSING | 5.159619 | 3 | 0.1605 |
| INFORMATION EXCHANGE | 3.469083 | 3 | 0.3248 |
| TECHNICAL SERVICES | 4.190828 | 3 | 0.2416 |
| CUSTOMERSERVICEPLANNINGANDCONTROL | 9.806157 | 3 | 0.0203 |
| AFTERDELIVERYSERVICES | 11.07373 | 3 | 0.0113 |
| RELIABILITY | 14.03162 | 3 | 0.0029 |
| DATABASE | 8.835216 | 3 | 0.0316 |
| PROCUREMENT PROCESS | 10.89372 | 3 | 0.0123 |
| MATERIAL MANAGEMENT | 12.14413 | 3 | 0.0069 |
| PROCUREMENT DECISION | 10.64562 | 3 | 0.0138 |
| ENGINEERING DATA CONTROL | 15.42948 | 3 | 0.0015 |
| INVENTORY CONTROL | 13.22498 | 3 | 0.0042 |
| REQUIREMENTS PLANNING | 3.255252 | 3 | 0.3539 |
| CAPACITY PLANNING | 4.428092 | 3 | 0.2188 |
| OPERATION SCHEDULING | 3.508903 | 3 | 0.3196 |
| SHOP FLOOR CONTROL | 10.28769 | 3 | 0.0163 |
| PURCHASING | 11.72131 | 3 | 0.0084 |
| QUALITY MANAGEMENT | 10.79536 | 3 | 0.0129 |
| PRODUCTION PLANNING | 8.4117 | 3 | 0.0382 |
| PRODUCT DESIGN | 4.313038 | 3 | 0.2296 |
| TOOLING DESIGN | 0.970969 | 3 | 0.8083 |
| DOCUMENTATION | 5.958344 | 3 | 0.1137 |
| ORDER REVIEW AND RELEASE | 15.5416 | 3 | 0.0014 |
| DETAILED SCHEDULING | 3.812448 | 3 | 0.2824 |
| MAINTENANCE | 9.21542 | 3 | 0.0266 |
| QUALITYP REVENTION | 3.226182 | 3 | 0.3580 |
| QUALITY APPRAISAL | 14.61725 | 3 | 0.0022 |
| RECEIVING | 25.05511 | 3 | 0.0000 |
| STORING | 23.98327 | 3 | 0.0000 |
| INCOMING MATERIAL INSPECTION | 18.6078 | 3 | 0.0003 |
| SPACE PLANNING | 19.79814 | 3 | 0.0002 |
| PICKING PACKAGING AND LABELING | 16.56032 | 3 | 0.0009 |
| SHIPPING | 10.0078 | 3 | 0.0185 |
| TRANSPORTATION | 13.61114 | 3 | 0.0035 |

a. Kruskal Wallis Test
b. Grouping Variable: Quality Grouping

Table 16: Rerun Average Ranks of Best-practices' Sub-elements by Quality Grouping

| | Quality Level | N | Mean Rank |
|---|---|---|---|
| ORDERP ROCESSING | Very Low | 30 | 45.13 |
| | Acceptable | 18 | 50.39 |
| | High | 24 | 54.71 |
| | Excellent | 34 | 61.68 |
| | Total | 106 | |
| INFORMATION EXCHANGE | Very Low | 30 | 47.52 |
| | Acceptable | 18 | 57.67 |
| | High | 24 | 61.17 |
| | Excellent | 34 | 51.16 |
| | Total | 106 | |
| TECHNICAL SERVICES | Very Low | 30 | 45.52 |
| | Acceptable | 18 | 59.47 |
| | High | 24 | 51.13 |
| | Excellent | 34 | 59.06 |
| | Total | 106 | |
| CUSTOMERSERVICEPLANNINGANDCONTROL | Very Low | 30 | 38.97 |
| | Acceptable | 18 | 59.64 |
| | High | 24 | 59.96 |
| | Excellent | 34 | 58.51 |
| | Total | 106 | |
| AFTERDELIVERYSERVICES | Very Low | 30 | 38.00 |
| | Acceptable | 18 | 61.64 |
| | High | 24 | 58.35 |
| | Excellent | 34 | 59.44 |
| | Total | 106 | |
| RELIABILITY | Very Low | 30 | 37.03 |
| | Acceptable | 18 | 67.72 |
| | High | 24 | 57.48 |
| | Excellent | 34 | 57.69 |
| | Total | 106 | |
| DATABASE | Very Low | 29 | 41.12 |
| | Acceptable | 18 | 60.14 |
| | High | 24 | 51.13 |
| | Excellent | 35 | 61.97 |
| | Total | 106 | |
| PROCUREMENT PROCESS | Very Low | 29 | 39.90 |
| | Acceptable | 18 | 66.25 |
| | High | 24 | 60.69 |
| | Excellent | 35 | 53.29 |
| | Total | 106 | |

Table 16: Continued

| | Quality Level | N | Mean Rank |
|---|---|---|---|
| MATERIAL MANAGEMENT | Very Low | 29 | 39.52 |
| | Acceptable | 18 | 64.75 |
| | High | 24 | 49.88 |
| | Excellent | 35 | 61.79 |
| | Total | 106 | |
| PROCUREMENT DECISION | Very Low | 29 | 39.98 |
| | Acceptable | 18 | 47.81 |
| | High | 24 | 62.98 |
| | Excellent | 34 | 59.81 |
| | Total | 105 | |
| ENGINEERING DATA CONTROL | Very Low | 29 | 36.52 |
| | Acceptable | 18 | 59.19 |
| | High | 24 | 51.73 |
| | Excellent | 34 | 64.68 |
| | Total | 105 | |
| INVENTORY CONTROL | Very Low | 29 | 38.47 |
| | Acceptable | 18 | 67.06 |
| | High | 24 | 51.69 |
| | Excellent | 35 | 60.23 |
| | Total | 106 | |
| REQUIREMENTS PLANNING | Very Low | 29 | 46.22 |
| | Acceptable | 18 | 61.33 |
| | High | 24 | 56.33 |
| | Excellent | 35 | 53.56 |
| | Total | 106 | |
| CAPACITY PLANNING | Very Low | 28 | 44.05 |
| | Acceptable | 18 | 61.06 |
| | High | 24 | 57.13 |
| | Excellent | 35 | 53.19 |
| | Total | 105 | |
| OPERATION SCHEDULING | Very Low | 29 | 44.31 |
| | Acceptable | 18 | 57.06 |
| | High | 24 | 56.77 |
| | Excellent | 34 | 55.60 |
| | Total | 105 | |
| SHOP FLOOR CONTROL | Very Low | 29 | 40.52 |
| | Acceptable | 18 | 56.00 |
| | High | 24 | 51.48 |
| | Excellent | 35 | 64.36 |
| | Total | 106 | |

Table 16: Continued

| | Quality Level | N | Mean Rank |
|---|---|---|---|
| PURCHASING | Very Low | 28 | 42.34 |
| | Acceptable | 18 | 43.50 |
| | High | 24 | 54.63 |
| | Excellent | 35 | 65.30 |
| | Total | 105 | |
| QUALITY MANAGEMENT | Very Low | 30 | 40.45 |
| | Acceptable | 18 | 60.89 |
| | High | 24 | 50.98 |
| | Excellent | 33 | 61.58 |
| | Total | 105 | |
| PRODUCTION PLANNING | Very Low | 30 | 41.03 |
| | Acceptable | 18 | 61.83 |
| | High | 23 | 53.22 |
| | Excellent | 35 | 60.09 |
| | Total | 106 | |
| PRODUCT DESIGN | Very Low | 29 | 43.29 |
| | Acceptable | 18 | 50.25 |
| | High | 24 | 56.06 |
| | Excellent | 32 | 57.83 |
| | Total | 103 | |
| TOOLING DESIGN | Very Low | 30 | 51.12 |
| | Acceptable | 18 | 50.39 |
| | High | 24 | 55.94 |
| | Excellent | 35 | 57.00 |
| | Total | 107 | |
| DOCUMENTATION | Very Low | 30 | 43.20 |
| | Acceptable | 17 | 58.18 |
| | High | 24 | 52.85 |
| | Excellent | 35 | 60.50 |
| | Total | 106 | |
| ORDER REVIEW AND RELEASE | Very Low | 31 | 40.29 |
| | Acceptable | 17 | 52.79 |
| | High | 24 | 50.71 |
| | Excellent | 35 | 68.99 |
| | Total | 107 | |
| DETAILED SCHEDULING | Very Low | 31 | 46.89 |
| | Acceptable | 17 | 50.50 |
| | High | 24 | 61.79 |
| | Excellent | 35 | 56.66 |
| | Total | 107 | |

