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# Development Of A Supplier's Delivery Time And Delivered Quality Performance Index And Assessment Of Alternative Decisions Regarding Underperforming Suppliers For The Aerospace Industry

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DEVELOPMENT OF A SUPPLIER'S DELIVERY TIME AND DELIVERED QUALITY  
PERFORMANCE INDEX AND ASSESSMENT OF ALTERNATIVE DECISIONS  
REGARDING UNDERPERFORMING SUPPLIERS FOR THE AEROSPACE INDUSTRY

by

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Bachelor of Engineering  
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Submitted in Partial Fulfillment of the Requirements

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## ABSTRACT

This study investigates current practices of supplier's delivery assessment so that a comprehensive index and a cost function model could be properly developed. Following a thorough literature review, a framework was created based on a penalty cost function that integrates both suppliers' ability to deliver on time, as well as suppliers' capability to deliver good quality. Afterward, suppliers could then be ranked and placed either in good standing, or transversely on probation. Underperforming suppliers face three potential outcomes based on current literature: (1) switching supplier, (2) increase collaboration, (3) maintaining the status quo. The decision vis-à-vis failing suppliers is based on an Analytical Hierarchy Process (AHP). This framework enables purchasing firms to assess their suppliers and take proactive measures against underachieving suppliers, which in turn also decreases the risk of supply chain disruption. Furthermore, a user interface was developed in order to help companies access the performance of their suppliers.

## PREFACE

The project was undertaken at the request of the South Carolina Department of Commerce with a goal of creating a multi-echelon cooperative supply chain network within South Carolina in order to increase the involvement of local aerospace related companies in the manufacturing of the Dreamliner (Boeing 787).

Boeing SC is seeking to reduce the supply chain risk of the Boeing 787 along with its operating costs. This reduction will be targeted by determining parts that are frequently late, and with relatively low dollar value. These parts would be sourced locally in South Carolina. This will eliminate inefficient and costly supply chain logistics (SCL) and procurement strategies by using in-depth data analysis.

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# CHAPTER 1

## INTRODUCTION

### 1.1 PREAMBLE

Supplier's performance is an important determinant of a firm's competitive advantage. According to Krause et al. (2001), cost, quality, and delivery measures are often used to conceptualize purchasing performance. Supplier's performance evaluation on operational criteria significantly influences cost, quality, delivery, and flexibility dimensions of purchasing performance in US-based manufacturing companies. This suggests that selecting suppliers on operational criteria such as cost, quality, delivery, and flexibility, as well as monitoring performance on those criteria significantly affects the desired capability of the same criteria internally (Nair et al. 2015).

The final product will not meet customer standards if poor-quality parts and materials are used (Bowersox et al. 2002). The quality of parts flowing through a manufacturing supply chain toward the original equipment manufacturer (OEM) can be viewed in several ways:

- Quality of each part overall (conforming or non-conforming)
- Quality of each part in some key quality characteristic,  $Y$
- Quality level of a 'batch' in discrete terms—percent conforming
- Quality level of a 'batch' in continuous terms—a distribution of quality, or

at least a mean  $\mu_Y$  and variance  $\sigma_Y^2$  (Batson & Mcgough, 2007)

The ideal risk avoidance strategy is taking care of risks when initially selecting the suppliers. Viswanadham and Samvedi (2013) presented the ecosystem model: it consists of the elements within the supply chain, the entities that influence goods, information, and financial flows through the supply chain. They demonstrate that performance is affected by the human, financial, infrastructural and natural resources, government actions and delivery logistics. Viswanadham and Samvedi (2013) further studied the risk contributions of all ecosystem elements and proceed to select suppliers to minimize the risk and enhance the performance.

Supplier evaluation is a multifaceted activity requiring the consideration of many important characteristics. In the case of joint evaluation of co-suppliers, whom supply the same component, previously published studies neglect stochastic co-supplier delivery timing interactions, which can affect joint co-supplier evaluations. This study presents a set of models that show this effect, explicitly considering the related interactions on joint co-supplier evaluation. The computational experiments highlight the importance of the interaction between co-suppliers and the ordering policy in supplier evaluation. It shows the ranking of co-supplier combinations that can change significantly depending on the ordering policy. This realization emphasizes the need to model supplier interactions and ordering policies more accurately in the practice of supplier evaluation and selection (Smith et al., 2006).

## 1.2 RESEARCH OBJECTIVE AND OUTLINE

The objective of this study is to develop a framework based on a current literature review and to lay the ground work for the development of a “Supplier’s Delivery Time and Delivered Quality Performance Index.” This Performance Index is first presented in section

4, and will be further developed in future work for the purpose of supplier evaluation. After assessing supplier's performance, a set of potential decisions regarding underperforming suppliers is to be studied.

Section 2 is an extensive literature review covering all topics studied in this study: (i) supplier evaluation criteria, (ii) supplier switching cost, (iii) collaborative planning, forecasting, and replenishment (CPFR), and (iv) a subsection discussing the literature review. Section 3 is the seedling of this project, where a part criticality index was first developed. Following, in section 4 a detailed framework is developed based on the literature to describe the methodology established for upcoming work starting with the development of the Performance Index and concluding with the assessment of alternatives regarding underperforming suppliers. Sections 5, 6, and 7 describe the alternatives an underperforming supplier has. Section 8 shows the user interface that was developed. Lastly, section 9 describes the findings of the study.

## CHAPTER 2

### LITERATURE REVIEW

According to the Boeing suppliers' website (Boeing Quality Management System, 2016), Boeing expects its suppliers to commit to excellent performance in terms of cost, quality and delivery. More specifically, Boeing considers capability, capacity, reliability, financial status, geographical location, performance, integrity, quality of product, delivery and overall customer-supplier relations when evaluating a potential supplier before and during the development of a purchase contract. The abovementioned reference to the Boeing suppliers' website was considered since this research is mainly focused on aerospace industries and more specifically Boeing South Carolina.

In the following literature review, three main topics are discussed: (1) suppliers evaluation criteria, (2) supplier switching cost, and (3) collaborative planning, forecasting, and replenishment (CPFR). These topics cover the process of supplier evaluation and what possible actions can be taken regarding underperforming suppliers. Additionally, current research approaches dealing with supplier's ranking and the costs involved are also explained in this study.

## 2.1 SUPPLIERS EVALUATION CRITERIA

According to Ho et al. (2010), 88% of the scientific articles related to suppliers' evaluation criteria consider quality during the process of supplier selection. Additionally, 82% of those articles regard delivery as a primary criterion in supplier selection. Due to quality and delivery maintaining the greatest significance in supplier selection, it can be stated that the cost of products supplied is not the main criterion used by customers when identifying their suppliers. Chan and Chan (2004) define the most important criteria for supplier selection in the semiconductor assembly equipment manufacturing industry as follows: quality, delivery, and cost. These were identified using the Analytical Hierarchy Process (AHP), which is shown in Figure 2.1.

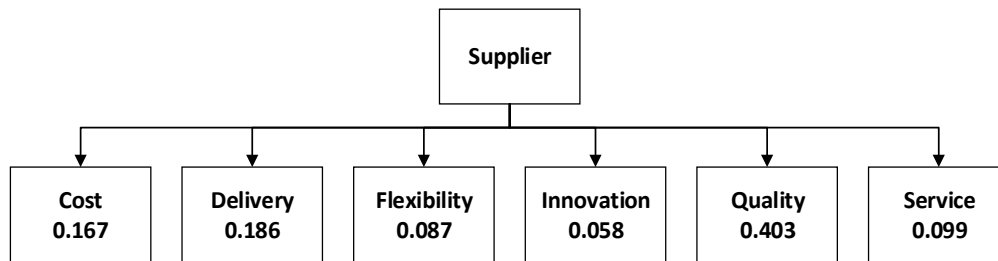


Figure 2.1 AHP criteria priorities for supplier selection in the semiconductor assembly equipment manufacturing industry (Chan & Chan, 2004)

In addition, Abdolshah (2013) ranked suppliers based on a literature review of 21 articles, where quality was ranked first among supplier evaluation criteria, followed by delivery and performance history. Founded on the frequency of appearance in previous studies, the primary criteria utilized in the supplier selection process is summarized in the diagram below (Inemek & Tuna, 2009).



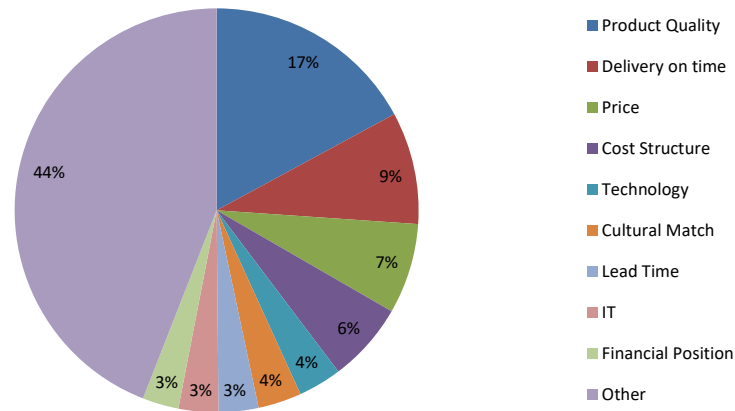


Figure 2.2 Frequency of supplier selection criteria in scientific articles (Inemek & Tuna, 2009)

Based on the literature, and according to Şen et al. (2008), the main criteria used when selecting suppliers are product quality, delivery, and service. The tables shown below identify the different attributes mentioned in previous scientific articles. These attributes are divided into 4 main categories: product quality, service quality, process quality, and delivery. With respect to prime literary resources, (i) product quality and (ii) product delivery are clearly the most prevalent attributes when evaluating a supplier (Chan & Chan, 2004; Inemek & Tuna, 2009). The upcoming subsections will dive into these two criteria in order to understand them more and see how literature is trying to quantify them.

### 2.1.1 Product Quality Criteria

The primary attributes of product quality discussed by Ho et al. (2010) are listed below in Table 2.1 Supplier evaluation criteria based on product quality. These attributes are directly related to the proportion of defects and quality of incoming deliveries.

Table 2.1 Supplier evaluation criteria based on product quality

Attributes	Definition	Metrics
------------	------------	---------

Parts per million (PPM)	PPM means one (defect or event) in a million or 1/1,000,000 (Wheeler, 2015)	PPM = number of defective parts total number of parts *106
Compliance with quality	Compliance is simply putting out sufficient effort to meet minimum requirements and measuring compliance against the law or standards. (Speer, 2014)	NA
Percentage of products or items rejected upon inspection (Acceptance Sampling)	A form of inspection applied to lots or batches of items before or after a process to judge conformance with predetermined standards or specifications. (Stevenson et al., 2015)	% of items rejected upon inspection = number of rejected items inspection batch size *100
Reliability of quality	“Reliability is usually referred to as the quality over time” (He et al., 2016)	Reliability = Pr (T > t) = Pr(Exterior and interior defects caused no failure during time t)
Costs of quality (CoQ)	CoQ is cost incurred in the design, implementation, operation and maintenance of an organization's quality management system. (Youngdahl, 1997)	NA

### 2.1.2 Product Delivery Criteria

Attributes that fall under this criterion include appropriateness of the delivery date, compliance with due date, delivery mistakes, number of shipments to arrive on time, and percentage of orders shipped to buyer on or before original promised ship date (Ho et al., 2010).

Table 2.2 Supplier evaluation criteria based on delivery

Attributes	References
Appropriateness of the delivery date	Ho et al., 2010; Hashemi et al., 2015 ; Simić et al., 2014 ; Onder & Kabadayi, 2015
Compliance with due date	Ho et al., 2010; Hashemi et al., 2015 ; Amindoust & Saghafinia, 2013 ;
Delivery mistakes	Ho et al., 2010
Number of shipments to arrive on time	Ho et al., 2010; Hashemi et al., 2015 ; Azadi et al., 2015
Percentage of orders shipped to buyer on or before original promised ship date	Ho et al., 2010

Concluding that the evaluation of suppliers is primarily derived from the product's quality at time of delivery (delivery quality) and the delivery time. The development of an

index founded upon these two attributes represent the performance of a supplier. This performance index is presented as the “*Supplier’s Delivery Time and Delivered Quality Performance Index.*”

## 2.2 SUPPLIER SWITCHING COST

In regards to an underperforming supplier, action to improve the status quo (increase productivity) is essential. For such an unfortunate circumstance, companies are confronted with deciding whether or not to take action; either by terminating the relationship and looking elsewhere for the product, or by increasing collaboration with the supplier. Both possibilities must be evaluated carefully due to related costs. The first option results in what is known as supplier switching costs, i.e. monetary or nonmonetary costs accumulated when switching from one supplier to another (Colwell et al., 2011).

Burnham et al. (2003) defines switching costs as the onetime costs that customers associate with the process of switching from one provider to another. Different facets of switching costs that a customer might encounter are: economic risk costs, evaluation costs, learning costs, setup costs, benefit loss costs, monetary loss costs, personal relationship loss costs, and brand relationship loss costs. Further study has then categorized these facets into three main types: procedural switching costs, financial switching costs, and relational switching costs (Vigolo & Cassia, 2014; Burnham et al., 2003; Vasudevan et al., 2006). Definitions of these types and facets are provided below:

### 2.2.1 Procedural Switching Costs

Procedural Switching Costs primarily involve the expenditure of time and effort.

- Economic Risk Costs: Uncertainty when obtaining a new supplier, due to insufficient information. Bettman developed a six-dimensional construct

conceptualizing consumption risk, three of which are relevant: performance risk, financial risk, and convenience risk (Bettman, 1973).

- **Evaluation Costs:** Before making the decision to switch, time and effort is devoted to searching and analysing potential providers. Collecting information about the suppliers is needed, as well as mental effort to analyse such information, in order to make an informed decision.
- **Learning Costs:** When switching to a new provider, there are skills and knowledge that must be acquired to effectively use the new product. Time and effort in relation to developing these new skills and knowledge are necessities when adapting to a new supplier.
- **Setup Costs:** Initiating a new relationship and/or developing the essentials to use a new product require time and effort. In relation to services, an abundance of information is exchanged between the new provider and the customer concerning selling risks and the customers' specific needs.

### *2.2.2 Financial Switching Costs*

Financial Switching Costs involve the loss of financially quantifiable resources.

- **Benefit Loss Costs:** Terminating a contract with a firm is likely to imply that the economic benefits that were once accumulated are now null and void. Discounts or benefits once acquired from the original supplier are now lost, due to the fact that they do not transfer.
- **Monetary Loss Costs:** Payments that are a one-time commitment when initially switching suppliers, not including the purchase of the new product. These expenditures are usually deposits and initiation fees. In addition,

monetary losses could be due to the consumer having to replace co-assets and sub-assets in relation with the new product.

### *2.2.3 Relational Switching Cost*

Relational Switching Costs involve psychological or emotional discomfort due to the loss of identity and the breaking of bonds.

- **Personal Relationship Loss Costs:** Bonds of identification are formed with the supplier's employees, thus, upon switching, those bonds break. The consumer developed a level of comfort with these employees, and that is not readily available with the new provider.
- **Brand Relationship Loss Costs:** Bonds of identification are formed with incumbent suppliers, thus, upon switching, those bonds break. Brand- or company- based relational bonds are formed due to customers drawing meaning from their associations, which became a part of their identity.

The supplier switching cost consists of numerous expenses developed during the process of terminating a supplier and hiring a new one. Although, it is important to remember that not every facet is applicable for each supplier-switching situation, Zhang et al. (2015) stated that the total switching cost is very much reliant on the quantity switched. While they have adequately supported this claim, their classifications of the switching costs are minimal. Zhang et al. (2015) identified setup costs, learning costs, variational costs, as well as the compensation for the incumbent supplier, as the main concerns relating to switching cost. Noting that the compensation for the incumbent supplier can be categorized under "monetary costs" (Burnham et al., 2003), the payment for the incumbent supplier arises when a firm desires to cancel their contract. A buyer-supplier relationship begins as

soon as a contract is signed. Cancelling such a contract and switching suppliers can be costly due to cancellation fees. These are onetime fees, which increase with the product quantity and must be paid to the incumbent before any switch can be made. In some cases, companies only desire to shift some of their demand to another provider. When that occurs, the incumbent supplier adjusts the contract due to a loss of “Economies of Scale”, i.e. they require the firm to pay a higher per unit price for the remaining products. Based on these considerations it is reasonable to claim that switching costs are volume-dependent. Zhang et al. (2015) also identified variational costs as an additional switching cost factor. Variational costs develop due to the location difference of the entrant supplier; the costs include the variation of transportation cost, communication cost, etc. (Hu et al., 2012).

Jones et al. (2002) states that when switching a provider the switching cost is comprised of six primary cost dimensions:

- Lost performance: costs derived from the termination of a relationship where benefits and perquisites were previously formed
- Uncertainty: costs formed due to the perceptions of risk surrounding the performance of an unknown or untested supplier
- Pre-switching search and evaluations: costs resulting from the time and effort involved in searching for available alternatives and evaluating their viability prior to switching
- Post-switching behavioural and cognitive: costs formed due to the time and effort needed to acquire and adapt to new procedures and routines
- Setup: costs derived from the perceived time and effort to relay needs and information to the provider subsequent to switching

- Sunk: costs due to the non-recoupable time, money, and effort invested in establishing and maintaining a relationship

These dimensions resemble the facets previously defined by Burnham et al. (2003) and Zhang et al. (2015). Due to the resemblance, these cost factors can be combined and categorized. The resulting switching cost classifications are procedural, search & evaluation, learning, setup, economic risk, financial, benefit loss, monetary loss, relational (psychological), personal relationship loss, brand relationship loss, and variational. Table 2.3 catalogues these classifications from prior switching cost typologies developed in literature.

Table 2.3 Review of switching cost typology in literature

Author	Switching Cost Typology	Classification
Klempere, P. (1995)	A. Need for compatibility with existing equipment	A- Setup
	B. Transaction costs of switching suppliers	B- Monetary Loss
	C. Costs of learning to use new brands	C- Learning
	D. Uncertainty about the quality of untested brands	D- Economic Risk
	E. Discount coupons and similar devices	E- Benefit Loss
	F. Psychological costs of switching, or non-economic "brand-loyalty"	F- Relational (Psychological) and Brand Relationship Loss

Jones et al. (2002)	<p>A. Continuity costs:</p> <ul style="list-style-type: none"> <li>a. Lost performance costs</li> <li>b. Uncertainty costs</li> </ul> <p>B. Learning costs:</p> <ul style="list-style-type: none"> <li>a. Pre-switching search and evaluation costs</li> <li>b. Post-switching behavioural and cognitive costs</li> <li>c. Setup costs</li> </ul> <p>C. Sunk costs</p>	<p>A- Benefit Loss</p> <ul style="list-style-type: none"> <li>a- Benefit Loss</li> <li>b- Economic Risk</li> </ul> <p>B- Learning</p> <ul style="list-style-type: none"> <li>a- Search &amp; Evaluation</li> <li>b- Personal Relationship Loss and Variational</li> <li>c- Setup</li> </ul> <p>C- Relational (Psychological)</p>
Burnham et al. (2003)	<p>A. Procedural switching costs:</p> <ul style="list-style-type: none"> <li>a. Economic risk costs</li> <li>b. Evaluation costs</li> <li>c. Learning costs</li> <li>d. Setup costs</li> </ul> <p>B. Financial switching costs:</p> <ul style="list-style-type: none"> <li>a. Benefit loss costs</li> <li>b. Monetary loss costs</li> </ul> <p>C. Relational switching costs, or psychological cost:</p> <ul style="list-style-type: none"> <li>a. Personal relationship loss costs</li> <li>b. Brand relationship loss costs</li> </ul>	<p>A- Procedural</p> <ul style="list-style-type: none"> <li>a- Economic Risk</li> <li>b- Search &amp; Evaluation</li> <li>c- Learning</li> <li>d- Setup</li> </ul> <p>B- Financial</p> <ul style="list-style-type: none"> <li>a- Benefit Loss</li> <li>b- Monetary Loss</li> </ul> <p>C- Relational (Psychological)</p> <ul style="list-style-type: none"> <li>a- Personal Relationship Loss</li> <li>b- Brand Relationship Loss</li> </ul>



Vasudevan et al. (2006)	<p>A. Procedural switching costs</p> <p>B. Financial switching costs</p> <p>C. Relational switching costs:</p> <p style="padding-left: 20px;">a. Personal relationship loss costs</p> <p style="padding-left: 20px;">b. Brand relationship loss costs</p> <p>D. Setup costs</p> <p>E. Termination costs, including the relationship specific investments that have no value outside the relationship</p>	<p>A- Procedural</p> <p>B- Financial</p> <p>C- Relational (Psychological)</p> <p style="padding-left: 20px;">a- Personal Relationship Loss</p> <p style="padding-left: 20px;">b- Brand Relationship Loss</p> <p>D- Setup</p> <p>E- Benefit Loss and Monetary Loss</p>
Whitten & Wakefield (2006)	<p>A. Uncertainty costs</p> <p>B. Post-switching behavioural and cognitive costs</p> <p>C. Setup costs</p> <p>D. Hiring and retraining costs</p> <p>E. System upgrade costs</p> <p>F. Lost benefit costs</p> <p>G. Pre-switching search and evaluation costs</p> <p>H. Sunk costs</p>	<p>A- Economic Risk</p> <p>B- Personal Relationship Loss and Variational</p> <p>C- Setup</p> <p>D- Setup and Learning</p> <p>E- Monetary Loss</p> <p>F- Benefit Loss</p> <p>G- Search &amp; Evaluation</p> <p>H- Relational (Psychological)</p>
Colwell et al. (2011)	<p>A. Time costs</p> <p>B. Effort costs</p> <p>C. Efficiency costs</p> <p>D. Training costs</p> <p>E. Knowledge costs</p> <p>F. Social connection costs</p>	<p>A- Procedural</p> <p>B- Procedural</p> <p>C- Setup and Variational</p> <p>D- Learning</p> <p>E- Learning</p> <p>F- Relational (Psychological)</p>

Phua, Y.S. (2011)	<p>A. Supplier search costs to identify and select suppliers</p> <p>B. Contracting costs to negotiate and write contracts</p> <p>C. Transition costs to oversee the transfer of operations and assess supplier processes prior to contract execution</p> <p>D. Monitoring and enforcement costs to ascertain compliance with contractual obligations and to sanction noncompliant behaviour</p> <p>E. Adjustment costs to correct for any subsequent misalignment</p> <p>F. Costs to build and maintain trust</p>	<p>A- Search &amp; Evaluation</p> <p>B- Monetary Loss</p> <p>C- Monetary Loss and Variational</p> <p>D- Setup and Learning</p> <p>E- Setup and Economic Risk</p> <p>F- Relational (Psychological)</p>
Barroso & Picón (2012)	<p>A. Benefit loss costs</p> <p>B. Personal relationship loss costs</p> <p>C. Economic risk costs</p> <p>D. Search and evaluation costs</p> <p>E. Setup costs</p> <p>F. Monetary loss costs</p>	<p>A- Benefit Loss</p> <p>B- Personal Relationship Loss</p> <p>C- Economic Risk</p> <p>D- Search &amp; Evaluation</p> <p>E- Setup</p> <p>F- Monetary Loss</p>

Hu et al. (2012)	<ul style="list-style-type: none"> <li>A. Searching costs</li> <li>B. Setup costs</li> <li>C. Learning costs</li> <li>D. Variational costs</li> <li>E. Compensation for the incumbent supplier</li> <li>F. Procedural costs</li> <li>G. Financial costs</li> <li>H. Relationship loss costs</li> <li>I. Information sharing loss costs</li> </ul>	<ul style="list-style-type: none"> <li>A- Search &amp; Evaluation</li> <li>B- Setup</li> <li>C- Learning</li> <li>D- Variational</li> <li>E- Monetary Loss</li> <li>F- Procedural</li> <li>G- Financial</li> <li>H- Relational (Psychological)</li> <li>I- Personal Relationship Loss</li> </ul>
Vigolo & Cassia (2014)	<ul style="list-style-type: none"> <li>A. Procedural switching costs: <ul style="list-style-type: none"> <li>a. Economic risk costs</li> <li>b. Evaluation costs</li> <li>c. Learning costs</li> <li>d. Setup costs</li> </ul> </li> <li>B. Financial switching costs: <ul style="list-style-type: none"> <li>a. Benefit loss costs</li> <li>b. Monetary loss costs</li> </ul> </li> <li>C. Relational switching costs: <ul style="list-style-type: none"> <li>a. Personal relationship loss costs</li> <li>b. Brand relationship loss costs</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>A- Procedural <ul style="list-style-type: none"> <li>a- Economic Risk</li> <li>b- Search &amp; Evaluation</li> <li>c- Learning</li> <li>d- Setup</li> </ul> </li> <li>B- Financial <ul style="list-style-type: none"> <li>a- Benefit Loss</li> <li>b- Monetary Loss</li> </ul> </li> <li>C- Relational (Psychological) <ul style="list-style-type: none"> <li>a- Personal Relationship Loss</li> <li>b- Brand Relationship Loss</li> </ul> </li> </ul>
Hu et al. (2014)	<ul style="list-style-type: none"> <li>A. Investigation, analysis, and evaluation costs</li> <li>B. Setup costs</li> <li>C. Learning costs</li> <li>D. Variation of transportation costs</li> <li>E. Compensation for the incumbent supplier</li> </ul>	<ul style="list-style-type: none"> <li>A- Search &amp; Evaluation</li> <li>B- Setup</li> <li>C- Learning</li> <li>D- Variational</li> <li>E- Monetary Loss</li> </ul>

Zhang et al. (2015)	A. Search and analysis costs	A- Search & Evaluation
	B. Setup costs	B- Setup
	C. Learning costs	C- Learning
	D. Variational costs	D- Variational
	E. Compensation for the incumbent supplier	E- Monetary Loss

The applied literature established multiple switching cost typologies, from which we drew our cost factor classifications. Table 2.3 catalogues the associated cost factors from these investigated typologies. The literature review in Table 2.4 is constructed as a tabulated structure of the classifications made per research article in Table 2.3. The intention of Table 2.4 is to provide an easy assessment to justify the chosen switching cost classifications.

Table 2.4 Classification assessment

	<b>Procedural</b>	<b>Search &amp; Evaluation</b>	<b>Learning</b>	<b>Setup</b>	<b>Economic Risk</b>	<b>Financial</b>	<b>Benefit Loss</b>	<b>Monetary Loss</b>	<b>Relational (Psychological)</b>	<b>Personal Relationship Loss</b>	<b>Brand Relationship Loss</b>	<b>Variational</b>
Klemperer, P. (1995)			*	*	*		*	*	*		*	
Jones et al. (2002)		*	*	*	*		*		*	*		*
Burnham et al. (2003)	*	*	*	*	*	*	*	*	*	*	*	
Vasudevan et al. (2006)	*			*		*	*	*	*	*	*	
Whitten & Wakefield (2006)		*	*	*	*		*	*	*	*		*
Colwell et al. (2011)	*		*	*					*			*
Phua, Y.S. (2011)		*	*	*	*			*	*			*
Barroso & Picón (2012)		*		*	*		*	*		*		
Hu et al. (2012)	*	*	*	*		*		*	*	*		*

Vigolo & Cassia (2014)	*	*	*	*	*	*	*	*	*	*	*	*
Hu et al. (2014)		*	*	*				*				*
Zhang et al. (2015)		*	*	*				*				*
<b>Total</b>	<b>5</b>	<b>9</b>	<b>10</b>	<b>12</b>	<b>7</b>	<b>4</b>	<b>7</b>	<b>10</b>	<b>9</b>	<b>7</b>	<b>4</b>	<b>7</b>

Based on the acknowledged cost factors within each literary article in Table 4, it is evident that our switching cost classifications are supported throughout literature. The primary factors identified as procedural, financial, and relational (psychological) are derived from research conducted by Burnham et al. (2003). These switching cost types encompass the majority from which supplier switching costs originate. This is supported due to the fact that other researchers identified them within their switching cost typologies. In the case they were not identified, the researchers' cost factors included their sub-facets. Procedural cost sub-facets are search & evaluation, learning, setup and economic risk; financial cost sub-facets are benefit loss and monetary loss; and relational (psychological) cost sub-facets are personal relationship loss and brand relationship loss. Lastly, our final classified switching cost factor, variational, is also supported throughout literature. This is evident by the 7 out of 12 typologies that include such variational costs. As a result, Table 4 justifies the initial cost factors constructed by Burnham et al. in 2003, as well as variational costs identified by Zhang et al. in 2015 as implicated costs when switching a supplier.

### 2.3 COLLABORATIVE PLANNING, FORECASTING, AND REPLENISHMENT

#### (CPFR)

When a supplier is underperforming, it becomes important for the customer to create a plan of action regarding the supplier. In order to do this, the customer is faced with two choices, either commit to improving the collaboration with the supplier or switch

supplier. Each of these tasks comes with a cost and the one with the lower cost should be chosen. In this study, we will create a model that will help determine the cost to a retailer of implementing Collaborative Planning, Forecasting, and Replenishment (CPFR). To do this we will calculate the time it takes to make the equivalent improvements of switching suppliers through the improvement of CPFR. The time will be calculated using a system dynamics and supply chain research.

### 2.3.1 CPFR Background

**Definition.** Collaborative Planning, Forecasting, and Replenishment (CPFR) is one of the newest and highly acknowledged approaches to inventory management, and provides a holistic method to improving supply chain integration (Varma & Bansal, 2010). It was created in 1998 by Voluntary Interindustry Commerce Solutions (VICS) committee and has the goal of increasing collaboration through improved planning, forecasting, and replenishment processes by increasing data and forecast sharing based on customer demand (Voluntary Interindustry Commerce Solutions, 2007). The basic process to achieve these results was laid in steps in that can be summarized by (1) creating a front-end agreement, (2) generating a joint business plan, (3) development of demand forecasts, (4) sharing forecasts, and (5) inventory replenishment (Fliedner, 2003).

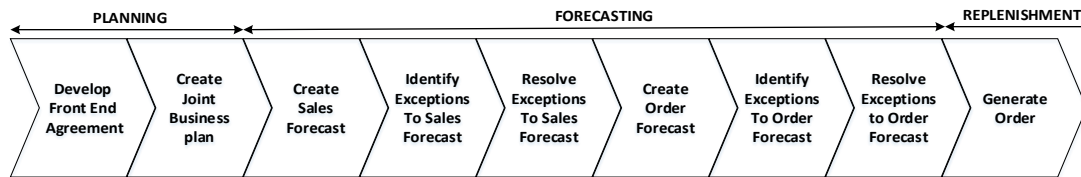


Figure 2.3 Activities in the CPFR process (Danese, 2007)

**Benefits.** The basic premise of CPFR is that by allowing the supply chain to maximize its profits as a whole, each individual member will also maximize their profits.

The benefits help both the supplier and vendor's companies increase productivity as positive business practices are at the base of CPFR (Voluntary Interindustry Commerce Solutions, 2007). Some of the most common benefits:

- Retailer benefits: increased sales and higher service levels
- Manufacturer benefits: higher order fill rates and faster cycle times
- Shared benefits: improved forecast accuracy and lower system expenses (Fliedner, 2003)

In addition, CPFR consistently shows a larger increase in supply chain performance than other standard practices (Danese, 2007). When Ryu (2006) conducted a study between consignment, VMI 1, VMI 2 and CPFR, CPFR was found to improve supply chain profit most significantly. Disney et al. (2004) demonstrated using a Beer game simulation that CPFR helped to reduce the bullwhip more significantly than VMI (Ryu, 2006; Fliender, 2003; Disney et al., 2004). Campo et al. (2003) pointed out that inadequate inventory would reduce the amount of future purchase from the customers.

Table 2.5 Typical CPFR benefits (Sheffi, 2002)

<b>Retailer Benefits</b>	<b>Typical Improvement</b>
Better Store Shelf Stock Rates	2% to 8%
Lower Inventory Levels	10% to 40%
Higher Sales	5% to 20%
Lower Logistics Costs	3% to 4%
<b>Manufacturer Benefits</b>	<b>Typical Improvement</b>
Lower Inventory Levels	10% to 40%
Faster Replenishment Cycles	12% to 30%

Higher Sales	2% to 10%
Better Customer Service	5% to 10%

**Implementation.** There are many different levels, types, and intensities of implementation. Depending on the partners involved, the roles in creating forecasts and orders will be affected (Voluntary Interindustry Commerce Solutions, 2007). Many companies begin with a pilot program, and depending on the success decide to expand CPFR to other products and suppliers (Panahifar et al., 2015). Companies and researchers are also continuously improving the base framework provided for CPFR. Several improvements that have been made are IT software, modelling techniques, and identification of key inhibitors and enablers.