Table 16: Continued

| | Quality Level | N | Mean Rank |
|---|---|---|---|
| MAINTENANCE | Very Low | 31 | 40.08 |
| | Acceptable | 16 | 60.38 |
| | High | 24 | 55.31 |
| | Excellent | 35 | 61.00 |
| | Total | 106 | |
| QUALITYP REVENTION | Very Low | 31 | 46.37 |
| | Acceptable | 17 | 59.79 |
| | High | 24 | 54.00 |
| | Excellent | 35 | 57.94 |
| | Total | 107 | |
| QUALITY APPRAISAL | Very Low | 31 | 42.92 |
| | Acceptable | 17 | 58.44 |
| | High | 24 | 45.21 |
| | Excellent | 35 | 67.69 |
| | Total | 107 | |
| RECEIVING | Very Low | 30 | 33.75 |
| | Acceptable | 18 | 64.06 |
| | High | 24 | 50.17 |
| | Excellent | 35 | 68.81 |
| | Total | 107 | |
| STORING | Very Low | 30 | 34.30 |
| | Acceptable | 18 | 69.75 |
| | High | 24 | 50.19 |
| | Excellent | 35 | 65.40 |
| | Total | 107 | |
| INCOMING MATERIAL INSPECTION | Very Low | 30 | 35.75 |
| | Acceptable | 18 | 59.47 |
| | High | 24 | 53.63 |
| | Excellent | 34 | 65.91 |
| | Total | 106 | |
| SPACE PLANNING | Very Low | 30 | 40.13 |
| | Acceptable | 18 | 54.44 |
| | High | 24 | 46.23 |
| | Excellent | 35 | 70.99 |
| | Total | 107 | |
| PICKING PACKAGING AND LABELING | Very Low | 29 | 36.69 |
| | Acceptable | 18 | 64.25 |
| | High | 24 | 50.54 |
| | Excellent | 35 | 63.93 |
| | Total | 106 | |

Table 16: Continued

| | Quality Level | N | Mean Rank |
|---|---|---|---|
| SHIPPING | Very Low | 29 | 40.88 |
| | Acceptable | 18 | 52.50 |
| | High | 24 | 54.02 |
| | Excellent | 34 | 62.88 |
| | Total | 105 | |
| TRANSPORTATION | Very Low | 29 | 37.19 |
| | Acceptable | 18 | 56.31 |
| | High | 22 | 51.70 |
| | Excellent | 35 | 63.73 |
| | Total | 104 | |

Table 17: Kruskal-Wallis Test for Best-practices' Sub-elements across the Value Stream by Suppliers' Delivery Grouping (initial run)

Test Statistics[a,b]

| | Chi-Square | df | Asymp. Sig. |
|---|---|---|---|
| ORDERP ROCESSING | 4.96642 | 3 | 0.1743 |
| INFORMATION EXCHANGE | 3.553956 | 3 | 0.3138 |
| TECHNICAL SERVICES | 6.522866 | 3 | 0.0888 |
| CUSTOMERSERVICEPLANNINGANDCONTROL | 0.832015 | 3 | 0.8418 |
| AFTERDELIVERYSERVICES | 3.287925 | 3 | 0.3493 |
| SALES FORECASTING | 0.800153 | 3 | 0.8494 |
| ORDER ENTRY | 7.194551 | 3 | 0.0659 |
| CLAIMS AND CREDITS | 7.674639 | 3 | 0.0532 |
| DATABASE | 1.604774 | 3 | 0.6583 |
| PROCUREMENT PROCESS | 0.640483 | 3 | 0.8871 |
| MATERIAL MANAGEMENT | 1.170213 | 3 | 0.7602 |
| PROCUREMENT DECISION | 3.160324 | 3 | 0.3676 |
| ENGINEERING DATA CONTROL | 2.767744 | 3 | 0.4288 |
| INVENTORY CONTROL | 1.625214 | 3 | 0.6537 |
| REQUIREMENTS PLANNING | 0.725733 | 3 | 0.8671 |
| CAPACITY PLANNING | 3.501531 | 3 | 0.3206 |
| OPERATION SCHEDULING | 1.657338 | 3 | 0.6465 |
| SHOP FLOOR CONTROL | 0.534516 | 3 | 0.9112 |
| PURCHASING | 2.802893 | 3 | 0.4230 |
| PRODUCTION PLANNING | 0.894706 | 3 | 0.8267 |
| PRODUCT DESIGN | 5.16501 | 3 | 0.1601 |
| TOOLING DESIGN | 4.381634 | 3 | 0.2231 |
| DOCUMENTATION | 2.277813 | 3 | 0.5168 |
| ORDER REVIEW AND RELEASE | 3.206586 | 3 | 0.3609 |
| DETAILED SCHEDULING | 0.709496 | 3 | 0.8710 |
| MAINTENANCE | 4.186867 | 3 | 0.2420 |
| QUALITYP REVENTION | 1.03537 | 3 | 0.7927 |
| QUALITY APPRAISAL | 4.829784 | 3 | 0.1847 |
| QUALITY FAILURE | 3.897983 | 3 | 0.2727 |
| EFFICIENCY | 0.819153 | 3 | 0.8449 |
| RECEIVING | 3.347785 | 3 | 0.3410 |
| STORING | 1.018904 | 3 | 0.7967 |
| INCOMING MATERIAL INSPECTION | 1.221175 | 3 | 0.7479 |
| SPACE PLANNING | 0.463492 | 3 | 0.9268 |
| PICKING PACKAGING AND LABELING | 3.132228 | 3 | 0.3717 |
| SHIPPING | 2.555701 | 3 | 0.4653 |
| TRANSPORTATION | 1.047106 | 3 | 0.7899 |

a. Kruskal Wallis Test

b. Grouping Variable: Delivery Grouping

Table 20: Rerun of Kruskal-Wallis Test for Best-practices' Sub-elements across the Value Stream by Suppliers' Delivery Grouping (3 groupings)

| | Chi-Square | df | Asymp. Sig. |
|---|---|---|---|
| ORDERP ROCESSING | 17.71527 | 2 | 0.00014 |
| INFORMATION EXCHANGE | 11.12873 | 2 | 0.00383 |
| TECHNICAL SERVICES | 12.92415 | 2 | 0.00156 |
| CUSTOMERSERVICEPLANNINGANDCONTROL | 9.104361 | 2 | 0.01054 |
| AFTERDELIVERYSERVICES | 7.38353 | 2 | 0.02493 |
| SALES FORECASTING | 3.604409 | 2 | 0.16493 |
| ORDER ENTRY | 17.01103 | 2 | 0.00020 |
| CLAIMS AND CREDITS | 18.9767 | 2 | 0.00008 |
| DATABASE | 11.0289 | 2 | 0.00403 |
| PROCUREMENT PROCESS | 9.848031 | 2 | 0.00727 |
| MATERIAL MANAGEMENT | 22.00618 | 2 | 0.00002 |
| PROCUREMENT DECISION | 10.46701 | 2 | 0.00533 |
| ENGINEERING DATA CONTROL | 8.203266 | 2 | 0.01655 |
| INVENTORY CONTROL | 6.563452 | 2 | 0.03756 |
| REQUIREMENTS PLANNING | 11.67403 | 2 | 0.00292 |
| CAPACITY PLANNING | 18.05308 | 2 | 0.00012 |
| OPERATION SCHEDULING | 13.82464 | 2 | 0.00100 |
| SHOP FLOOR CONTROL | 6.696435 | 2 | 0.03515 |
| PURCHASING | 10.41949 | 2 | 0.00546 |
| PRODUCTION PLANNING | 3.385736 | 2 | 0.18399 |
| PRODUCT DESIGN | 11.5724 | 2 | 0.00307 |
| TOOLING DESIGN | 15.70456 | 2 | 0.00039 |
| DOCUMENTATION | 13.67426 | 2 | 0.00107 |
| ORDER REVIEW AND RELEASE | 5.946473 | 2 | 0.05114 |
| DETAILED SCHEDULING | 9.680008 | 2 | 0.00791 |
| MAINTENANCE | 10.15867 | 2 | 0.00622 |
| QUALITYP REVENTION | 13.63863 | 2 | 0.00109 |
| QUALITY APPRAISAL | 5.600037 | 2 | 0.06081 |
| QUALITY FAILURE | 9.865758 | 2 | 0.00721 |
| EFFICIENCY | 3.830837 | 2 | 0.14728 |
| RECEIVING | 10.85466 | 2 | 0.00439 |
| STORING | 16.49758 | 2 | 0.00026 |
| INCOMING MATERIAL INSPECTION | 10.01294 | 2 | 0.00669 |
| SPACE PLANNING | 17.8175 | 2 | 0.00014 |
| PICKING PACKAGING AND LABELING | 20.25664 | 2 | 0.00004 |
| SHIPPING | 18.55079 | 2 | 0.00009 |
| TRANSPORTATION | 15.73734 | 2 | 0.00038 |

a. Kruskal Wallis Test
b. Grouping Variable: Delivery Grouping

Table 21: Rerun Average Ranks of Best-practices' Sub-elements by Delivery Grouping (3 groupings)

| | Delivery Level | N | Mean Rank |
|---|---|---|---|
| ORDERP ROCESSING | Very Low | 41 | 39.94 |
| | Acceptable | 38 | 55.78 |
| | High | 27 | 70.89 |
| | Total | 106 | |
| INFORMATION EXCHANGE | Very Low | 41 | 43.48 |
| | Acceptable | 38 | 53.88 |
| | High | 27 | 68.19 |
| | Total | 106 | |
| TECHNICAL SERVICES | Very Low | 41 | 41.46 |
| | Acceptable | 38 | 56.3 |
| | High | 27 | 67.83 |
| | Total | 106 | |
| CUSTOMERSERVICEPLANNINGANDCONTROL | Very Low | 41 | 44.12 |
| | Acceptable | 38 | 54.24 |
| | High | 27 | 66.7 |
| | Total | 106 | |
| AFTERDELIVERYSERVICES | Very Low | 41 | 44.17 |
| | Acceptable | 38 | 62.58 |
| | High | 27 | 54.89 |
| | Total | 106 | |
| SALES FORECASTING | Very Low | 41 | 46.48 |
| | Acceptable | 38 | 57.61 |
| | High | 27 | 58.39 |
| | Total | 106 | |
| ORDER ENTRY | Very Low | 41 | 44.11 |
| | Acceptable | 38 | 49.24 |
| | High | 27 | 73.76 |
| | Total | 106 | |
| CLAIMS AND CREDITS | Very Low | 40 | 37.35 |
| | Acceptable | 38 | 59.62 |
| | High | 27 | 66.87 |
| | Total | 105 | |
| DATABASE | Very Low | 40 | 43.86 |
| | Acceptable | 38 | 52.67 |
| | High | 28 | 68.39 |
| | Total | 106 | |

Table 21: Continued

| | Delivery Level | N | Mean Rank |
|---|---|---|---|
| PROCUREMENT PROCESS | Very Low | 40 | 42.79 |
| | Acceptable | 38 | 56.01 |
| | High | 28 | 65.39 |
| | Total | 106 | |
| MATERIAL MANAGEMENT | Very Low | 40 | 37.14 |
| | Acceptable | 38 | 58.29 |
| | High | 28 | 70.38 |
| | Total | 106 | |
| PROCUREMENT DECISION | Very Low | 40 | 42.24 |
| | Acceptable | 37 | 55.04 |
| | High | 28 | 65.68 |
| | Total | 105 | |
| ENGINEERING DATA CONTROL | Very Low | 40 | 43.14 |
| | Acceptable | 38 | 57.28 |
| | High | 28 | 63.18 |
| | Total | 106 | |
| INVENTORY CONTROL | Very Low | 40 | 43.94 |
| | Acceptable | 38 | 58.37 |
| | High | 28 | 60.55 |
| | Total | 106 | |
| REQUIREMENTS PLANNING | Very Low | 40 | 41.18 |
| | Acceptable | 38 | 56.63 |
| | High | 27 | 65.41 |
| | Total | 105 | |
| CAPACITY PLANNING | Very Low | 40 | 40.34 |
| | Acceptable | 37 | 52.72 |
| | High | 28 | 71.46 |
| | Total | 105 | |
| OPERATION SCHEDULING | Very Low | 40 | 39.86 |
| | Acceptable | 38 | 57.66 |
| | High | 27 | 65.91 |
| | Total | 105 | |
| SHOP FLOOR CONTROL | Very Low | 40 | 44.74 |
| | Acceptable | 38 | 55.22 |
| | High | 28 | 63.68 |
| | Total | 106 | |

Table 21: Continued

| | Delivery Level | N | Mean Rank |
|---|---|---|---|
| PURCHASING | Very Low | 40 | 44.79 |
| | Acceptable | 38 | 51.71 |
| | High | 28 | 68.38 |
| | Total | 106 | |
| PRODUCTION PLANNING | Very Low | 41 | 48.15 |
| | Acceptable | 38 | 54.54 |
| | High | 28 | 61.84 |
| | Total | 107 | |
| PRODUCT DESIGN | Very Low | 40 | 39.59 |
| | Acceptable | 34 | 62.07 |
| | High | 27 | 53.96 |
| | Total | 101 | |
| TOOLING DESIGN | Very Low | 41 | 41.71 |
| | Acceptable | 38 | 54.8 |
| | High | 28 | 70.91 |
| | Total | 107 | |
| DOCUMENTATION | Very Low | 41 | 42.2 |
| | Acceptable | 38 | 55.29 |
| | High | 28 | 69.54 |
| | Total | 107 | |
| ORDER REVIEW AND RELEASE | Very Low | 41 | 45.74 |
| | Acceptable | 37 | 54.39 |
| | High | 28 | 63.68 |
| | Total | 106 | |
| DETAILED SCHEDULING | Very Low | 41 | 42.85 |
| | Acceptable | 37 | 55.16 |
| | High | 27 | 65.44 |
| | Total | 105 | |
| MAINTENANCE | Very Low | 41 | 42.82 |
| | Acceptable | 37 | 55.86 |
| | High | 28 | 66.02 |
| | Total | 106 | |
| QUALITYP REVENTION | Very Low | 41 | 40.85 |
| | Acceptable | 37 | 57.12 |
| | High | 28 | 67.23 |
| | Total | 106 | |

Table 21: Continued

| | Delivery Level | N | Mean Rank |
|---|---|---|---|
| QUALITY APPRAISAL | Very Low | 40 | 48.75 |
| | Acceptable | 37 | 48.14 |
| | High | 27 | 64.04 |
| | Total | 104 | |
| QUALITY FAILURE | Very Low | 40 | 43.58 |
| | Acceptable | 37 | 52.89 |
| | High | 28 | 66.61 |
| | Total | 105 | |
| EFFICIENCY | Very Low | 40 | 46.16 |
| | Acceptable | 37 | 54.96 |
| | High | 28 | 60.18 |
| | Total | 105 | |
| RECEIVING | Very Low | 40 | 44.56 |
| | Acceptable | 38 | 51.68 |
| | High | 28 | 68.73 |
| | Total | 106 | |
| STORING | Very Low | 40 | 39.15 |
| | Acceptable | 38 | 56.54 |
| | High | 27 | 68.54 |
| | Total | 105 | |
| INCOMING MATERIAL INSPECTION | Very Low | 40 | 42.03 |
| | Acceptable | 37 | 56.59 |
| | High | 28 | 63.93 |
| | Total | 105 | |
| SPACE PLANNING | Very Low | 40 | 38.05 |
| | Acceptable | 38 | 60.18 |
| | High | 28 | 66.5 |
| | Total | 106 | |
| PICKING PACKAGING AND LABELING | Very Low | 39 | 35.82 |
| | Acceptable | 38 | 62.24 |
| | High | 27 | 62.89 |
| | Total | 104 | |
| SHIPPING | Very Low | 38 | 36.17 |
| | Acceptable | 37 | 59.91 |
| | High | 28 | 63.04 |
| | Total | 103 | |
| TRANSPORTATION | Very Low | 40 | 39.35 |
| | Acceptable | 36 | 55.21 |
| | High | 28 | 67.8 |
| | Total | 104 | |