**Inhibitors.** Though the rewards of CPFR can be great, implementation is not an easy task (Barratt & Oliveira, 2001; Danese, 2007). Despite CPFR's initial excitement, relatively few companies have implemented CPFR in their supply chains (Barratt & Oliveira., 2001). This is largely due to inhibiting factors and barriers, which can be divided into four categories: managerial, process, technological, and cultural (Panahifar et al., 2014). In addition, the barriers can take the form of either intra-company or inter-company issues (Panahifar et al., 2015). The largest inhibiting factors found by Panahifar et al. (2014) using ISM analysis are lack of leadership, lack of technical expertise, difficulties in information sharing and lack of compatibility of partner's abilities. Barret et al. (2001) found through a survey that trust, scalability, and lack of software were some of the key barriers. Lastly, Terwiesch et al. (2005) used an empirical analysis to conclude that even when the best practices are put in place, CPFR can still fail due to forecast volatility.



**Enablers.** Unlike inhibitors, enabling factors help with the implementation of CPFR in supply chains. There has been considerable research and case studies to identify the factors that allow for the practical applications of CPFR (Voluntary Interindustry Commerce Solutions, 2007; Barratt & Oliveira, 2001; Panahifar et al., 2015; Fu et al., 2010; Panahifar et al., 2015(2)). These enablers are interconnected and as they improve, other enablers will improve, as will the supply chain as a whole. Panahifar et al. (2015) uses a survey sent to many of the leading experts in CPFR implementation to find, rank, and tier the main enablers. It is found that competition pressure is the most significant enabler and drives factors such as, senior management support and clear communication planning. In another study, Fu et al. (2010) implemented fuzzy AHP analysis and a questionnaire to determine the key enablers regarding technology, organization, and environment.

### *2.3.2 Models/Simulations of CPFR*

There have been numerous attempts at modelling the effects of CPFR on a supply chain system to compare different collaboration models and calculate the potential benefits of CPFR. Several models investigate the effects of increased collaboration on reducing bullwhip effects (Disney et al., 2004; Ryu, 2006). Others compare different collaboration techniques and provide monetary cost reductions according to different variables in simulations (Disney et al., 2004; Sari, 2008; Ryu, 2006). These simulations are important (1) to validate our choice in using CPFR to increasing collaboration and evaluating a cost function and (2) to understand the different modelling techniques and variables used in calculating CPFR performance.

Aviv (2001, 2002, and 2007) has made significant contributions to the modelling of CPFR. In 2001, Aviv looks at a cooperative, two stage supply system consisting of a retailer and supplier. The comparison is made between a supply chain where inventory and forecast information is only known locally vs. a single forecast system being jointly maintained. Aviv uses lead times, holding costs, backorder demand to calculate the total costs to the partners. Aviv found that the absolute benefits of CPFR are a cost reduction of 19.43% and the marginal benefits are 9.56% (Aviv, 2001). Aviv continued with this work in 2002 by presenting a similar simulation using a demand that evolves an auto-regressive time series. The research brings a sharper focus showing that Vendor Managed Inventory (VMI) and Collaborative Forecasting (CF) programs become more important as the demand process is correlated across periods (Aviv, 2002). According to Torkul et al. (2016), many factors can increase the inventory holding costs: (1) variation of demand, (2) large safety stock. Aviv investigates CF partnerships where the supply chains are capacity constrained. The model addresses three specific components: (1) co-evolution of demand and information, (2) supply chain scorecard, and (3) production and inventory policies. The model demonstrates how the benefits of CF can be unevenly split (Aviv, 2001). Finally, in 2007 Aviv creates another simulation that investigates the optimal relative explanatory power of the partners (Aviv, 2007).

Disney et al. (2004) investigates how the different collaboration models can work together with the growth of e-commerce. The Beer Game he developed is used to calculate the impact of the bullwhip effect using five supply chains types created from a combination internet, communications technologies (ICT), and collaboration methods. The model uses single and aggregate product types, and demonstrates that CPFR can reduce the bullwhip

effect and the e-shopping supply chain, where all information is immediately shared with all parties, has the greatest reduction in the bullwhip effect.

Sari (2008) explores the appropriate level of collaboration between partners depending on business conditions. A simple model is created using a traditional supply system and two that involve VMI and CPFR. The findings demonstrate that the benefits are always greater using CPFR, but sometimes the additional resources do not justify the improvements.

Ryu (2006) compared five different supply chains methods (traditional, consignment, VMI1, VMI2, and CPFR) to find the largest reduction in total costs. At first an analytical approach is used to determine profit maximization. CPFR showed the largest supply chain profit, though the benefits were skewed towards the supplier. Then, a supply chain system model was implemented to look at how six different independent variables, one of which was coordination mechanism, affected the dependent variables: economic measure, customer satisfaction, and the bullwhip effect. In all, it was found that CPFR produces the most supply chain profit, but collaboration mechanisms that focused wholly on profit maximization may lead to a decrease in performance regarding variables such as customer service and the bullwhip effect.

#### 2.4 LITERATURE REVIEW SUMMARY AND DISCUSSION

Based on the literature regarding suppliers' evaluation criteria, it was established that product quality and product delivery are the primary criteria used to evaluate suppliers on their performance. In this study, the proportion of defective supplied parts by supplier and lateness of deliveries will be used in the development of the suppliers' Delivery Time and Delivered Quality Performance Index.

The facets developed by Burnham et al. (2003) are the basis on which our supplier switching cost research is derived. It is evident from the literature review in Table 4 that the three main switching cost types (procedural, financial, and relational) encompass the majority from which supplier switching costs originate. Some authors identify the main types as a cost factor, while others identify the specific facets that form these types. Furthermore, the literature identified variational as an additional cost factor. Variational costs were unable to be classified within any previously defined switching cost factor, thus the decision to include it as its own dimension. The resulting cost factors from which the supplier switching cost is developed are procedural, financial, relational, and variational costs. It is important to state that in every supplier-switching situation, not every type and/or facet is appropriate to account for, but with that said, the majority of these costs will arise in any supplier switching transition.

CPFR is realized to be an effective method to enhance not only collaboration with suppliers but also suppliers' performance.

#### *2.4.1 Research Framework*

After understanding the current practices utilized for supplier assessment and the valuation of possible actions taken regarding underperforming suppliers, the below research framework (Figure 2.4) was developed. This framework will be applied in future work, where focus will be on the development of models for supplier evaluation and decision-making.

The framework first identifies the development of the Supplier's Delivery Time and Delivered Quality Performance Cost Function. Established from this cost function, suppliers will be ranked in order to classify the bottom 5%. The bottom 5% will then be

placed under review and the suppliers' switching cost and the cost of collaborative planning, forecasting and replenishment (CPFR) will be developed, so that an easy comparison can be made between these two alternatives and the current cost.. The next step will be to decide whether to switch suppliers, increase collaboration, or maintain the status quo. In order to make such a decision an analytical hierarchy process (AHP) will be developed to choose between the alternatives based on cost, feasibility, and management willingness.

Based on the literature review, it became evident that the main attributes implemented when assessing suppliers are the delivery time and delivered quality. Hence, the introduction of an index founded upon these two attributes; recognized as the "Supplier's Delivery Time and Delivery Quality Performance Index." This index represents the performance of suppliers and is necessary for further development into supplier evaluation. When faced with an underperforming supplier, management evaluates whether to switch their demand to a new supplier or to increase collaboration with the incumbent supplier, so that the current performance may be enhanced. This decision is primarily prompted by the cost of each alternative.

Cost models for these alternatives are necessary for management to come to an informed decision, one to calculate the potential cost of switching suppliers and the other to calculate the potential cost of collaborative planning. These two models adjacent to the current cost would aid in the assessment of the alternatives: (1) maintain the status quo, (2) switch supplier and (3) increase collaborative planning, forecasting and replenishment.

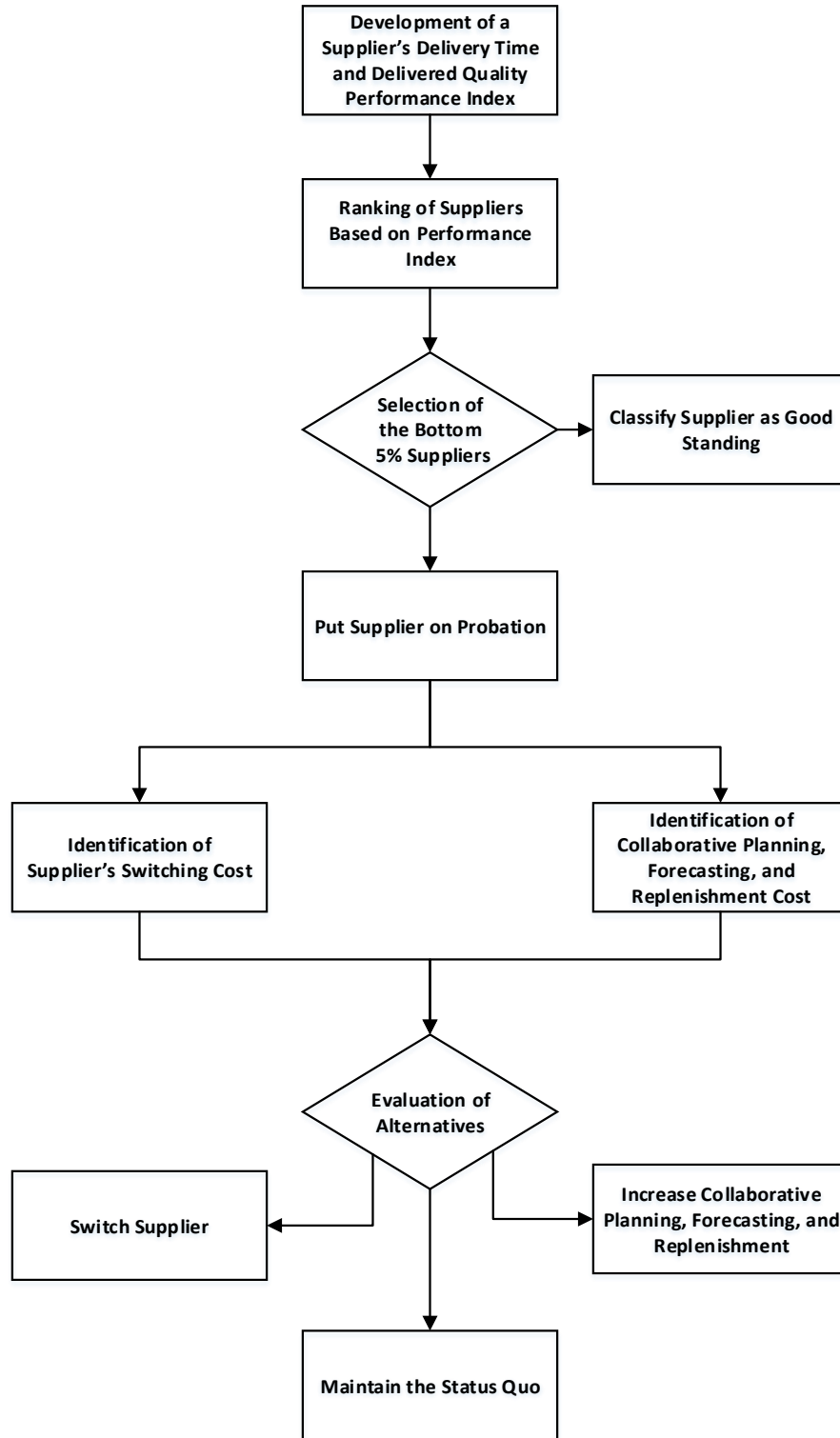


Figure 2.4: Research Framework

The current evaluation process norm is to study the alternatives and then make an “educated guess,” a decision primarily based on intuition. A more reliable evaluation system is possible by further assessment using an analytical evaluation using these cost models accompanied by the Analytical Hierarchy Process (AHP). The Analytical Hierarchy Process (AHP) is a theory developed in 1977 by Thomas L. Saaty based on pairwise comparison and connoisseurs’ judgments to generate the priority scale (Saaty, 2008). AHP is a multi-criteria decision making tool providing an approach to identify interaction among multiple decision factors (Barker & Zabinsky, 2011). In future work, the AHP will be an integral part in the assessment of supplier alternatives, along with a multi-criteria perspective in the cases where cost is not the only criterion to consider.

## CHAPTER 3

### DEVELOPMENT OF A PART CRITICALITY INDEX IN INVENTORY MANAGEMENT

As businesses grow in size, inventory management analysis is becoming more important to increase efficiency and profits by reducing backorders and surpluses. Part of this change is a result of limited in house production of parts and a focus on final assembly, which creates a need to evaluate part criticality in the supply chain. The two fundamental problems that arise from a poor supply chain are a large backlog and surplus. The percentage of items backordered and the number of backorder days are important measures of the quality of a company's customer service and the effectiveness of its inventory management. On the other hand, if the business has an inventory surplus it will incur costs to store, track and insure inventory. Therefore, creating an inventory management system that ranks part criticality based on their creation of backorders and surpluses can create significant financial and customer service improvements for a business.

Two common inventory-management strategies are the just-in-time (JIT) method, where companies plan to receive items as they are needed rather than maintaining high inventory levels, and materials requirement planning (MRP), which schedules material deliveries based on sales forecasts. JIT means that manufacturers and retailers keep only what they need to produce and sell products in inventory, which reduces storage and



insurance costs, as well as the cost of liquidating or discarding unused, unwanted inventory. To balance this style of inventory management, manufacturers and retailers must work together to monitor the availability of resources on the manufacturer's end and consumer demand on the retailer's. The MRP inventory management method is sales-forecast dependent. This means that manufacturers must have accurate sales records to enable accurate planning of inventory needs and to communicate those needs with materials suppliers in a timely manner. These methods are geared towards supply chain management and are concerned with when certain products are to be ordered but do not incorporate in what order and whether they should be ordered. Overall, these methods view all parts as having equal importance and miss the part criticality tier that helps account for imperfections and differentiation between different parts that affect production time.

To achieve a balance between efficient customer service and low inventory cost, an optimization model should be set in place that finds a part that is most critical amongst the bills of material. Companies cannot spread their resources equally amongst all the products and inventory management. By defining the most important parts companies will be able to more efficiently delegate their resources. In order to do this, an algorithm will be created using different components of existing part criticality models found through a literature review. Then the part criticality index will be generated in order to target critical parts on the inventory floor and will be simulated through randomly generated number tests. Finally, the system will be placed in a real world application to test its effectiveness.

As business and production facilities grow in size and complexity, inventory and supply chain management have grown increasingly important to gain an upper edge. Today's environment is no longer brand vs brand but instead involves entire supply chains

(Lambert and Cooper, 2000). A large part of this supply chain is material requirement planning and safety stock decisions. With the cost of holding inventory as high as 40% of the inventory value, it is important to maintain the optimal amount (Sandyig and Reistad, 2000).

Modeling and determining the optimal amount of inventory depends on several factors. Depending on the company size, either a single or a multi-echelon system should be put in place. If the model represents a single entity, such as a warehouse, a single echelon model is used. Multi-echelon, composed of many single-echelon systems, models are used most often due to current companies size (Hausman and Erkip, 1994). Finally, event occurrences can be assigned numbers, deterministic or stochastic, when creating inventory models. All these variables create a variety of inventory management policies.

The first part criticality inventory system investigated is the spare parts theory, which involves the assignment of criticality to the parts that make up the manufacturing equipment. Due to the high uncertainty of the requirement of the spare parts and small amount of suppliers, spare parts are inherently difficult to manage. This generally causes a large amount of overstocking (Roda et al., 2014). In order to deal with these issues, spare parts are generally put into categories in order help create proper stocking. Drekker began this by allowing equipment criticality to determine the stock of spare parts by assigning each piece of equipment a status of either “critical and non-critical” (Dekker et al., 1998).

In order to determine the optimal order quantity and reorder point for aircraft spare parts, Aisyati et al. (2013) used a continuous review model. The suggested model resulted in smaller total cost compared with existing policy. An ABC classification system was used to categorize the parts based on their dollar contribution. Focus was on class A and B which

commonly known as important classes. The result from the research indicates that the continuous review policy gives a significant amount of saving compared to the pre-existing policy. Finally, in order to expand on the ABC model, Stoll et al. (2015) used a three dimensional approach allowing for the predictability of demand and importance of the part to be calculated in. The spare part inventory theories lay the groundwork for determining the criticality of different parts of a production facility.