# Appendix D: Details of the Proposed-Model Calculations

## A. Details of the quality model:

Score Summary

| | Element | Score | Weight (100) | Element Final Score |
|---|---|---|---|---|
| 1 | Customer Service/Sales | 57.14% | 13.2 | 7.54 |
| 2 | Purchasing | 82.14% | 13.5 | 11.09 |
| 3 | Production Planning and Control | 77.14% | 14.6 | 11.26 |
| 4 | Manufacturing Engineering Department | 71.43% | 13.6 | 9.71 |
| 5 | Shop Floor & Quality Control | 95.24% | 15.1 | 14.38 |
| 6 | Receiving/ Warehouse | 100.00% | 15.2 | 15.20 |
| 7 | Shipping/ warehouse | 95.24% | 14.8 | 14.10 |
| | | | Quality Score (Out of 100) | 83.29 |

| | Element | Sub-Element | Questions Score (1-7) | Max. Score | Element Score |
|---|---|---|---|---|---|
| 1 | Customer Service/Sales | 1.4. Customer Services Planning | 6 | 7 | 57.14% |
| | | 1.5. After Delivery Services | 1 | 7 | |
| | | 1.6. Reliability | 5 | 7 | |
| | | Total | 12 | 21 | |

| | Element | Sub-Element | Questions Score (1-7) | Max. Score | Element Score |
|---|---|---|---|---|---|
| 2 | Purchasing | 2.1. Database | 5 | 7 | 82.14% |
| | | 2.2. Procurement Process | 6 | 7 | |
| | | 2.3. Material management | 6 | 7 | |
| | | 2.4. Procurement Decision | 6 | 7 | |
| | | Total | 23 | 28 | |

| | Element | Sub-Element | Questions Score (1-7) | Max. Score | Element Score |
|---|---|---|---|---|---|
| 3 | Production Planning and Control | 3.1. Engineering Data control | 5 | 7 | 77.14% |
| | | 3.2. Inventory control | 5 | 7 | |
| | | 3.6 .Shop floor control | 5 | 7 | |

| | Element | Sub-Element | Questions Score (1-7) | Max. Score |
|---|---|---|---|---|
| | | 3.7. Purchasing | 5 | 7 |
| | | 3.8. Quality Management | 7 | 7 |
| | | **Total** | **27** | **35** |

| | Element | Sub-Element | Questions Score (1-7) | Max. Score | Element Score |
|---|---|---|---|---|---|
| 4 | **Manufacturing Engineering Department** | 4.1. Production Planning | 5 | 7 | 71.43% |
| | | **Total** | **5** | **7** | |

| | Element | Sub-Element | Questions Score (1-7) | Max. Score | Element Score |
|---|---|---|---|---|---|
| 5 | **Shop Floor & Quality Control** | 5.1. Order Review and release | 7 | 7 | 95.24% |
| | | 5.3. Maintenance | 6 | 7 | |
| | | 5.5. Quality/Appraisal | 7 | 7 | |
| | | **Total** | **20** | **21** | |

| | Element | Sub-Element | Questions Score (1-7) | Max. Score | Element Score |
|---|---|---|---|---|---|
| 6 | **Receiving** | 6.1. Receiving | 7 | 7 | 100.00% |
| | | 6.2. Storing | 7 | 7 | |
| | | 6.3. Incoming Material Inspection | 7 | 7 | |
| | | 6.4. Space Planning | 7 | 7 | |
| | | **Total** | **28** | **28** | |

| | Element | Sub-Element | Questions Score (1-7) | Max. Score | Element Score |
|---|---|---|---|---|---|
| 7 | **Shipping** | 7.2. Picking/Packaging and labeling | 7 | 7 | 95.24% |
| | | 7.3. Shipping | 7 | 7 | |
| | | 7.5. Transportation | 6 | 7 | |
| | | **Total** | **20** | **21** | |

## B. Details of the on-time delivery prediction model:

**Score Summary**

| | Element | Score | Weight (100) | Element Final Score |
|---|---|---|---|---|
| 1 | Customer Service/Sales | 57.14% | 14.4 | 8.23 |
| 2 | Purchasing | 39.29% | 14.5 | 5.70 |
| 3 | Production Planning and Control | 38.78% | 14.2 | 5.51 |
| 4 | Manufacturing Engineering Department | 42.86% | 14.0 | 6.00 |
| 5 | Shop Floor & Quality Control | 50.00% | 14.2 | 7.10 |
| 6 | Receiving/ Warehouse | 46.43% | 14.5 | 6.73 |
| 7 | Shipping/ warehouse | 47.62% | 14.2 | 6.76 |
| | | Delivery Score (Out of 100) | | 46.03 |

| | Element | Sub-Element | Questions Score (1-7) | Max. Score | Element Score |
|---|---|---|---|---|---|
| 1 | Customer Service/Sales | 1.1. Order Processing | 4 | 7 | 57.14% |
| | | 1.3. Order entry | 4 | 7 | |
| | | 1.4. Information exchange | 5 | 7 | |
| | | 1.5. Claims and credits | 3 | 7 | |
| | | 1.6. Technical services | 5 | 7 | |
| | | 1.7. Customer service planning and control | 4 | 7 | |
| | | 1.8. After delivery services | 3 | 7 | |
| | | Total | 28 | 49 | |

| | Element | Sub-Element | Questions Score (1-7) | Max. Score | Element Score |
|---|---|---|---|---|---|
| 2 | Purchasing | 2.1. Database | 3 | 7 | 39.29% |
| | | 2.2. Procurement Process | 3 | 7 | |
| | | 2.3. Material management | 2 | 7 | |
| | | 2.4. Procurement Decision | 3 | 7 | |

| | | | Total | 11 | 28 | |
|---|---|---|---|---|---|---|

| | Element | Sub-Element | Questions Score (1-7) | Max. Score | Element Score |
|---|---|---|---|---|---|
| 3 | **Production Planning and Control** | 3.1. Engineering Data control | 2 | 7 | 38.78% |
| | | 3.2. Inventory control | 2 | 7 | |
| | | 3.4. Requirements planning | 3 | 7 | |
| | | 3.5. Capacity planning | 3 | 7 | |
| | | 3.6. Operation scheduling | 4 | 7 | |
| | | 3.7. Shop floor control | 2 | 7 | |
| | | 3.8. Purchasing | 3 | 7 | |
| | | **Total** | **19** | **49** | |

| | Element | Sub-Element | Questions Score (1-7) | Max. Score | Element Score |
|---|---|---|---|---|---|
| 4 | **Manufacturing Engineering Department** | 4.1. Production Planning | 3 | 7 | 42.86% |
| | | 4.2.Product Design | 3 | 7 | |
| | | 4.3.Tooling Design | 3 | 7 | |
| | | 4.4. Documentation | 3 | 7 | |
| | | **Total** | **12** | **28** | |

| | Element | Sub-Element | Questions Score (1-7) | Max. Score | Element Score |
|---|---|---|---|---|---|
| 5 | **Shop Floor & Quality Control** | 5.1. Order Review and release | 4 | 7 | 50.00% |
| | | 5.2. Detailed scheduling (Lean Manufacturing) | 4 | 7 | |
| | | 5.3. Maintenance | 4 | 7 | |
| | | 5.4. Quality/Prevention | 3 | 7 | |
| | | 5.5. Quality/Appraisal | 3 | 7 | |
| | | 5.6 Failure | 3 | 7 | |
| | | **Total** | **21** | **42** | |

| | Element | Sub-Element | Questions Score (1-7) | Max. Score | Element Score |
|---|---|---|---|---|---|
| 6 | **Receiving** | 6.1. Receiving | 3 | 7 | 46.43% |
| | | 6.2. Storing | 3 | 7 | |
| | | 6.3. Incoming Material Inspection | 4 | 7 | |

| | | | | |
|---|---|---|---|---|
| | | 6.4. Space Planning | 3 | 7 |
| | | **Total** | **13** | **28** |

| | Element | Sub-Element | Questions Score (1-7) | Max. Score | Element Score |
|---|---|---|---|---|---|
| **7** | **Shipping** | 7.2. Picking/Packaging and labeling | **3** | **7** | 47.62% |
| | | 7.3. Shipping | **4** | **7** | |
| | | 7.5. Transportation | **3** | **7** | |
| | | **Total** | **10** | **21** | |