Another way to examine the importance of a part is to investigate the intricate web of the interactions among the units of related systems. One of the most successful recent approaches to capturing the fundamental features of the structure and dynamics of complex systems has been the investigation of the networks associated with the units (nodes) together with their relations (edges). Mones et al. (2012) developed an approach and proposed a measure capable of capturing the essential features of the structure and the degree of hierarchy in a complex network. The measure introduced is based on a generalization of the m-reach centrality, which is first extending to directed/partially directed graphs. Then, a global reaching centrality (GRC) was defined, which is the difference between the maximum and the average value of the generalized reach centralities over the network. Results for real networks show that the hierarchy measure is related to the controllability of the given system.

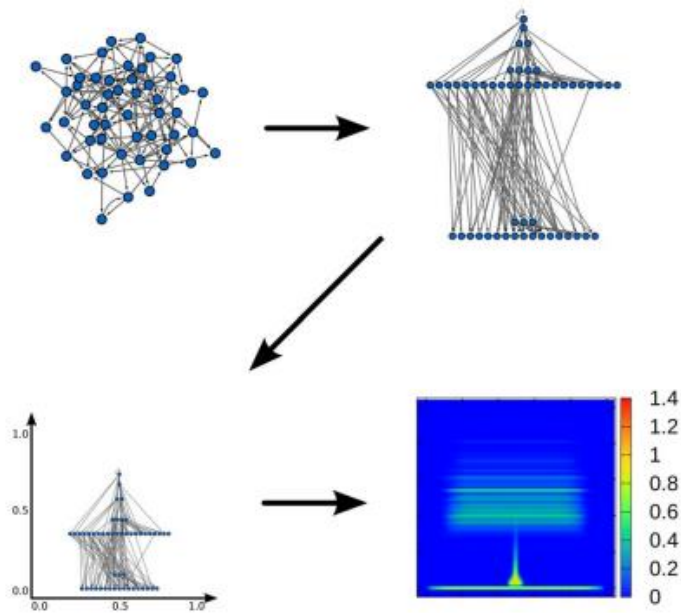


Figure 3.1 Diagram illustrating the process of visualizing an ensemble of networks. (Mones et al., 2012)

Manzini et al (2015) uses the method of nodes and edges to create a system to deal with manufacturing-to-order and assembly-to-order processes. Since each product is unique there is no large part inventory to pick from. To formalize the utilization of the part in the production, Manzini lets the source node be when the part is introduced and the sink node be the milestone before the production operation requiring the component. Then to evaluate the criticality of the part, Manzini finds the overlap of the probability that the component is needed in the production operation and the probability that component has not arrived. An overlap of these provides a risk that determines the criticality of the part. The system of edges and nodes works well in production lines because of the step-by-step nature of manufacturing facilities.

### 3.1 DEFINING THE PART CRITICALITY INDEX

The solution employed in this study focuses on the idea on part Criticality in Inventory Management. This idea stems from:

- The spare parts inventory management technique where equipment spare parts are assigned a value due to their criticalness to the production line (Dekker et al., 1998).
- The system of nodes and edges Mones et al. put forward to describe the fundamental features and hierarchies of a structure and dynamics of complex systems (Mones et al., 2012).

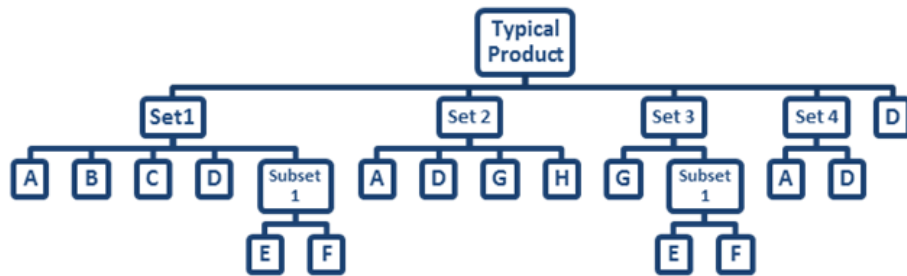


Figure 3.2 Typical Product

Combining these two systems gave a unique approach to determining the part criticality. The spare parts inventory management system introduced the concept of backlogs and order demand to part criticality while the system of nodes and edges allowed for the complex system of a product and production line to be simplified and quantified.

The system of nodes and edges can be applied to a production line if the nodes are looked at as parts and edges being the assembly links. If a part is out of stock, this cuts off connections not allowing the production to flow through the map to the final assembly. The most critical parts of a product then become the parts with the most connections due to their ability to cut off more of the production line and are therefore given preference in stocking systems. The spare part inventory technique was used to rank the product criticality by including the demand and backlog. This way the most important part could be found by combining the most important parts and products of a production line. This

will help envision the bigger supply chain later in order to tackle criticality not only on the factory floor but by reaching suppliers and enhancing the cooperation between all the supply chain entities. A general approach for the creation of each factor in the methodology is listed below followed by a more detailed approach.

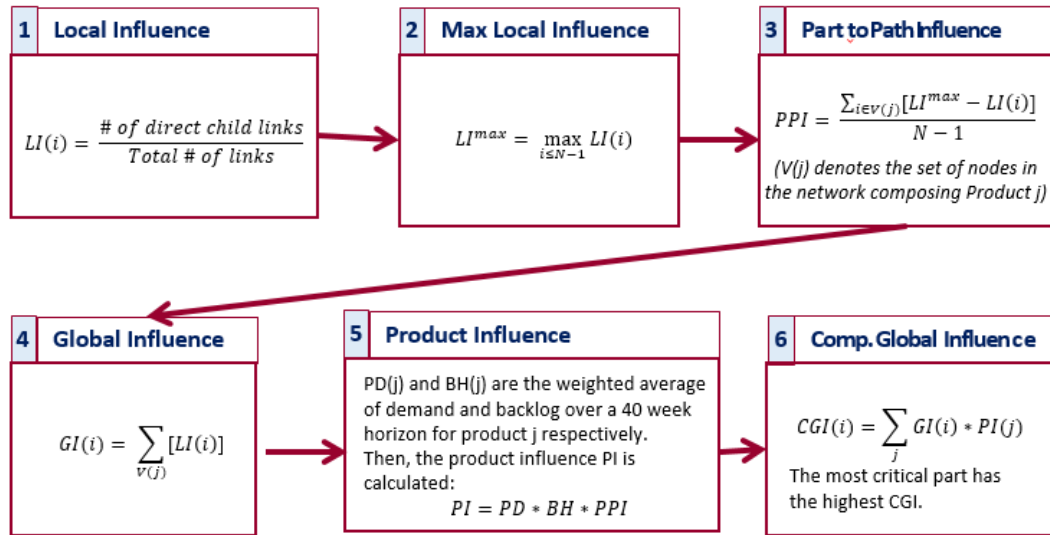


Figure 3.3 Path to find part criticality

### 3.1.1 Local Influence

The first step is to define the local influence of a certain node  $i$  (nodes in this case represent parts, sub-parts, and the final product) in an unweighted directed graph. The studied network is a directed network since only parts lead to sub-parts which lead to final product and not the other way around. The local influence,  $LI(i)$ , is defined as the proportion of all nodes in the graph that can be reached from node  $i$  via incoming edges to  $i$ .

$$LI(i) = \frac{\# \text{ of direct child links}}{\text{Total \# of links}} \quad (1)$$

A child link is a link that connects the parent node to the child node  $i$ .

### 3.1.2 Maximum Local Influence

After calculating local influence at all nodes, we designate  $LI^{max}$  as the highest Local Influence.  $LI^{max}$  will be used in the following step in order to normalize the Local Influence to compare LI of a certain part between different products.

$$LI^{max} = \max_{i \leq N-1} LI(i) \quad (2)$$

### 3.1.3 Part to Product Influence

Thus, we can calculate the Part to Product Influence (PPI):

$$PPI = \frac{\sum_{i \in V(j)} [LI^{max} - LI(i)]}{N - 1} \quad (3)$$

Note that  $V(j)$  denotes the set of nodes in the network composing Product  $j$ . Calculating the PPI allows us compare the influence of the parts on different products.

### 3.1.4 Global Influence

The Global Influence of a Part in a Product can be calculated as follows:

$$GI(i) = \sum_{V(j)} [LI(i)] \quad (4)$$

In other words  $GI(i)$  represents the weight of each part in a product, bigger  $GI(i)$  shows that part  $i$  is a major component of the product.

### 3.1.5 Product Influence and Backlog History

Calculate Product Influence and Backlog History of each product. This is an important criterion to relate each product to the larger picture of the entire production facility.

- a.  $PD(j)$  is the weighted average of Demand over a 40 week horizon for product  $j$ .

- b. BH(j) is the weighted average backlog over a 40 week horizon for product j.
- c. Calculate the product Index PI which is the product of PPI, PD, and BH.

### 3.1.6 Compound Global Index

The last step is to find the Compound Global Index (CGI) that represents the part criticality among all products. The CGI brings together the most important parts and products to find the most critical parts to the production line. To calculate CGI for each part, we use the following equation representing the sum-product of parts Global Influence in each product and the Product Influence:

$$CGI(i) = \sum_j GI(i) * PI(j) \quad (5)$$

## 3.2 INVENTORY MODEL

### 3.2.1 Products

Six fictional products were created in order to apply the above-mentioned algorithm. Each product consists of a set of parts, subsets, and sets. Note that subsets are subassemblies of parts, and sets are subassemblies of parts and subsets. Creating multiple products helps create a more realistic representation of a large final assembly production facility.

### 3.2.2 Supply and Demand

In this model, both supply and demand are set as constant stochastic variables. The distribution used is the uniform distribution. Furthermore, a finite planning horizon of 40 weeks is used.



### 3.2.3 Inventory and Backlog

In order to perform accurate long run simulations a model was created to help us simulate a realistic scenario where inventory is not scrapped from period to another and unmet demand is met in the upcoming periods. In create this model inventory from one period to another is kept and unmet demand from one period to another is backlogged.

Inventory,  $I(n)$ , and shortage,  $S(n)$ , for a typical period  $n$  is calculated as follows:

$$I(n) = I(n - 1) + \text{Max}[ Q(n) - D(n), 0 ] \quad (6)$$

$$I(0) = 0$$

$$S(n) = S(n - 1) + \text{Max}[ D(n) - Q(n), 0 ] \quad (7)$$

$$S(0) = 0$$

Note that  $D(n)$  and  $Q(n)$  represent Demand and Supply during a period  $n$  respectively.

## 3.3 DISCUSSION OF RESULTS

### 3.3.1 Primitive Model

A first model was developed with the following assumptions: surplus inventory from one term to another is scrapped and backlog is not allowed, i.e., unmet demand during a certain period is disregarded in the next period. For this model, all random simulation led to same result, the same part was found to be critical. But, this model is not logical since inventory can be kept from one period to another and unmet demand is usually met in the upcoming periods. Hence, a more realistic model was developed in order to take into consideration surplus inventory and backlog. The integration of these parameters was already discussed in section 3.3.

### 3.3.2 Short Run Results

After embedding surplus inventory and backlog in the model, short run simulation were run based on a 40-week horizon, and then long run results were calculated. The long run results were based on a series of 10 short runs.

Many short run simulations were run, and every time a different part was found to be critical. This randomization was boosted by the introduction of the 2 assumptions discussed above. 5 runs are documented in the table below. For the first run, part N was the most critical, for the second and fourth run, part D was the most critical, and followed by part A. And for the third and fifth runs, Part A was the most critical followed by part D. this can be explained by the probabilistic distributions used to represent both supply and demand and their involvement in the calculation of the Product Index PI (section 3.5). The short run simulations did not provide definitive results so the long-term model was though of and put in place to see if a more consistent results could be obtained.

Table 3.1 Global Compound Index Calculation

Part	Run 1	Run 2	Run 3	Run 4	Run 5	Long Run
Set 1	0.00377075	0.01551306	0.00278513	0.01262664	0.00974517	0.00762882
Set 2	0.01476691	0.00870292	0.00638843	0.01012183	0.01360051	0.01741808
Set 6	0.0147669	0.0004902	0.00369514	0	0.01181458	0.00638000
Set 7	0.0147669	0.0004902	0.00369514	0	0.01181458	0.00638000
Subset1	0.0037707	0.0155130	0.00547842	0.01473918	0.01065167	0.01095505
A	0.0336402	0.0340810	0.02179057	0.03309916	0.03720555	0.04400146
B	0.0037707	0.0237257	0.00278513	0.02063593	0.01062458	0.01534066
D	0.0223084	0.0479417	0.01465198	0.04549695	0.03487678	0.04371381
E	0.0037707	0.0155130	0.00547842	0.01473918	0.01065167	0.01095505
F	0.0076533	0.0314087	0.00763605	0.02532956	0.01957679	0.01576854
G	0.0147669	0.0087029	0.00908172	0.01223438	0.01450702	0.02074432
H	0.0148787	0.0090855	0.00845421	0.01019812	0.01368696	0.01792899
J	0.0147669	0.0087029	0.00369514	0.00800929	0.01269400	0.01409185
L	0.0148787	0.0008728	0.00576092	7.63E-05	0.01190104	0.00689090
M	0.0334164	0.0168612	0.00954791	0.0105903	0.0325542	0.01757349
N	0.0443007	0.0014706	0.01108543	0	0.03544376	0.019140008
O	0.0223084	0.03151636	0.00387883	0.02102819	0.02949191	0.01498517

### 3.3.3 Long Run Results

In order to develop the long run results, ten short run simulations were run and a weighted average of the CGI for every part was calculated. This procedure was repeated three times, and the same part was found to be critical. This shows that regardless of the variations on the short term, on the long term, the same part will be critical. Table 1 shows that the most critical part on the long run is A followed by the part D. The long run simulation amortized the effect of the stochastic distribution of the demand and supply leading to one part being critical on the long run.

### 3.3.4 Pareto Analysis

Ideally, management wants to focus its attention on fixing the most important problems. But how do they decide which problems they need to deal with first? Pareto Analysis helps prioritize the most critical parts by finding the 20 percent of parts that generate 80 percent of the criticality.

In this simulation, 80 percent of the criticality is caused by more than 20 percent of the parts (figures 2 and 3), thus violating the 80/20 rule. Pareto charts are extremely useful for analyzing what problems need attention first because the taller bars on the chart, clearly illustrate which parts have the greatest cumulative effect on a given system.

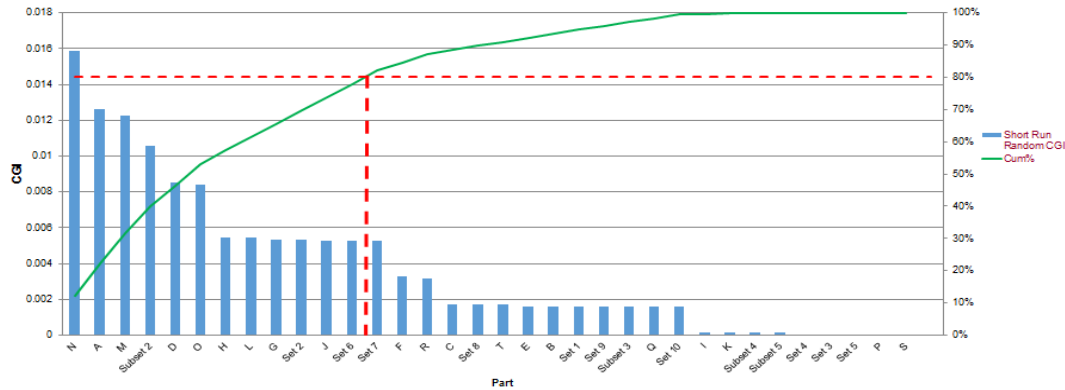


Figure 3.4 Random Short Run Pareto Chart

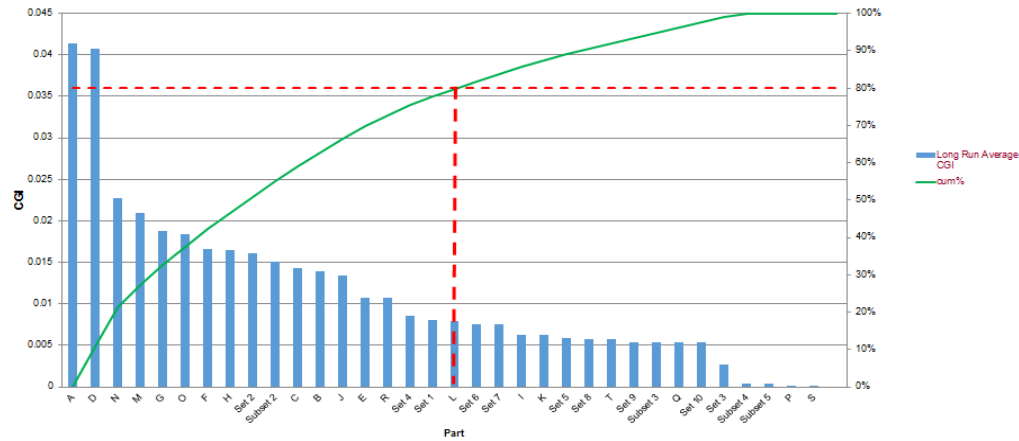


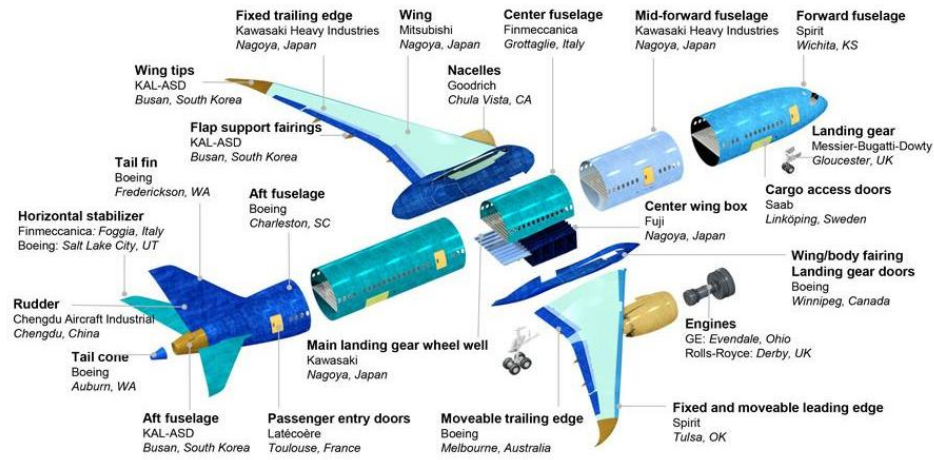
Figure 3.5 Long Run Pareto Chart

### 3.4 INDUSTRY SIGNIFICANCE

Our next step is to create a program that optimizes inventory management by identifying the criticality of parts to a company's production. The program will allow a company to insert data from their production line and the most important parts will then be determined using a part criticality algorithm. These parts will then be given priority in the pre-existing inventory management system.

The long-term goal for this project will be to create a wiki-like database for local manufacturers that can create parts used in the aerospace industry. Many large companies such as Boeing outsource many of the parts that go into their planes first from outside the USA and second from outside of South Carolina. Therefore, if a part is defective there are long shipping times and delays that may occur. Determining both the criticality of the parts used on the assembly line and the parts in the products delivered could help reduce these issues because local manufacturers could be identified in order to get the part quickly. This would be a part of the actions taken in order to help engage local suppliers in the advancement of the aerospace market in South Carolina. The figure below shows the breakdown of the Boeing 787 airplane along with the origin of each part.

The figure below shows the breakdown and origin of major parts of the Boeing 787 manufactured in Charleston, SC.



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Figure 3.6 Boeing 787 Breakdown

The below image shows the spread of first tier suppliers hired by Boeing.



Figure 3.7 Countries Supplying Parts for Boeing Charleston

Figure 6 shows the available aerospace related companies in South Carolina. These companies can be beneficial for Boeing since they are close to the plant in Charleston leading to easier cooperation and less variability.



Figure 3.8 Potential Aerospace Suppliers in South Carolina

Our goal is to create a multi-echelon cooperative supply chain network within South Carolina in order to increase the involvement of local aerospace related companies in the manufacturing of the Dreamliner and hence decreasing the criticality among the parts since suppliers will be more within reach.

### 3.5 SUMMARY

In this chapter, we determined the Part Criticality defined as Compound Global Index. This index defined part criticality by utilizing the interdependence of different parts as well as backorder and surplus quantities. A set of simple products having common parts was employed in order to validate the algorithm. Results showed that on the short term, criticality might vary from one term to another. This is mainly caused by the variability of demand and supply. Furthermore, this criticality was affected by the inventory policy set in place for this simulation.

A further step would be to simulate other inventory policies in order to study their effect on the part criticality. As for the long run results, it was realized that one part was

the most critical. This short run/long run differentiation helps the management have a plan to tackle parts that are critical on the short term as well as creating long term improvement policies to decrease the long term part criticality.

## CHAPTER 4

### DEVELOPMENT OF A SUPPLIER'S DELIVERY TIME AND DELIVERED QUALITY PERFORMANCE INDEX

Chapter 4 demonstrates the rationale behind the development of the Supplier's Delivery Time and Delivery Time Cost Function. In the first section, the Markov model is developed along with the long-run penalty cost, and then the next section shows the reasoning behind the determination of variable and constant costs in the cost function. The last section refers to the ranking of suppliers based on their delivery time and delivered quality performance.

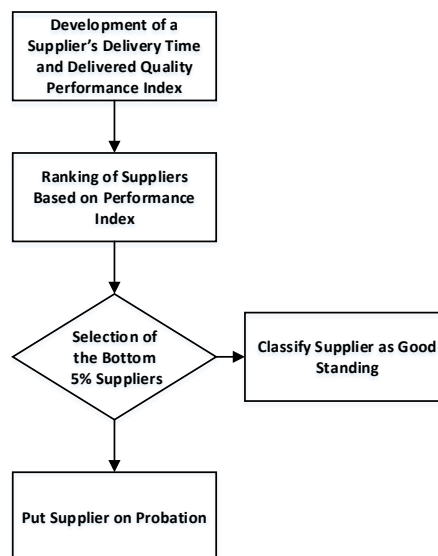


Figure 4.1 Steps taken in this chapter



Based on the literature review, it became evident that the main attributes implemented when assessing suppliers are (1) delivery time and (2) delivered quality. Hence, the development of an index founded upon these two attributes represent the performance of suppliers.

#### 4.1 PROPOSED MODEL – MARKOV CHAIN MODEL

In probability theory and related fields, a Markov process, named after the Russian mathematician Andrey Markov, is a stochastic process that satisfies the Markov property (sometimes characterized as "memorylessness"). Loosely speaking, a process satisfies the Markov property if one can make predictions for the future of the process based solely on its present state just as well as one could make predictions knowing the process's full history. Hence independently from such history; i.e., conditional on the present state of the system, its future and past states are independent (Ross, 2014).

##### 4.1.1 Markov Chain

Let  $\{X_n, n = 0, 1, 2 \dots\}$  be a stochastic process that takes on a finite or countable number of possible values. Unless otherwise mentioned, this set of possible values of the process will be denoted by the set of nonnegative integers  $\{0, 1, 2 \dots\}$ . If  $X_n = i$ , then the process is said to be in state  $i$  at time  $n$ . We suppose that whenever the process is in state  $i$ , there is a fixed probability  $P_{ij}$  that it will next be in state  $j$ . That is, we suppose that:

$$P\{X_{n+1} = j \mid X_n = i, X_{n-1} = i_{n-1}, \dots, X_1 = i_1, X_0 = i_0\} = P_{ij} \quad (8)$$

For all states  $i_0, i_1, \dots, i_{n-1}, i, j$  and all  $n \geq 0$ . Such a stochastic process is known as a Markov chain. The equation above may be interpreted as stating that, for a Markov chain, the conditional distribution of any future state  $X_{n+1}$ , given the past states  $X_0, X_1, \dots, X_{n-1}$

and the present state  $X_n$ , is independent of the past states and depends only on the present state.

The value  $P_{ij}$  represents the probability that the process will, when in state  $i$ , next make a transition into state  $j$ . Since probabilities are nonnegative and since the process must make a transition into some state, we have:

$$P_{ij} \geq 0, \quad i, j \geq 0; \quad \sum_{j=0}^{\infty} P_{ij} = 1, \quad i = 0, 1, \dots \quad (9)$$

Let  $P$  denote the matrix of one-step transition probabilities  $P_{ij}$ , so that:

$$P = \begin{bmatrix} P_{00} & P_{01} & P_{02} & \dots \\ P_{10} & P_{11} & P_{12} & \dots \\ \vdots & \vdots & \vdots & \dots \\ P_{i0} & P_{i1} & P_{i2} & \dots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix} \quad (10)$$

The long run behavior of regular Markov Chain is derived from the following set of equations:

$$\begin{cases} \pi_j = \sum_{k=0}^n \pi_k P_{kj}, & j = 0, 1, \dots, N-1 \\ \sum_{i=0}^N \pi_i = 1 \end{cases} \quad (11)$$

#### 4.1.2 The Model

In our case, states will be defined based on the supplier's delivery time. The supplier will be given a window of 2 days early and 3 days tardy in order to be considered on time. Or else, the supplier will be considered late. Lateness is completion time minus deadline; positive lateness is tardiness; negative lateness is earliness.

$$Earliness = \min\{Actual\ Delivery\ Date - Planned\ Delivery\ Date, 0\} \quad (12)$$

$$Tardiness = \max\{Actual\ Delivery\ Date - Received\ by\ Date, 0\} \quad (13)$$

$$Lateness = \begin{cases} Earliness & \text{if } |Earliness| > Tardiness \\ Tardiness & \text{if } |Earliness| < Tardiness \end{cases} \quad (14)$$

#### 4.1.3 Long-Run Average Penalty Cost Function

Our total cost will be based on the long run probabilities we got from the Markov Chain model we developed. The long run penalty cost for every supplier  $j$  can be represented as follow:

$$\begin{aligned} & Long - Run\ Average\ Penalty\ Cost(j) \\ &= \pi_{0,j} * QC_j * Q_j * d_j \\ &+ \sum_{i < 0} [(QC_j * Q_j * d_j + IC_j * Q_j * (1 - d_j) * |i|) * \pi_{i,j}] \\ &+ \sum_{0 < i \leq dis} [(QC_j * Q_j * d_j + SC_j * Q_j * (1 - d_j) * i) * \pi_{i,j}] \\ &+ \pi_{dis,j} * SC_j * Q_j \quad \forall j \end{aligned} \quad (15)$$

Where:

- $\pi_{i,j}$  – Value of the long-run probability for state  $i$ , and supplier  $j$
- $QC_j$  – Cost of poor quality per unit for supplier  $j$
- $Q_j$  – Ordering quantity by supplier  $j$
- $d_j$  – Proportion of defective supplied parts by supplier  $j$
- $IC_j$  – cost of holding 1 unit for 1 day for supplier  $j$

- $SC_j$  – cost of 1 short unit for 1 day for supplier j

According to equation 8, when the supplier is on time, a quality cost will be only incurred since no inventory or shortage cost will be incurred. However, when he is early or tardy, in addition to the quality cost, an inventory holding cost or shortage cost will be incurred respectively. Nonetheless, when suppliers exceed the allowed time, and order is cancelled or disregarded, only a shortage cost will be incurred on all quantity regardless if there was any defect.

#### 4.2 DETERMINATION OF COSTS INTEGRATED IN THE SUPPLIER'S DELIVERY TIME AND DELIVERED QUALITY PERFORMANCE COST FUNCTION

Some costs used in the development of the Supplier's Delivery Time and Delivered Quality Performance Cost Function are constant costs determined by the firm itself. Below is a summary of the determination of some of these costs.

##### 4.2.1 Determination of Cost of Poor Quality (COPQ)

COPQ is the cost associated with poor quality of products and services (Prashar, 2014). According to the American Society of Quality, and more specifically to its Quality Cost Committee, costs of quality can be categorized into four types: (1) prevention costs, (2) appraisal costs, (3) internal failure costs, (4) external failure costs. Kondic et al. (2016) state that internal failure costs are losses caused by poor production quality and total cost of quality can be calculated as follows (Kondoc, et al., 2016):

$$\begin{aligned}
 & \textit{Total Quality Cost} \\
 & = \textit{Prevention Cost} + \textit{Appraisal Cost} \\
 & + \textit{Internal Poor Quality Cost} \\
 & + \textit{External Poor Quality Cost}
 \end{aligned} \tag{16}$$

Cost of poor quality from supplied can be generated in two cases:

- Supplier producing defective products
- Damaging material during delivery

#### 4.2.2 Determination of Inventory Holding Cost

Currently, inventory is considered dead money and management always tries to decrease its inventory as much as possible without disrupting their processes in order to minimize their holding costs. According to Torkul et al. (2016), many reasons can increase the inventory holding costs: (1) variation of demand, (2) large safety stock.

Inventory holding cost can be broken down into the following sub-costs:

- Opportunity cost of money invested in inventory.
- Space cost comprising rent/land buying, depreciation, O&M costs, insurance, and taxes, etc.
- Cost of material handling.
- Cost of mishandling and obsolescence.

The inventory holding cost IC part that is based on the actually space cost and related cost can be determined based on numbers of SKUs occupied and the cost of occupying one SKU.

Torkul et al. (2016) define Total Inventory Holding Cost (TIHC) for the basic inventory model (Economic Order Quantity EOQ) as follows (Torkul et al., 2016):

$$TIHC = CT * CCW + \frac{Q * UVC * CT}{2} \quad (17)$$

Where (1) CT = cycle time, (2) CCW = constant cost of warehousing, (3) Q = initial inventory amount, (4) UVC = unit variable cost.

Hence, the Average Inventory Holding Cost (AIHC) can be calculated:

$$AIHC = \frac{TIHC}{CT} \quad (18)$$

#### 4.2.3 Determination of Shortage Cost

According to Xu (2017), shortage cost is incurred when demand is greater than inventory available (Xu, 2017). Shortage cost has a major influence on effective inventory management. Shortage results in sales lost, bad customer experiences and backorder costs. Campo et al. (2003) pointed out that inadequate inventory would reduce the amount of future purchase from the customers [25]. Xu (2017) derived a statistical function in order to calculate the average shortage cost  $E(x)$ . The function below shows his work (Xu, 2017).

$$E(x) = \begin{cases} \frac{1}{2} \exp\left(\frac{v\lambda^2}{2b^2}\right) \frac{\lambda}{\lambda - b} & \text{if } \lambda > b \\ \text{indeterminate} & \text{otherwise} \end{cases} \quad (19)$$

Where: (1)  $v$  = variance parameter, (2)  $\lambda$  = expected shortage amount, (3)  $b$  = burn rate.

#### 4.3 SUPPLIERS RANKING

In order to compare suppliers and rank them based on their performances, the long-run average penalty cost should be normalized. Equation 8 represents the long-run average penalty cost per cycle; suppliers might have different cycle length and different order quantities. One way to normalize all costs is to find the long-run average penalty cost per unit per year using the equation below:

$$\begin{aligned} & \text{Long Run Average Penalty Cost}(j) \text{ per unit. year} \\ & = \frac{\text{Long - Run Average Penalty Cost}(j)}{Q_j} \end{aligned} \quad (20)$$

In the above equation, the number of cycles per year gets cancelled since it is present in both the numerator and the denominator.

After getting the normalized long-run average penalty cost for every supplier  $j$ , suppliers can be ranked in order to monitor suppliers with high penalty costs.

#### 4.4 SUMMARY

Evaluating suppliers is a tough job that requires critical decision-making. When assessable, qualitative and quantitative figures and numbers help management monetize the alternatives at hand, the resultant decision making strategy provides a more in-depth evaluation of suppliers that goes beyond management intuition.

Based on the literature review, it became evident that the main attributes implemented when assessing suppliers are the (1) delivery time and (2) delivered quality. Hence, the development of an index founded upon these two attributes, which represent the performance of suppliers.

This study is part of a bigger picture where a detailed literature on current practices of supplier's assessment and valuation of decisions regarding underperforming suppliers was developed (Saidy et al., 2017). A detailed research framework was developed based on this extensive literature. The first step of the framework is to identify the Supplier's Delivery Time and Delivered Quality Performance Cost Function based on a Markov chain model developed in this study. Based on the normalized Cost of all suppliers, suppliers are ranked in order to classify underperforming ones.

Following this step, two other cost models are to be developed in order to calculate supplier's switching cost and the cost of collaborative planning, forecasting and replenishment (CPFR). This will help decision makers chose to either switch supplier or increase collaboration.

In order to decide whether to switch suppliers, increase collaboration, or maintain the status quo, an analytical hierarchy process will be developed to choose between alternatives based on cost, feasibility, and management willingness [26]



## CHAPTER 5

### DETERMINATION OF SUPPLIER SWITCHING COST

Switching costs are the costs that a consumer incurs as a result of changing brands, suppliers or products. Although most prevalent switching costs are monetary in nature, there are also psychological, effort- and time-based switching costs. A switching cost can manifest itself in the form of significant time and effort necessary to change suppliers, the risk of disrupting normal operations of a business during a transition period, high cancellation fees, and a failure to obtain similar replacement of products or services.