# Appendix E: Responses Reliability and Validity Test

Table 12: Randomly Selected Suppliers' Responses

| **Supp. 1 A** | **Supp. 1 B** | **Supp. 2 A** | **Supp. 2 B** | **Supp. 3 A** | **Supp. 3 B** | **Supp. 4 A** | **Supp. 4 B** | **Supp. 5 A** | **Supp. 5 B** |
|---|---|---|---|---|---|---|---|---|---|
| 4 | 4 | 7 | 7 | 4 | 4 | 7 | 7 | 6 | 4 |
| 6 | 5 | 7 | 7 | 2 | 4 | 5 | 5 | 6 | 6 |
| 4 | 4 | 5 | 4 | 4 | 6 | 5 | 3 | 5 | 6 |
| 5 | 5 | 7 | 1 | 3 | 3 | 7 | 6 | 5 | 6 |
| 4 | 2 | 5 | 7 | 3 | 2 | 6 | 1 | 5 | 5 |
| 6 | 5 | 7 | 7 | 2 | 3 | 6 | 5 | 6 | 5 |
| 5 | 4 | 7 | 7 | 3 | 2 | 4 | 6 | 5 | 4 |
| 4 | 5 | 7 | 7 | 3 | 4 | 6 | 7 | 5 | 5 |
| 4 | 5 | 7 | 7 | 3 | 3 | 6 | 5 | 5 | 5 |
| 4 | 5 | 7 | 7 | 3 | 4 | 5 | 5 | 5 | 5 |
| 3 | 4 | 7 | 7 | 4 | 4 | 5 | 6 | 6 | 6 |
| 4 | 5 | 7 | 6 | 5 | 5 | 5 | 6 | 6 | 5 |
| 4 | 4 | 6 | 7 | 5 | 5 | 6 | 6 | 4 | 5 |
| 5 | 5 | 7 | 7 | 3 | 4 | 5 | 5 | 4 | 5 |
| 4 | 4 | 7 | 7 | 3 | 4 | 6 | 5 | 5 | 4 |
| 5 | 5 | 6 | 7 | 4 | 5 | 5 | 6 | 7 | 5 |
| 4 | 4 | 6 | 7 | 4 | 5 | 5 | 5 | 6 | 4 |
| 4 | 3 | 7 | 7 | 5 | 6 | 6 | 5 | 6 | 5 |
| 4 | 4 | 7 | 7 | 4 | 3 | 6 | 5 | 5 | 5 |
| 4 | 5 | 6 | 1 | 5 | 4 | 6 | 5 | 6 | 5 |
| 6 | 4 | 7 | 7 | 7 | 4 | 6 | 7 | 6 | 7 |
| 4 | 4 | 7 | 7 | 4 | 3 | 5 | 5 | 5 | 5 |
| 4 | 4 | 6 | 7 | 3 | 3 | 5 | 4 | 4 | 5 |
| 4 | 4 | 6 | 4 | 5 | 4 | 4 | 4 | 5 | 5 |
| 5 | 5 | 7 | 7 | 4 | 5 | 5 | 4 | 5 | 4 |
| 5 | 6 | 7 | 7 | 4 | 4 | 6 | 7 | 5 | 4 |
| 4 | 3 | 6 | 6 | 4 | 5 | 5 | 6 | 6 | 6 |
| 5 | 3 | 7 | 7 | 4 | 4 | 5 | 6 | 5 | 5 |
| 5 | 4 | 7 | 7 | 6 | 5 | 6 | 7 | 5 | 6 |
| 5 | 5 | 7 | 7 | 6 | 6 | 5 | 7 | 4 | 5 |
| 5 | 4 | 7 | 7 | 6 | 5 | 6 | 5 | 4 | 6 |
| 4 | 4 | 7 | 6 | 5 | 3 | 1 | 4 | 4 | 5 |
| 4 | 4 | 7 | 7 | 5 | 6 | 5 | 7 | 5 | 5 |
| 4 | 4 | 7 | 7 | 4 | 7 | 6 | 7 | 6 | 5 |
| 4 | 3 | 7 | 7 | 5 | 6 | 6 | 7 | 6 | 5 |
| 4 | 4 | 7 | 7 | 4 | 5 | 6 | 7 | 5 | 4 |
| 5 | 4 | 7 | 7 | 5 | 5 | 6 | 7 | 6 | 4 |
| 4 | 4 | 7 | 7 | 6 | 7 | 7 | 7 | 7 | 5 |
| 5 | 5 | 6 | 7 | 5 | 6 | 6 | 6 | 5 | 5 |

### Paired T-Test and CI: Supp.1 A, Supp.1 B

Paired T for Supp.1 A - Supp.1 B

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| Supp.1 A | 39 | 4.43590 | 0.68036 | 0.10894 |
| Supp.1 B | 39 | 4.23077 | 0.77668 | 0.12437 |
| Difference | 39 | 0.205128 | 0.832861 | 0.133364 |

95% CI for mean difference: (-0.064854, 0.475110)
T-Test of mean difference = 0 (vs not = 0): T-Value = 1.54  P-Value = 0.132

### Paired T-Test and CI: Supp. 2 A, Supp. 2 B

Paired T for Supp. 2 A - Supp. 2 B

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| Supp. 2 A | 39 | 6.69231 | 0.56911 | 0.09113 |
| Supp. 2 B | 39 | 6.46154 | 1.46622 | 0.23478 |
| Difference | 39 | 0.230769 | 1.404158 | 0.224845 |

95% CI for mean difference: (-0.224406, 0.685945)
T-Test of mean difference = 0 (vs not = 0): T-Value = 1.03  P-Value = 0.311

### Paired T-Test and CI: Supp. 3 A, Supp. 3 B

Paired T for Supp. 3 A - Supp. 3 B

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| Supp. 3 A | 39 | 4.20513 | 1.15119 | 0.18434 |
| Supp. 3 B | 39 | 4.43590 | 1.25226 | 0.20052 |
| Difference | 39 | -0.230769 | 1.157619 | 0.185367 |

95% CI for mean difference: (-0.606026, 0.144487)
T-Test of mean difference = 0 (vs not = 0): T-Value = -1.24  P-Value = 0.221

### Paired T-Test and CI: Supp. 4 A, Supp. 4 B

Paired T for Supp. 4 A - Supp. 4 B

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| Supp. 4 A | 39 | 5.46154 | 1.02202 | 0.16365 |
| Supp. 4 B | 39 | 5.58974 | 1.33215 | 0.21332 |
| Difference | 39 | -0.128205 | 1.379922 | 0.220964 |

95% CI for mean difference: (-0.575524, 0.319114)
T-Test of mean difference = 0 (vs not = 0): T-Value = -0.58  P-Value = 0.565

### Paired T-Test and CI: Supp. 5 A, Supp. 5 B

Paired T for Supp. 5 A - Supp. 5 B

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| Supp. 5 A | 39 | 5.28205 | 0.79302 | 0.12698 |
| Supp. 5 B | 39 | 5.02564 | 0.70663 | 0.11315 |
| Difference | 39 | 0.256410 | 1.044231 | 0.167211 |

95% CI for mean difference: (-0.082090, 0.594911)
T-Test of mean difference = 0 (vs not = 0): T-Value = 1.53  P-Value = 0.133