#### 5.1 BACKGROUND

Based on the acknowledged cost factors within each literary article in the table below, it is evident that our switching cost classifications are supported throughout literature. The primary factors identified as procedural, financial, and relational (psychological) are derived from research conducted by Burnham et al. (2003). These switching cost types encompass the majority from which supplier switching costs originate. This is supported due to the fact that other researchers identified them within their switching cost typologies. In the case they were not identified, the researchers' cost factors included their sub-facets.

Table 5.1 Classification Assessment

	Procedural	Search & Evaluation	Learning	Setup	Economic Risk	Financial	Benefit Loss	Monetary Loss	Relational (Psychological)	Personal Relationship Loss	Brand Relationship Loss	Variational
Klemperer, P. (1995)			*	*	*		*	*	*		*	
Jones et al. (2002)		*	*	*	*		*		*	*		*
Burnham et al. (2003)	*	*	*	*	*	*	*	*	*	*	*	
Vasudevan et al. (2006)	*			*		*	*	*	*	*	*	
Whitten & Wakefield (2006)		*	*	*	*		*	*	*	*		*
Colwell et al. (2011)	*		*	*					*			*
Phua, Y.S. (2011)		*	*	*	*			*	*			*
Barroso & Picón (2012)		*		*	*		*	*		*		
Hu et al. (2012)	*	*	*	*		*		*	*	*		*
Vigolo & Cassia (2014)	*	*	*	*	*	*	*	*	*	*	*	
Hu et al. (2014)		*	*	*				*				*
Zhang et al. (2015)		*	*	*				*				*
<b>Total</b>	<b>5</b>	<b>9</b>	<b>10</b>	<b>12</b>	<b>7</b>	<b>4</b>	<b>7</b>	<b>10</b>	<b>9</b>	<b>7</b>	<b>4</b>	<b>7</b>

Procedural cost sub-facets are search & evaluation, learning, setup and economic risk; financial cost sub-facets are benefit loss and monetary loss; and relational (psychological) cost sub-facets are personal relationship loss and brand relationship loss. Lastly, our final classified switching cost factor, variational, is also supported throughout literature. This is evident by the 7 out of 12 typologies that include such variational costs. As a result, table 4 justifies the initial cost factors constructed by Burnham et al. in 2003,

as well as variational costs identified by Zhang et al. in 2015 as implicated costs when switching a supplier.

## 5.2 SWITCHING COST EQUATION DEVELOPMENT

Based on literature review developed in Saïdy et al. (2017), supplier's switching cost can be presented in the below diagram.

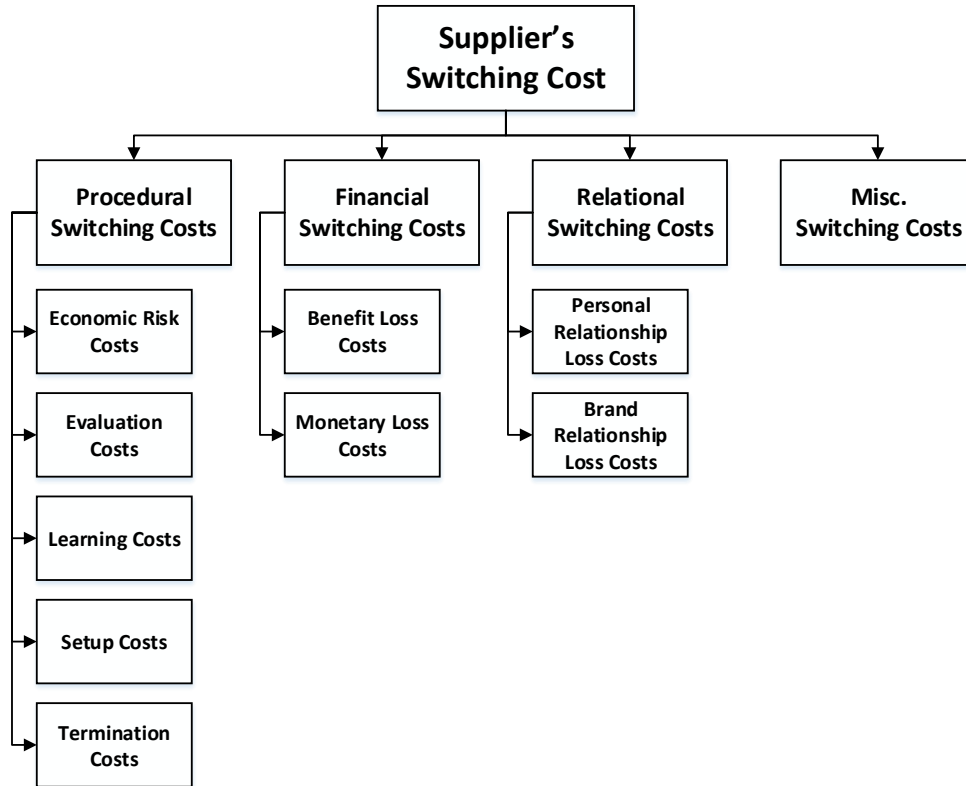


Figure 5.1 Switching Cost Breakdown

Therefore, the equation for supplier's switching cost can be developed as follow:

$$\begin{aligned}
 & \textit{Switching Costs} \\
 & = \textit{Procedural Switching Cost} \\
 & + \textit{Financial Switching Costs} \\
 & + \textit{Relational Switching Costs} + \textit{Misc. Switching Costs}
 \end{aligned} \tag{21}$$

Where:

$$\begin{aligned}
& \textit{Procedural Switching Cost} \\
& = \textit{Economic Risk Costs} + \textit{Evaluation Costs} \\
& + \textit{Learning Costs} + \textit{Setup Costs}
\end{aligned}
\tag{22}$$

- **Economic Risk Costs:** Uncertainty when obtaining a new supplier, due to insufficient information. Bettman developed a six-dimensional construct conceptualizing consumption risk, three of which are relevant: performance risk, financial risk, and convenience risk (Bettman, 1973).
- **Evaluation Costs:** Before making the decision to switch, time and effort is devoted to searching and analyzing potential providers. Collecting information about the suppliers is needed, as well as mental effort to analyze such information, in order to make an informed decision. This is sometimes identified as searching costs.
- **Learning Costs:** When switching to a new provider, there are skills and knowledge that must be acquired in order to effectively use the new product. Time and effort in relation to developing these new skills and knowledge is essential to adapt to the new supplier.
- **Setup Costs:** Initiating a new relationship and/or developing the necessities to use a new product require time and effort. In relation to services, an abundance of information is exchanged between the new provider and the customer concerning selling risks and the customers' specific needs.

$$\begin{aligned}
& \textit{Financial Switching Cost} \\
& = \textit{Benefit Loss Costs} + \textit{Monetary Loss Costs}
\end{aligned}
\tag{23}$$

- **Benefit Loss Costs:** Terminating a contract with a firm is likely to imply that the economic benefits that were once accumulated are now null and void. Discounts or benefits once acquired from the original supplier are now lost, due to the fact they do not transfer.
- **Monetary Loss Costs:** Payments that are a one time commitment when initially switching suppliers, not including the purchase of the new product. These expenditures are usually deposits and initiation fees. In addition, monetary losses could be due to the consumer having to replace co-assets and sub-assets in relation with the new product.

$$\begin{aligned}
 & \textit{Relational Switching Cost} \\
 = & \textit{Personal Relationship Loss Costs} & (24) \\
 + & \textit{Brand Relationship Loss Costs}
 \end{aligned}$$

- **Personal Relationship Loss Costs:** Bonds of identification are formed with the supplier's employees, thus, upon switching, those bonds break. The consumer developed a level of comfort with these employees, and that is not really available with the new provider.
- **Brand Relationship Loss Costs:** Bonds of identification are formed with incumbent suppliers, thus, upon switching, those bonds break. Brand- or company- based relational bonds are formed due to customers drawing meaning from their associations, which became a part of their identity.

## CHAPTER 6

### DETERMINATION OF COLLABORATIVE PLANNING, FORECASTING, AND REPLINSHMENT (CPFR) COST

When a supplier is underperforming, it becomes important for the customer to create a plan of action regarding the supplier. In order to do this, the customer is faced with two choices, either commit to improving the collaboration with the supplier or switch supplier. Each of these tasks comes with a cost and the one with the lower cost should be chosen. In this study, we will create a model that will help determine the cost to a retailer of implementing CPFR. To do this we will calculate the time it takes to make the equivalent improvements of switching suppliers through the improvement of CPFR. The time will be calculated using a system dynamics and supply chain research.

#### 6.1 CPFR MODELS

The literature offers various models that organize CPFR according to processes, steps, activities and tasks. The first model was published by the VICS committee in 1998 in a working paper. The different models offered in the literature are introduced in Table 2 and discussed herein. The 1998 VICS model begins with the creation of a front-end agreement that establishes the scope and assigns roles, responsibilities, checkpoints and escalation procedures with respect to collaboration. Furthermore, it develops a scorecard to track SC metrics and establishes incentives. Objectives and requirements of all trading

partners are discussed and clarified (Caridi et al., 2005; Cassivi, 2006), and a joint business plan is created to identify the significant events that affect supply and demand in the planning period (e.g. promotion, product introductions), logistics parameters (e.g. safety stocks, frozen periods, delivery dates, order minimums and multiples), the information to be exchanged and the exception criteria to resolve planning variances between the trading partner's demand forecasts (Chang and Wang, 2008; Shu et al., 2010). During the forecasting process, the volumes of sales are forecast, the differences between the trading partners' volumes (exceptions) are discussed and a mutually agreed sales forecast is created. The combination of sales forecasts, inventory levels, inventory strategies and other information make it possible to generate a specific order forecast that allows the seller simultaneously to: first, allocate production capacity against demand; and second, minimize safety stock. The exceptions are again discussed, and a common order forecast is created. Finally, the replenishment plan is created, thus transforming the order forecast into a committed order (Caridi et al., 2005).

Table 6.1 CPFR Models

Reference	Model Description
VICS (1998)	CPFR is based on a linear process with nine steps: (1) develop front-end agreement; (2) create joint business plan; (3) create sales forecast; (4) identify exceptions to sales forecast; (5) resolve exceptions to sales forecast; (6) create order forecast; (7) identify exceptions to order forecast; (8) resolve exceptions to order forecast; and (9) generate order. These nine steps are

	organized into three processes: planning, forecasting and replenishment.
Fliender (2003)	CPFR is established through five iterative steps: (1) create front-end agreement; (2) create joint business plan; (3) develop forecast; (4) sharing forecast; and (5) replenish inventory.
VICS (2004)	CPFR consists of four activities, each of which is divided into two tasks: (1) strategy and planning: collaborative arrangement and joint business plan; (2) demand and supply management: sales forecasting and order planning/forecasting; (3) execution: order generation and order fulfilment; (4) analysis: exception management and performance assessment.
Caridi et al. (2005, 2006)	This model is based on VICS (1998) and suggests that the process can be improved with autonomous agents. The authors propose two CPFR models with agent-based models to optimize the negotiation steps (exception management) in the CPFR process. The autonomous agents are entities that have problem-solving capabilities can therefore propose solutions to solve the exceptions.
Chang et al. (2007)	This model is an augmented CPFR also based on VICS (1998). The authors include in the process an application service



	<p>provider (ASP) that uses market information to improve forecast accuracy and replenishment. The process has nine steps: (1) draft agreement; (2) develop joint business plan; (3) forecast sales; (4) identify unusual sales forecasts; (5) deal collaboratively with unusual items; (6) forecast orders; (7) identify unusual order forecasts; (8) deal collaboratively with unusual items; and (9) generate order.</p>
Chang and Wang (2008)	<p>The model is based on VICS (2004) with the same four activities; however, it incorporates the DMAIC (define, measure, analyze, improve and control) cycle from Six Sigma methodology into the demand and supply management activity to improve forecast accuracy.</p>
Du et al (2009)	<p>This model is based on VICS (1998), though the authors reorganized the model into three steps: (1) development of collaborative arrangement and preparation of joint business plan; (2) generation of collaborative sales and order forecast; and (3) generation of order and execution of shipments. This last step can be subdivided into three separate steps to include collaborative schedule production and delivery, exception management and execution of shipments.</p>

Shu et al. (2010)	<p>This model is based on VICS (1998), though the authors propose a process with three processes and eleven steps: (1) decompose and search for a module; (2) reach a forward collaboration agreement, (3) create a collaboration plan; (4) forecast sales; (5) confirm exceptions in sales forecasts; (6) resolve exceptions in sales forecasts; (7) order forecasts; (8) confirm exceptions in order forecasts; (9) resolve exceptions in order forecasts; (10) create an order; and (11) produce and service. The three first steps correspond to the planning process, steps (4) to (9) correspond to the forecasting process and the last two steps comprise the replenishment process.</p>
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The figure below breaks down the CPFR model to the next level of detail based on the 2004 VICS model. There are eight tasks – two for each of the four Collaboration Activities.

Within Strategy & Planning, Collaboration Arrangement is the process of setting the business goals for the relationship, defining the scope of collaboration and assigning roles, responsibilities, checkpoints and escalation procedures. The Joint Business Plan then identifies the significant events that affect supply and demand in the planning period, such as promotions, inventory policy changes, store openings/closings, and product introductions.

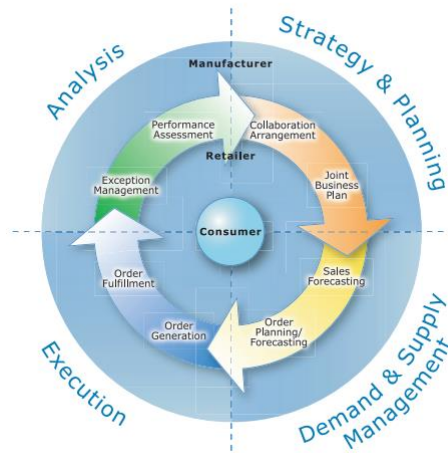


Figure 6.1 CPFR Model – Collaboration Tasks (VICS, 2004)

Demand & Supply Management is broken into Sales Forecasting, which projects consumer demand at the point of sale, and Order Planning/Forecasting, which determines future product ordering and delivery requirements based upon the sales forecast, inventory positions, transit lead times, and other factors. Execution consists of Order Generation, which transitions forecasts to firm demand, and Order Fulfillment, the process of producing, shipping, delivering, and stocking products for consumer purchase. Analysis tasks include Exception Management, the active monitoring of planning and operations for out-of-bounds conditions, and Performance Assessment, the calculation of key metrics to evaluate the achievement of business goals, uncover trends or develop alternative strategies.

## 6.2 CPFR STEPS

Below are the CPFR steps detailed in the form of flow diagrams.



Figure 6.2 CPFR Steps

### 6.2.1 Collaboration Arrangement

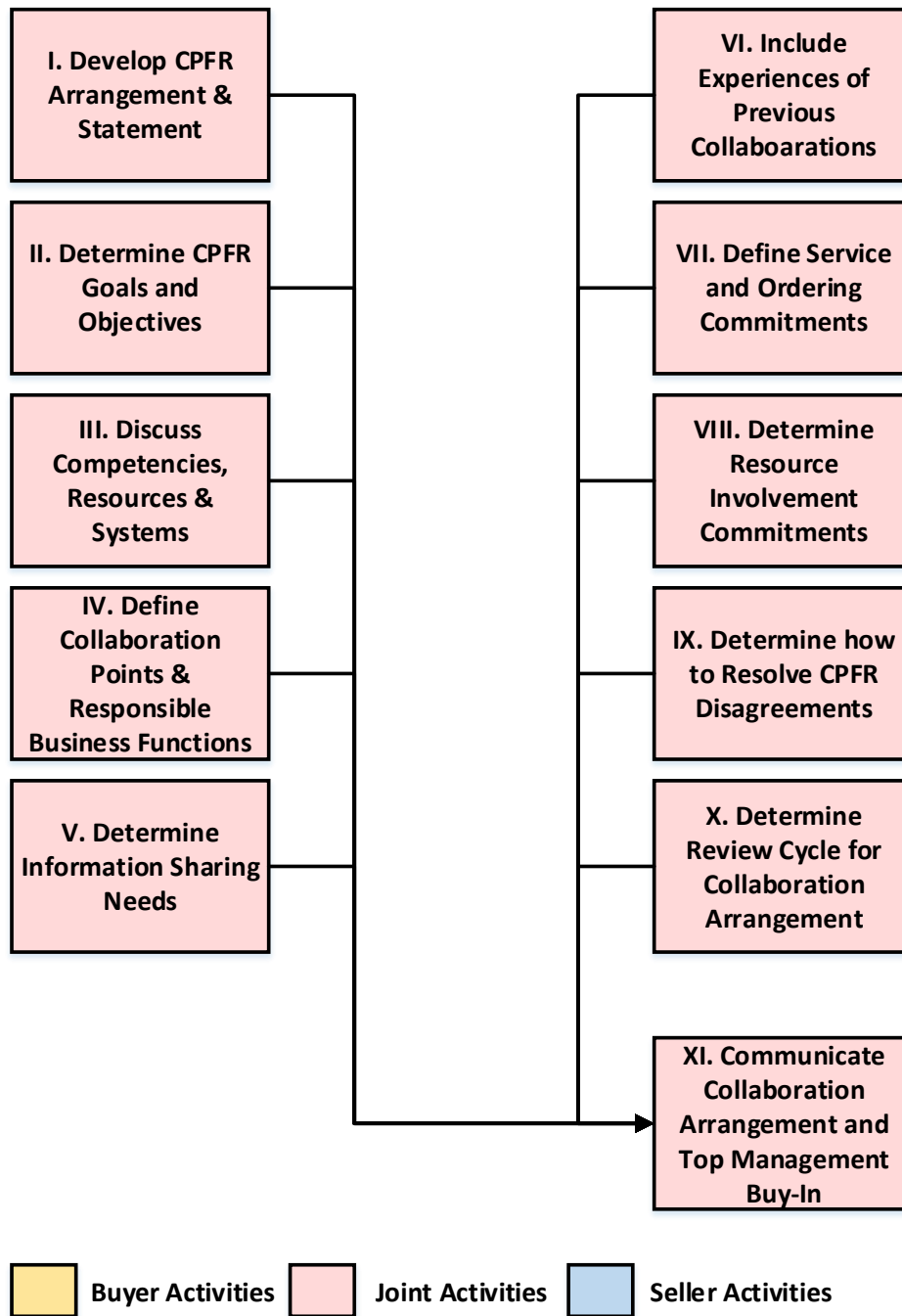


Figure 6.3 CPFR - Step 1

### 6.2.2 Joint Business Plan

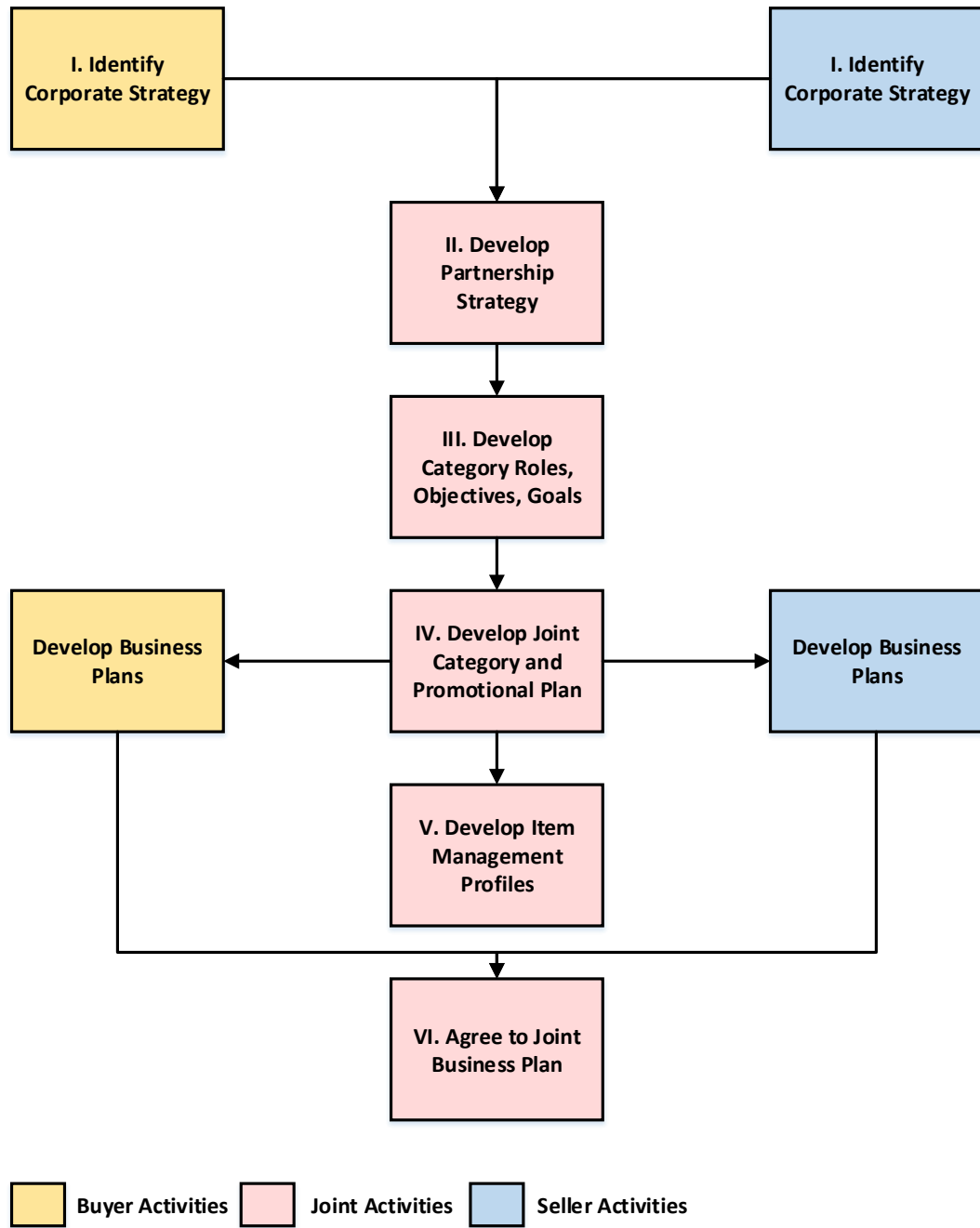


Figure 6.4 CPFR - Step 2

### 6.2.3 Sales Forecasting

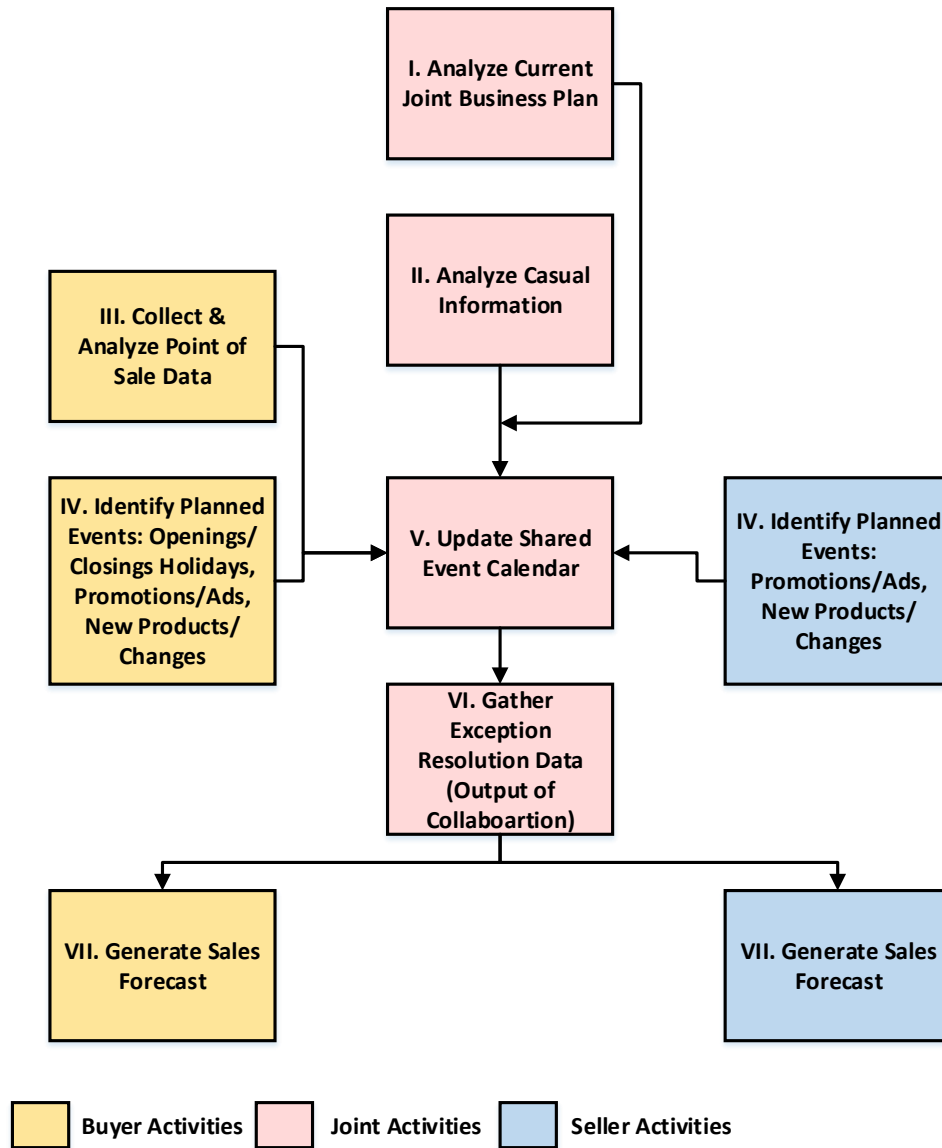


Figure 6.5 CPFR - Step 3

6.2.4 Order Planning/Forecasting

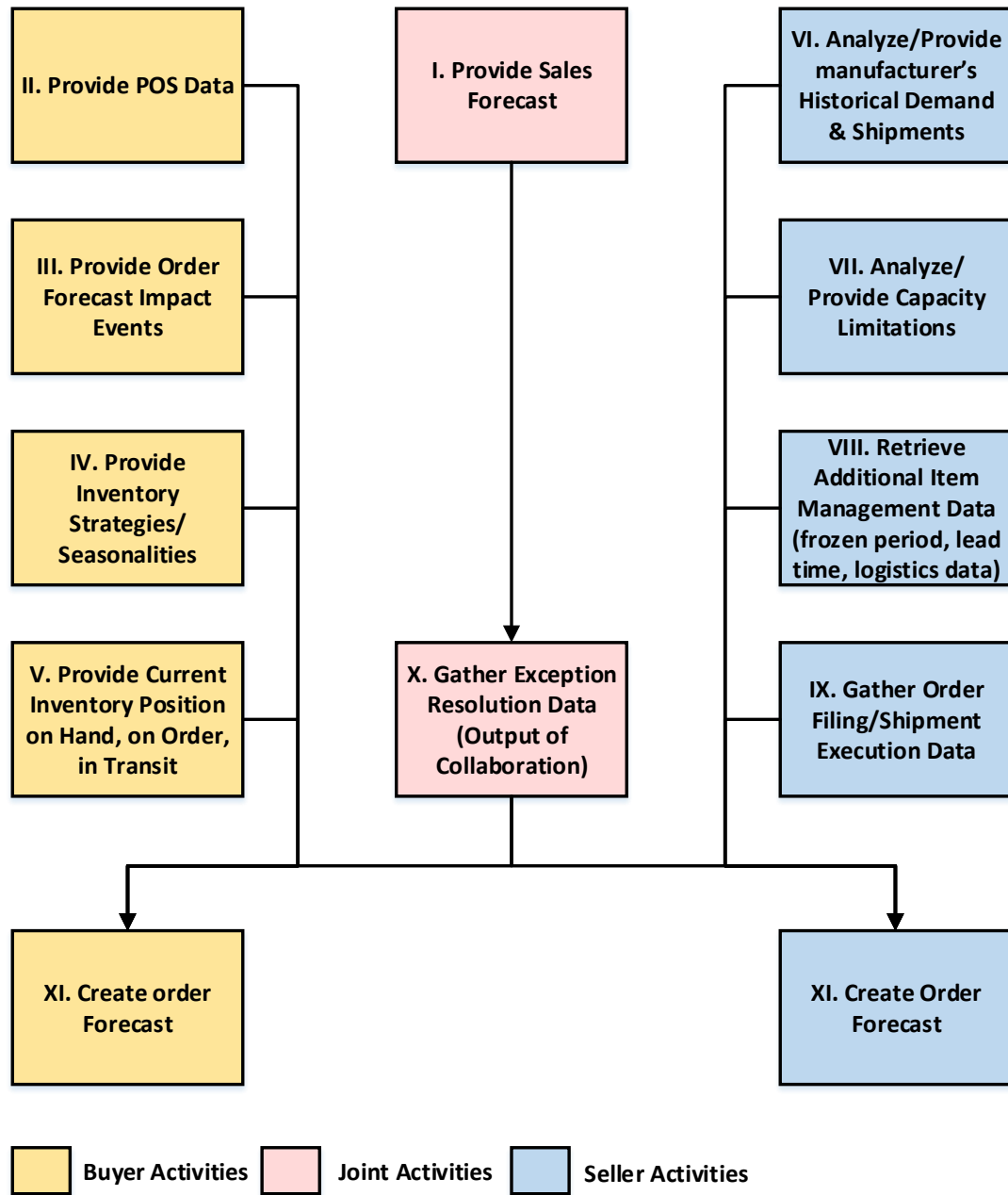


Figure 6.6 CPFR - Step 4



### 6.2.5 Order Generation and Fulfillment

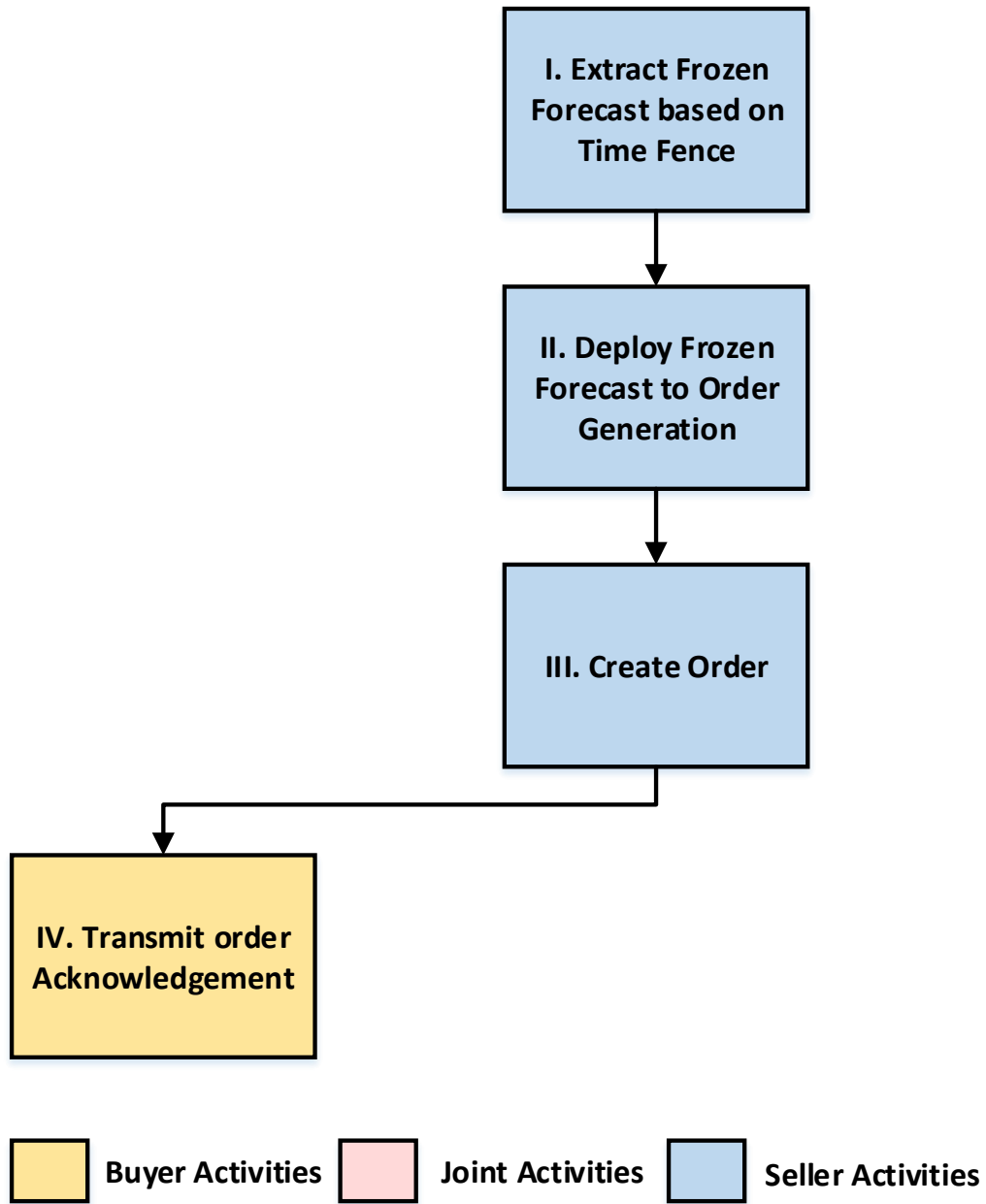


Figure 6.7 CPFR - Steps 5 and 6

6.2.6 Expectation Management

Identify Forecast Exceptions

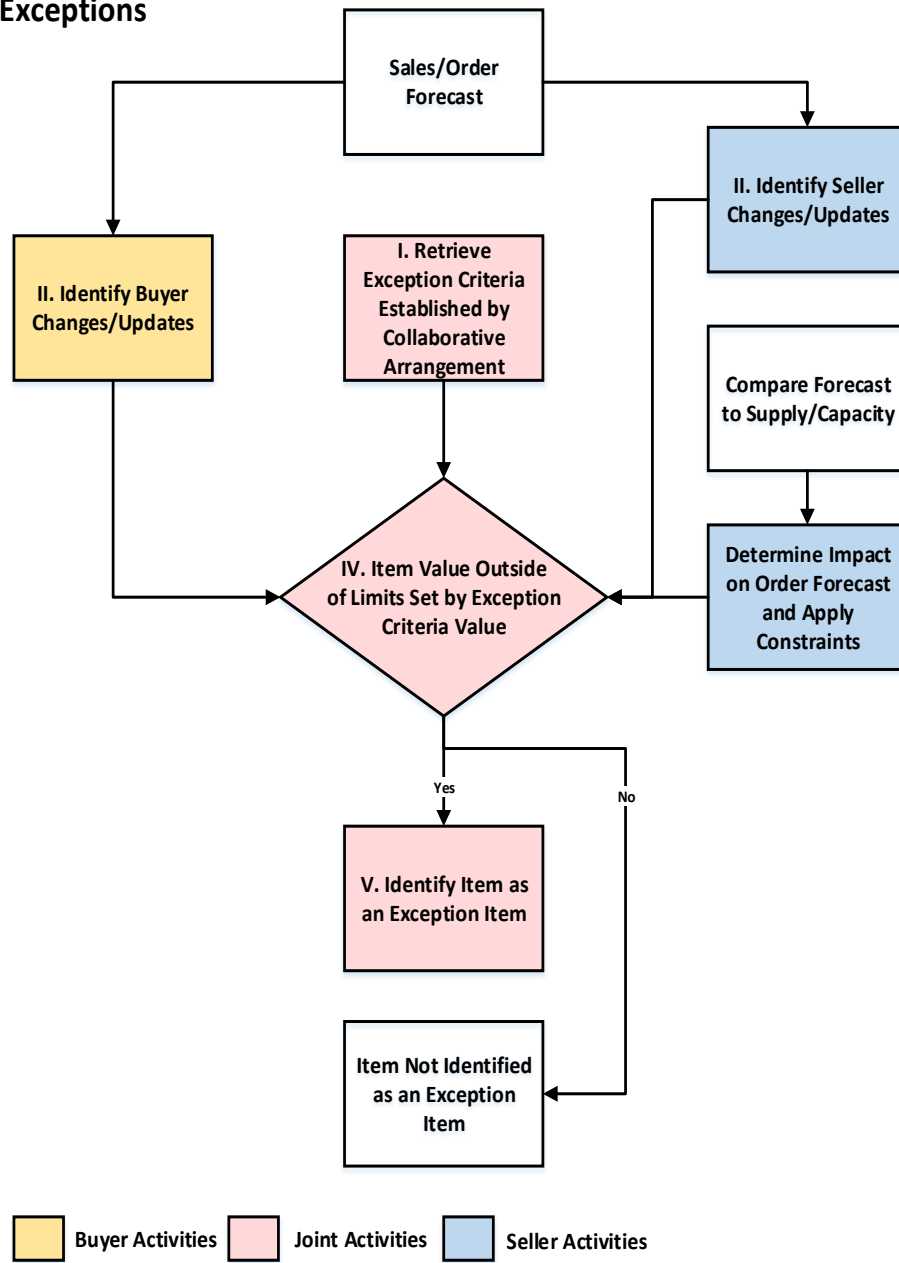


Figure 6.8 CPFR - Step 7a

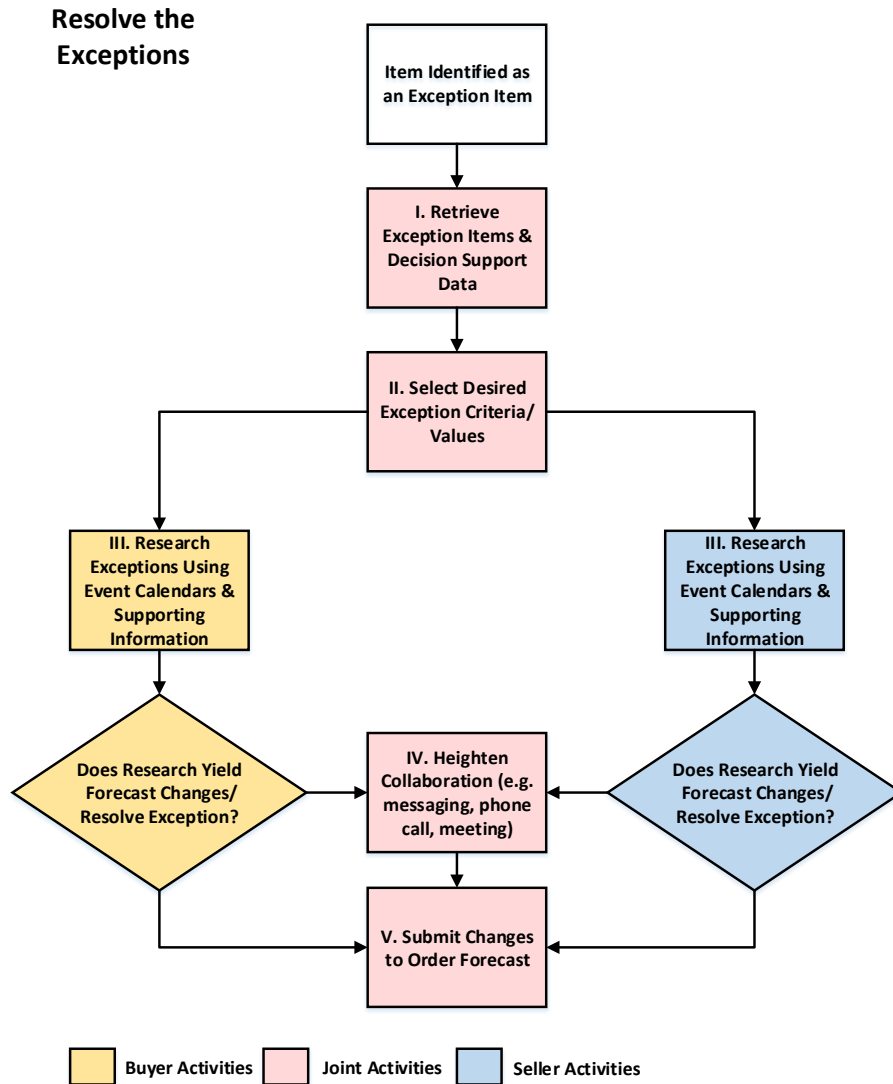


Figure 6.9 CPFR - Step 7b

### 6.2.7 Performance Assessment

Performance assessment is essential to any understanding of collaboration benefits. The specific measures can vary from one situation to the next, but generally fall into two categories:

- Operational measures: fill rates, service levels, forecast accuracy, lead times, inventory turns, etc.
- Financial measures: Costs, item and category profitability, etc.

In reality, partners are often reluctant to share financial measures and estimates of “profitability” can vary widely, depending on how one defines and assigns costs.

### 6.3 CPFRR COST FUNCTION

$$\begin{aligned} \text{CPFRR Cost} &= \text{Strategy and Planning Costs} \\ &+ \text{Demand and Supply Management Costs} \\ &+ \text{Execution Costs} + \text{Analysis Costs} \end{aligned} \quad (25)$$

Strategy and planning costs is divided into collaboration and arrangement costs:

- The collaboration arrangement should yield to a document that gives both partners a co-authored blueprint for beginning the collaborative relationship. This document: (1) Defines the process in practical terms, (2) Identifies the roles of each trading partner and how the performance of each will be measured, (3) Spells out the readiness of each organization and the opportunities available to maximize the benefits from their relationship, (4) Formalizes each party’s commitment and willingness to exchange knowledge and share in the risk.
- A mutually agreed upon joint business plan that clearly identifies the roles, strategies, and tactics for the SKUs that are to be brought under the umbrella of CPFRR. This plan: (1) Cornerstone of the forecasting process, (2) Should greatly reduce exceptions and the need for excessive interactions.

Demand and supply management costs is divided into sales forecasting costs and order planning/forecasting costs:

- Consumption data is used to create a sales forecast. This consumption data differs depending on the product, industry, and trading partners: (1) Retailer POS data, (2) Distribution center withdrawals, (3) Manufacturer consumption

data. Important to incorporate information on any planned events (ex. – Promotions, plant shut downs, etc.).

- Using POS forecast and inventory policy information, we can calculate when each store needs to release an order to the Retailer DC. And this info is then used to generate a replenishment forecast for the DC. The same process can be used to develop an order forecast for the manufacturer. The order forecast allows the seller to allocate production capacity against demand while minimizing safety stock. The real-time collaboration reduces uncertainty between trading partners and leads to consolidated supply chain inventories. Inventory levels are decreased, and customer service responsiveness is increased. A platform for continual improvement among trading partners is established.