# Appendix F: Model Weights Calculation

## A. Quality Weights:

| | | Quality Level | N | Mean Rank | Total Mean Rank | % Emphasis of High Level by Sub-element | % Emphasis by Element | Weighted Percentage by Value Stream |
|---|---|---|---|---|---|---|---|---|
| 1- Customer Service/ Sales | CUSTOMER SERVICE PLANNING AND CONTROL | Very Low | 30 | 38.97 | | | | |
| | | Acceptable | 18 | 59.64 | | | | |
| | | High | 24 | 59.96 | | 100 | | |
| | | Excellent | 34 | 58.51 | 217.08 | 0.26953197 | | |
| | | Total | 106 | | | | | |
| | AFTER DELIVERY SERVICES | Very Low | 30 | 38 | | | | |
| | | Acceptable | 18 | 61.64 | | | | |
| | | High | 24 | 58.35 | | | | |
| | | Excellent | 34 | 59.44 | 217.43 | 0.273375339 | | |
| | | Total | 106 | | | | | |
| | RELIABILITY | Very Low | 30 | 37.03 | | | | |
| | | Acceptable | 18 | 67.72 | | | | |
| | | High | 24 | 57.48 | | | | |
| | | Excellent | 34 | 57.69 | 219.92 | 0.262322663 | 0.26840999 | 0.132 |
| | | Total | 106 | | | | | |
| 2- Purchasing | DATABASE | Very Low | 29 | 41.12 | | | | |
| | | Acceptable | 18 | 60.14 | | | | |
| | | High | 24 | 51.13 | | | | |
| | | Excellent | 35 | 61.97 | 214.36 | 0.289093114 | | |
| | | Total | 106 | | | | | |
| | PROCUREMENT PROCESS | Very Low | 29 | 39.9 | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Acceptable | 18 | 66.25 | | | | |
| | | High | 24 | 60.69 | | | | |
| | | Excellent | 35 | 53.29 | 220.13 | 0.242084223 | | |
| | | Total | 106 | | | | | |
| | MATERIAL MANAGEMENT | Very Low | 29 | 39.52 | | | | |
| | | Acceptable | 18 | 64.75 | | | | |
| | | High | 24 | 49.88 | | | | |
| | | Excellent | 35 | 61.79 | 215.94 | 0.286144299 | | |
| | | Total | 106 | | | | | |
| | PROCUREMENT DECISION | Very Low | 29 | 39.98 | | | | |
| | | Acceptable | 18 | 47.81 | | | | |
| | | High | 24 | 62.98 | | | | |
| | | Excellent | 34 | 59.81 | 210.58 | 0.284025074 | 0.27533668 | 0.135 |
| | | Total | 105 | | | | | |
| 3- Production Planning and Control | ENGINEERING DATA CONTROL | Very Low | 29 | 36.52 | | | | |
| | | Acceptable | 18 | 59.19 | | | | |
| | | High | 24 | 51.73 | | | | |
| | | Excellent | 34 | 64.68 | 212.12 | 0.304921742 | | |
| | | Total | 105 | | | | | |
| | INVENTORY CONTROL | Very Low | 29 | 38.47 | | | | |
| | | Acceptable | 18 | 67.06 | | | | |
| | | High | 24 | 51.69 | | | | |
| | | Excellent | 35 | 60.23 | 217.45 | 0.276983215 | | |
| | | Total | 106 | | | | | |
| | SHOP FLOOR CONTROL | Very Low | 29 | 40.52 | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Acceptable | 18 | 56 | | | | |
| | | High | 24 | 51.48 | | | | |
| | | Excellent | 35 | 64.36 | 212.36 | 0.303070258 | | |
| | | Total | 106 | | | | | |
| | PURCHASING | Very Low | 28 | 42.34 | | | | |
| | | Acceptable | 18 | 43.5 | | | | |
| | | High | 24 | 54.63 | | | | |
| | | Excellent | 35 | 65.3 | 205.77 | 0.317344608 | | |
| | | Total | 105 | | | | | |
| | QUALITY MANAGEMENT | Very Low | 30 | 40.45 | | | | |
| | | Acceptable | 18 | 60.89 | | | | |
| | | High | 24 | 50.98 | | | | |
| | | Excellent | 33 | 61.58 | 213.9 | 0.287891538 | 0.29804227 | 0.146 |
| | | Total | 105 | | | | | |
| 4- Manufacturing Engineering Department | PRODUCTION PLANNING | Very Low | 30 | 41.03 | | | | |
| | | Acceptable | 18 | 61.83 | | | | |
| | | High | 23 | 53.22 | | | | |
| | | Excellent | 35 | 60.09 | 216.17 | 0.277975667 | 0.27797567 | 0.136 |
| | | Total | 106 | | | | | |
| 5- Shop Floor & Quality Control | ORDER REVIEW AND RELEASE | Very Low | 31 | 40.29 | | | | |
| | | Acceptable | 17 | 52.79 | | | | |
| | | High | 24 | 50.71 | | | | |
| | | Excellent | 35 | 68.99 | 212.78 | 0.324231601 | | |
| | | Total | 107 | | | | | |
| | MAINTENANCE | Very Low | 31 | 40.08 | | | | |
| | | Acceptable | 16 | 60.38 | | | | |
| | | High | 24 | 55.31 | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Excellent | 35 | 61 | 216.77 | 0.281404253 | | |
| | | Total | 106 | | | | | |
| | QUALITY APPRAISAL | Very Low | 31 | 42.92 | | | | |
| | | Acceptable | 17 | 58.44 | | | | |
| | | High | 24 | 45.21 | | | | |
| | | Excellent | 35 | 67.69 | 214.26 | 0.315924578 | 0.30718681 | 0.151 |
| | | Total | 107 | | | | | |
| 6- Receiving | RECEIVING | Very Low | 30 | 33.75 | | | | |
| | | Acceptable | 18 | 64.06 | | | | |
| | | High | 24 | 50.17 | | | | |
| | | Excellent | 35 | 68.81 | 216.79 | 0.317403939 | | |
| | | Total | 107 | | | | | |
| | STORING | Very Low | 30 | 34.3 | | | | |
| | | Acceptable | 18 | 69.75 | | | | |
| | | High | 24 | 50.19 | | | | |
| | | Excellent | 35 | 65.4 | 219.64 | 0.297759971 | | |
| | | Total | 107 | | | | | |
| | INCOMING MATERIAL INSPECTION | Very Low | 30 | 35.75 | | | | |
| | | Acceptable | 18 | 59.47 | | | | |
| | | High | 24 | 53.63 | | | | |
| | | Excellent | 34 | 65.91 | 214.76 | 0.306900726 | | |
| | | Total | 106 | | | | | |
| | SPACE PLANNING | Very Low | 30 | 40.13 | | | | |
| | | Acceptable | 18 | 54.44 | | | | |
| | | High | 24 | 46.23 | | | | |
| | | Excellent | 35 | 70.99 | 211.79 | 0.335190519 | | |
| | | Total | 107 | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | PICKING PACKAGING AND LABELING | Very Low | 29 | 36.69 | | | | |
| | | Acceptable | 18 | 64.25 | | | | |
| | | High | 24 | 50.54 | | | | |
| | | Excellent | 35 | 63.93 | 215.41 | 0.296782879 | 0.31080761 | 0.152 |
| | | Total | 106 | | | | | |
| 7- Shipping | SHIPPING | Very Low | 29 | 40.88 | | | | |
| | | Acceptable | 18 | 52.5 | | | | |
| | | High | 24 | 54.02 | | | | |
| | | Excellent | 34 | 62.88 | 210.28 | 0.299029865 | | |
| | | Total | 105 | | | | | |
| | TRANSPORTATION | Very Low | 29 | 37.19 | | | | |
| | | Acceptable | 18 | 56.31 | | | | |
| | | High | 22 | 51.7 | | | | |
| | | Excellent | 35 | 63.73 | 208.93 | 0.305030393 | 0.30203013 | 0.148 |
| | | Total | 104 | | | | | |
| | | | | | | **Total** | 2.03978915 | 1 |

**B. Delivery Weights:**

| | | Delivery Level | N | Mean Rank | Total Mean Rank | % Emphasis of High Level by Sub-element | % Emphasis by Element | Weighted Percentage by Value Stream |
|---|---|---|---|---|---|---|---|---|
| 1- Customer Service/ Sales | ORDERP ROCESSING | Very Low | 41 | 39.94 | | | | |
| | | Acceptable | 38 | 55.78 | | | | |
| | | High | 27 | 70.89 | 166.61 | 0.425484665 | | |
| | | Total | 106 | | | | | |
| | INFORMATION EXCHANGE | Very Low | 41 | 43.48 | | | | |
| | | Acceptable | 38 | 53.88 | | | | |
| | | High | 27 | 68.19 | 165.55 | 0.411899728 | | |
| | | Total | 106 | | | | | |
| | TECHNICAL SERVICES | Very Low | 41 | 41.46 | | | | |
| | | Acceptable | 38 | 56.3 | | | | |
| | | High | 27 | 67.83 | 165.59 | 0.409626185 | | |
| | | Total | 106 | | | | | |
| | CUSTOMERSERVICEPLANNINGAND CONTROL | Very Low | 41 | 44.12 | | | | |
| | | Acceptable | 38 | 54.24 | | | | |
| | | High | 27 | 66.7 | 165.06 | 0.40409548 | | |
| | | Total | 106 | | | | | |
| | AFTERDELIVERYSERVICES | Very Low | 41 | 44.17 | | | | |
| | | Acceptable | 38 | 62.58 | | | | |
| | | High | 27 | 54.89 | 161.64 | 0.339581787 | | |
| | | Total | 106 | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ORDER ENTRY | Very Low | 41 | 44.11 | | | | |
| | | Acceptable | 38 | 49.24 | | | | |
| | | High | 27 | 73.76 | 167.11 | 0.441385913 | | |
| | | Total | 106 | | | | | |
| | CLAIMS AND CREDITS | Very Low | 40 | 37.35 | | | | |
| | | Acceptable | 38 | 59.62 | | | | |
| | | High | 27 | 66.87 | 163.84 | 0.40814209 | 0.40574512 | 0.143818787 |
| | | Total | 105 | | | | | |
| 2- Purchasing | DATABASE | Very Low | 40 | 43.86 | | | | |
| | | Acceptable | 38 | 52.67 | | | | |
| | | High | 28 | 68.39 | 164.92 | 0.414685908 | | |
| | | Total | 106 | | | | | |
| | PROCUREMENT PROCESS | Very Low | 40 | 42.79 | | | | |
| | | Acceptable | 38 | 56.01 | | | | |
| | | High | 28 | 65.39 | 164.19 | 0.398258116 | | |
| | | Total | 106 | | | | | |
| | MATERIAL MANAGEMENT | Very Low | 40 | 37.14 | | | | |
| | | Acceptable | 38 | 58.29 | | | | |
| | | High | 28 | 70.38 | 165.81 | 0.424461733 | | |
| | | Total | 106 | | | | | |
| | PROCUREMENT DECISION | Very Low | 40 | 42.24 | | | | |
| | | Acceptable | 37 | 55.04 | | | | |
| | | High | 28 | 65.68 | 162.96 | 0.403043692 | 0.41011236 | 0.145366782 |
| | | Total | 105 | | | | | |
| 3- Production Planning and Control | ENGINEERING DATA CONTROL | Very Low | 40 | 43.14 | | | | |
| | | Acceptable | 38 | 57.28 | | | | |
| | | High | 28 | 63.18 | 163.6 | 0.386185819 | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Total | 106 | | | | | |
| | INVENTORY CONTROL | Very Low | 40 | 43.94 | | | | |
| | | Acceptable | 38 | 58.37 | | | | |
| | | High | 28 | 60.55 | 162.86 | 0.371791723 | | |
| | | Total | 106 | | | | | |
| | REQUIREMENTS PLANNING | Very Low | 40 | 41.18 | | | | |
| | | Acceptable | 38 | 56.63 | | | | |
| | | High | 27 | 65.41 | 163.22 | 0.400747457 | | |
| | | Total | 105 | | | | | |
| | CAPACITY PLANNING | Very Low | 40 | 40.34 | | | | |
| | | Acceptable | 37 | 52.72 | | | | |
| | | High | 28 | 71.46 | 164.52 | 0.434354486 | | |
| | | Total | 105 | | | | | |
| | OPERATION SCHEDULING | Very Low | 40 | 39.86 | | | | |
| | | Acceptable | 38 | 57.66 | | | | |
| | | High | 27 | 65.91 | 163.43 | 0.403291929 | | |
| | | Total | 105 | | | | | |
| | SHOP FLOOR CONTROL | Very Low | 40 | 44.74 | | | | |
| | | Acceptable | 38 | 55.22 | | | | |
| | | High | 28 | 63.68 | 163.64 | 0.389146908 | | |
| | | Total | 106 | | | | | |
| | PURCHASING | Very Low | 40 | 44.79 | | | | |
| | | Acceptable | 38 | 51.71 | | | | |
| | | High | 28 | 68.38 | 164.88 | 0.414725861 | 0.40003488 | 0.141794759 |
| | | Total | 106 | | | | | |
| 4- Manufacturing Engineering Department | PRODUCT DESIGN | Very Low | 40 | 39.59 | | | | |
| | | Acceptable | 34 | 62.07 | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | High | 27 | 53.96 | 155.62 | 0.346742064 | | | |
| | | Total | 101 | | | | | | |
| | TOOLING DESIGN | Very Low | 41 | 41.71 | | | | | |
| | | Acceptable | 38 | 54.8 | | | | | |
| | | High | 28 | 70.91 | 167.42 | 0.423545574 | | | |
| | | Total | 107 | | | | | | |
| | DOCUMENTATION | Very Low | 41 | 42.2 | | | | | |
| | | Acceptable | 38 | 55.29 | | | | | |
| | | High | 28 | 69.54 | 167.03 | 0.416332395 | 0.39554001 | 0.140201525 | |
| | | Total | 107 | | | | | | |
| 5- Shop Floor & Quality Control | ORDER REVIEW AND RELEASE | Very Low | 41 | 45.74 | | | | | |
| | | Acceptable | 37 | 54.39 | | | | | |
| | | High | 28 | 63.68 | 163.81 | 0.388743056 | | | |
| | | Total | 106 | | | | | | |
| | DETAILED SCHEDULING | Very Low | 41 | 42.85 | | | | | |
| | | Acceptable | 37 | 55.16 | | | | | |
| | | High | 27 | 65.44 | 163.45 | 0.400367085 | | | |
| | | Total | 105 | | | | | | |
| | MAINTENANCE | Very Low | 41 | 42.82 | | | | | |
| | | Acceptable | 37 | 55.86 | | | | | |
| | | High | 28 | 66.02 | 164.7 | 0.40085003 | | | |
| | | Total | 106 | | | | | | |
| | QUALITYP REVENTION | Very Low | 41 | 40.85 | | | | | |
| | | Acceptable | 37 | 57.12 | | | | | |
| | | High | 28 | 67.23 | 165.2 | 0.406961259 | | | |
| | | Total | 106 | | | | | | |
| | QUALITY APPRAISAL | Very Low | 40 | 48.75 | | | | | |
| | | Acceptable | 37 | 48.14 | | | | | |
| | | High | 27 | 64.04 | 160.93 | 0.397936991 | | | |
| | | Total | 104 | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | QUALITY FAILURE | Very Low | 40 | 43.58 | | | | |
| | | Acceptable | 37 | 52.89 | | | | |
| | | High | 28 | 66.61 | 163.08 | 0.408449841 | 0.40055138 | 0.141977833 |
| | | Total | 105 | | | | | |
| 6- Receiving | RECEIVING | Very Low | 40 | 44.56 | | | | |
| | | Acceptable | 38 | 51.68 | | | | |
| | | High | 28 | 68.73 | 164.97 | 0.416621204 | | |
| | | Total | 106 | | | | | |
| | STORING | Very Low | 40 | 39.15 | | | | |
| | | Acceptable | 38 | 56.54 | | | | |
| | | High | 27 | 68.54 | 164.23 | 0.417341533 | | |
| | | Total | 105 | | | | | |
| | INCOMING MATERIAL INSPECTION | Very Low | 40 | 42.03 | | | | |
| | | Acceptable | 37 | 56.59 | | | | |
| | | High | 28 | 63.93 | 162.55 | 0.393294371 | | |
| | | Total | 105 | | | | | |
| | SPACE PLANNING | Very Low | 40 | 38.05 | | | | |
| | | Acceptable | 38 | 60.18 | | | | |
| | | High | 28 | 66.5 | 164.73 | 0.403690888 | 0.407737 | 0.14452482 |
| | | Total | 106 | | | | | |
| 7- Shipping | PICKING PACKAGING AND LABELING | Very Low | 39 | 35.82 | | | | |
| | | Acceptable | 38 | 62.24 | | | | |
| | | High | 27 | 62.89 | 160.95 | 0.390742467 | | |
| | | Total | 104 | | | | | |
| | SHIPPING | Very Low | 38 | 36.17 | | | | |
| | | Acceptable | 37 | 59.91 | | | | |
| | | High | 28 | 63.04 | 159.12 | 0.396178984 | | |
| | | Total | 103 | | | | | |
| | TRANSPORTATION | Very Low | 40 | 39.35 | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Acceptable | 36 | 55.21 | | | | |
| | | High | 28 | 67.8 | 162.36 | 0.41759054 | 0.401504 | 0.142315495 |
| | | Total | 104 | | | | | |
| | | | | | | **Total** | 2.82122475 | |

# Appendix G: Statistical Test Results for the Proposed Model Application

Table 22: Comparison between Suppliers Quality Using Traditional and Proposed Model

| Supplier | Actual Performance (PPM) | Traditional (Company) Model Score | Proposed Model Score |
|---|---|---|---|
| 1 | 6548 | 25 | 57.47 |
| 2 | 91408 | 40 | 81.1 |
| 3 | 33973 | 44 | 83.81 |
| 4 | 18214 | 53 | 80.96 |
| 5 | 333333 | 58 | 49.28 |
| 6 | 7617 | 60 | 61.01 |
| 7 | 22084 | 67 | 89.91 |
| 8 | 14048 | 67 | 64.91 |
| 9 | 26316 | 67 | 62.43 |
| 10 | 74074 | 72 | 49.02 |
| 11 | 74074 | 72 | 49.02 |
| 12 | 74074 | 72 | 49.02 |
| 13 | 74074 | 72 | 49.02 |
| 14 | 74074 | 72 | 49.02 |
| 15 | 74074 | 72 | 49.02 |
| 16 | 74074 | 72 | 49.02 |
| 17 | 13505 | 75 | 23.94 |
| 18 | 13505 | 75 | 23.94 |
| 19 | 13505 | 75 | 23.94 |
| 20 | 6539 | 78 | 80.86 |
| 21 | 699 | 53 | 71.71 |
| 22 | 2851 | 56 | 96.35 |
| 23 | 2851 | 56 | 92.32 |
| 24 | 1009 | 58 | 57.97 |
| 25 | 1461 | 62 | 78.51 |
| 26 | 1461 | 62 | 78.51 |
| 27 | 1461 | 62 | 78.51 |
| 28 | 3401 | 72 | 87.15 |
| 29 | 1641 | 80 | 91.14 |
| 30 | 1641 | 80 | 91.14 |
| 31 | 1653 | 80 | 54.66 |
| 32 | 670 | 83 | 86.74 |
| 33 | 3746 | 83 | 85.02 |
| 34 | 566 | 42 | 88.33 |
| 35 | 19 | 47 | 87.23 |
| 36 | 547 | 53 | 84.27 |
| 37 | 224 | 62 | 83.21 |
| 38 | 307 | 63 | 79.4 |
| 39 | 102 | 67 | 57.07 |
| 40 | 256 | 67 | 89.21 |

Table 22: Continued

| Supplier | Actual Performance (PPM) | Traditional (Company) Model Score | Proposed Model Score |
|---|---|---|---|
| 41 | 529 | 67 | 64.87 |
| 42 | 77 | 67 | 58.8 |
| 43 | 77 | 67 | 63.28 |
| 44 | 77 | 67 | 95.14 |
| 45 | 73 | 69 | 41.85 |
| 46 | 18 | 72 | 100 |
| 47 | 18 | 72 | 100 |
| 48 | 18 | 72 | 100 |
| 49 | 18 | 72 | 100 |
| 50 | 206 | 80 | 71.09 |
| 51 | 461 | 83 | 85.63 |
| 52 | 0 | 56 | 88.43 |
| 53 | 0 | 58 | 89.83 |
| 54 | 0 | 58 | 92.18 |
| 55 | 0 | 58 | 82.29 |
| 56 | 0 | 58 | 90.95 |
| 57 | 0 | 59 | 62.1 |
| 58 | 0 | 61 | 100 |
| 59 | 0 | 64 | 96.41 |
| 60 | 0 | 67 | 83.53 |
| 61 | 0 | 70 | 86.31 |
| 62 | 0 | 78 | 94.66 |
| 63 | 0 | 78 | 98.73 |
| 64 | 0 | 89 | 80.31 |
| 65 | 0 | 89 | 81.72 |

Table 23: Comparison between Suppliers Delivery Using Traditional and Proposed Model

| Supplier | Actual Delivery Performance | Traditional (Company) Model Score | Proposed Model Score |
|---|---|---|---|
| 1 | 99 | 67 | 91.03 |
| 2 | 91 | 56 | 90.4 |
| 3 | 100 | 58 | 77.43 |
| 4 | 100 | 64 | 95.76 |
| 5 | 100 | 69 | 72.32 |
| 6 | 100 | 70 | 81.3 |
| 7 | 97 | 72 | 99.33 |
| 8 | 97 | 72 | 99.33 |
| 9 | 97 | 72 | 99.33 |
| 10 | 90 | 72 | 82.61 |
| 11 | 97 | 42 | 61.27 |
| 12 | 90 | 42 | 61.27 |
| 13 | 90 | 42 | 61.27 |
| 14 | 90 | 42 | 61.27 |
| 15 | 90 | 42 | 61.27 |
| 16 | 90 | 42 | 61.27 |
| 17 | 90 | 42 | 61.27 |
| 18 | 100 | 67 | 98.47 |
| 19 | 94 | 100 | 85.24 |
| 20 | 93 | 33 | 85.6 |
| 21 | 83 | 67 | 86.55 |
| 22 | 81 | 67 | 85.47 |
| 23 | 86 | 56 | 78.27 |
| 24 | 88 | 100 | 58.99 |
| 25 | 88 | 58 | 54.38 |
| 26 | 88 | 58 | 54.38 |
| 27 | 88 | 58 | 54.38 |
| 28 | 88 | 58 | 54.38 |
| 29 | 83 | 0 | 73.35 |
| 30 | 82 | 33 | 72.72 |
| 31 | 88 | 78 | 94.44 |
| 32 | 82 | 33 | 87.54 |
| 33 | 89 | 89 | 79.3 |
| 34 | 89 | 89 | 82 |
| 35 | 44 | 0 | 54.5 |
| 36 | 76 | 50 | 65.17 |
| 37 | 55 | 67 | 39.47 |
| 38 | 71 | 33 | 69.93 |
| 39 | 52 | 58 | 57.14 |
| 40 | 75 | 58 | 81.3 |

Table 23: Continued

| Supplier | Actual Delivery Performance | Traditional (Company) Model Score | Proposed Model Score |
|---|---|---|---|
| 41 | 58 | 33 | 89.44 |
| 42 | 52 | 59 | 61.13 |
| 43 | 50 | 62 | 86.85 |
| 44 | 68 | 100 | 83.58 |
| 45 | 68 | 67 | 92.47 |
| 46 | 70 | 67 | 73.14 |
| 47 | 55 | 33 | 59.4 |
| 48 | 55 | 33 | 62.04 |
| 49 | 35 | 33 | 68.9 |
| 50 | 66 | 69 | 43.33 |
| 51 | 55 | 42 | 61.27 |
| 52 | 51 | 67 | 22.79 |
| 53 | 51 | 67 | 22.79 |
| 54 | 51 | 67 | 22.79 |
| 55 | 55 | 76 | 56.96 |
| 56 | 55 | 76 | 74.89 |
| 57 | 66 | 33 | 67.99 |
| 58 | 49 | 82 | 42.86 |
| 59 | 39 | 67 | 66.94 |
| 60 | 27 | 67 | 47.12 |

## A: Quality Score Results:

Correlations: Actual Performance (PPM) Traditional (Company) Model Score Proposed Model Score

| | Actual Performance (PPM) | Proposed Model Score |
|---|---|---|
| Proposed Model Score | -0.378<br>0.002 | |
| Traditional (Company) Model Score | -0.083<br>0.511 | -0.090<br>0.474 |
| | | |

**Two-Sample T-Test and CI:** Proposed Model Score**,** Traditional (Company) Model Score

Two-sample T for Proposed Model Score Vs Traditional (Company) Model Score

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| Proposed Model Score | 65 | 74.7 | 20.1 | 2.5 |
| Traditional (Company) Model Score | 65 | 66.3 | 11.9 | 1.5 |

Difference = mu (Proposed Model Score) - mu (Traditional (Company) Model Score)
Estimate for difference: 8.40400
95% CI for difference: (2.65777, 14.15023)
T-Test of difference = 0 (vs not =): T-Value = 2.90 P-Value = 0.005 DF = 103

## A: Delivery Score Results:

### Two-Sample T-Test and CI: Actual Delivery Performance, Traditional Model Score

Two-sample T for Actual Delivery Performance vs Traditional Model Score

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| Actual Delivery Performance | 60 | 75.8 | 19.8 | 2.6 |
| Traditional Model Score | 60 | 57.9 | 20.8 | 2.7 |

Difference = mu (Actual Delivery Performance) - mu (Traditional Model Score)
Estimate for difference: 17.8500
95% CI for difference: (10.5082, 25.1918)
T-Test of difference = 0 (vs not =): T-Value = 4.82 P-Value = 0.000 DF = 117

### Two-Sample T-Test and CI: Actual Delivery Performance , Proposed Model

Two-sample T for Actual Delivery Performance vs Proposed Model

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| Actual Delivery Performance | 60 | 75.8 | 19.8 | 2.6 |
| Proposed Model | 60 | 69.6 | 18.9 | 2.4 |

Difference = mu (Actual Delivery Performance) - mu (Proposed Model)
Estimate for difference: 6.16033
95% CI for difference: (-0.84436, 13.16503)
T-Test of difference = 0 (vs not =): T-Value = 1.74 P-Value = 0.084 DF = 117

### Two-Sample T-Test and CI: Traditional Model Score, Proposed Model

Two-sample T for Traditional Model Score vs. Proposed Model

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| Traditional Model Score | 60 | 57.9 | 20.8 | 2.7 |
| Proposed Model | 60 | 69.6 | 18.9 | 2.4 |

Difference = mu (Traditional Model Score ) - mu (Proposed Model)
Estimate for difference: -11.6897
95% CI for difference: (-18.8794, -4.5000)
T-Test of difference = 0 (vs not =): T-Value = -3.22 P-Value = 0.002 DF = 116

# VITA

Ammar Mohamed Aamer was born in Sana'a, Yemen. He attended high school in Yemen, where he graduated from Alahlia high School in 1992. Aamer came to the United States of America in 1994 to pursue his education. He completed his Bachelor's in 1998 and his Master's of Science in 1999 with a concentration in Industrial Engineering at the University of Tennessee. From 1998-2003, Aamer worked as a student consultant during his graduate studies. He consulted with more than 26 different companies. He also developed training materials and trained in the areas of Len Enterprise and Six Sigma.

From 2003-2005, Aamer was hired as an Instructor in the Industrial Engineering department at the University of Tennessee. He taught 2 junior level courses (Simulation Modeling, and Engineering Data Analysis & Process Improvement) and one senior level course (Process Improvement through Planned Experimentation).

Aamer is presently completing his doctorate of philosophy in Industrial Engineering at the University of Tennessee.