Execution costs are mainly generated from order generation and fulfillment costs. This step marks the transformation of the order forecast into a committed order. Either the seller or buyer can handle order generation depending on competencies, systems, and resources. Regardless of who completes this task, the created order is expected to consume the forecast.

Analysis costs is formed of exception management costs and performance assessment costs:

- Exceptions need to be handled in both sales forecasts and order forecasts. The exception criteria are agreed to in the collaboration arrangement. Sales and order forecast exceptions are resolved by querying shared data, email, telephone

conversations, meetings, and so on, and submitting any resulting changes to the appropriate forecast.

- Performance assessment is essential to any understanding of collaboration benefits.

## CHAPTER 7

### ASSESSMENT OF ALTERNATIVES USING ANALYTICAL HIERARCHY PROCESS (AHP)

Analytical Hierarchy Process (AHP) is a theory developed in 1977 by Thomas L. Saaty based on pairwise comparison and connoisseurs' judgments in order to come up with the priority scale (Saaty, 2008). AHP is a multi-criteria decision making tool providing an approach to identify interaction among decision factors (Barker and Zabinsky, 2011).

#### 7.1 ALTERNATIVE DECISIONS VIS-À-VIS UNDERPERFORMING SUPPLIERS

In order for a company to decide whether to switch suppliers or increase the collaborative planning, forecasting and replenishment, these alternatives should be studied based on different parameters; hence the use of the Analytical Hierarchy Process. The alternatives in this study are:

- Switch supplier (A1)
- Increase the collaborative planning, forecasting and replenishment (A2)
- Maintain the status quo (A3)

#### 7.2 CRITERIA FOR ALTERNATIVES EVALUATION

The criteria involved in the selection of one of these alternatives are:

- Cost (C1)
- Feasibility (C2)

- Management willingness (C3)

### 7.3 AHP MODEL

Based on the alternatives and criteria developed in the subsections above, an AHP model is developed and hierarchy is shown in the diagram below.

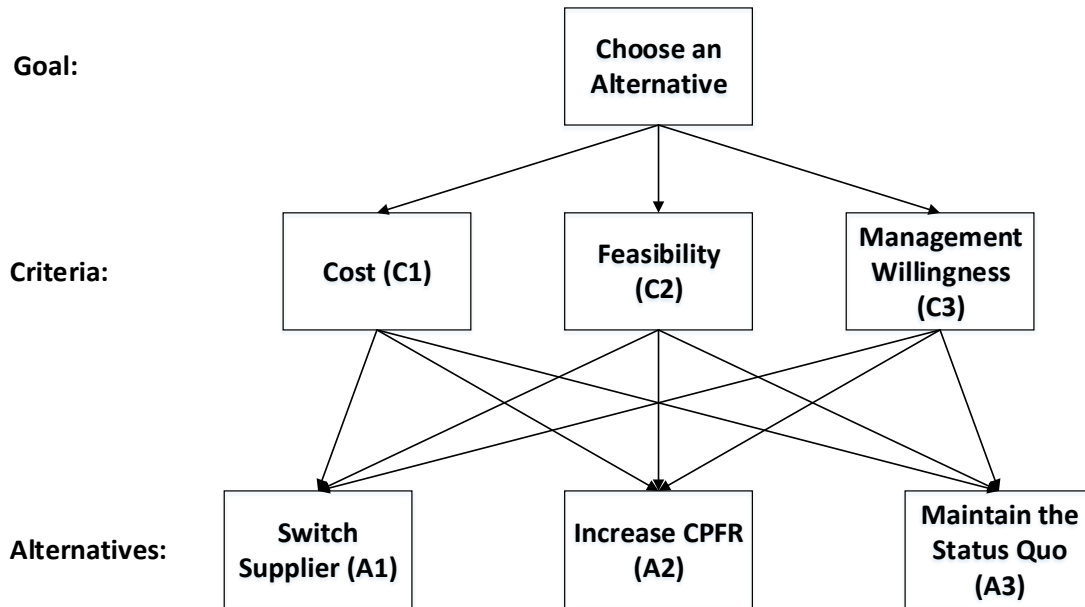


Figure 7.1 AHP Hierarchy Diagram

The first step in the AHP procedure is making pair wise comparison between each criterion (Saaty & Vargas, 1991). The below table summarizes the scales defined by Saaty (2008).



## CHAPTER 8

### USER INTERFACE ARCHITECTURE

We are currently developing a tool where users can assess suppliers, and take proactive measures against those that may be underachieving. The tool is designed to identify the lowest performing suppliers based on (1) the suppliers' ability to deliver on time and (2) their capability to deliver good quality. The system can also differentiate and identify the lowest performing suppliers per subcategory of product type supplied. The tool can then be used to evaluate the most effective solution, whether it be to switch suppliers, increase collaboration, or maintain the status quo. This interface is developed using Java script.

The figure below depicts one of the main tabs in the interface where the user specifies interest parameters for testing, and whether it was which suppliers the user is concerned in looking at, or which criterion they are interested to include in the index calculation (total quality cost, delivery time, or both).

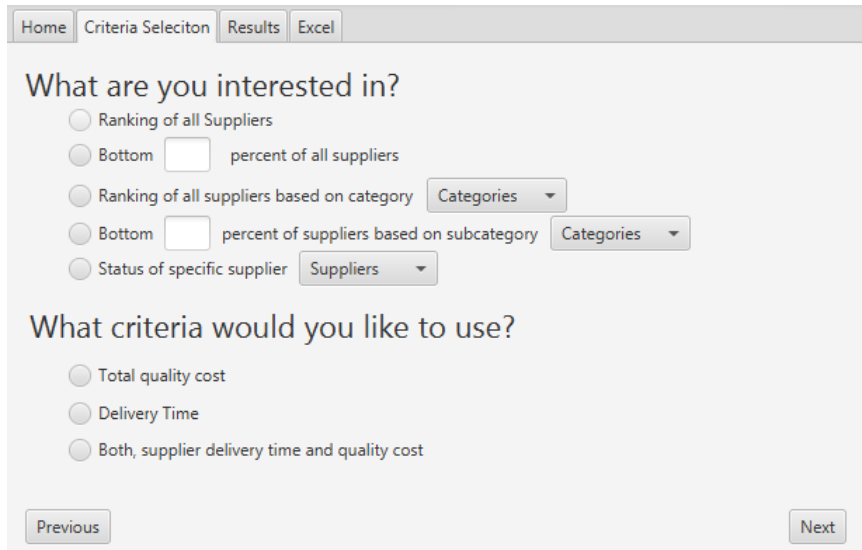


Figure 8.1 The interface's main tab

Below are some tabs from the architecture of the user interface currently being developed. The interface is developed using Java language.

First, user has to input an Excel© file containing the necessary information about their suppliers: suppliers' names, expected delivery dates, actual delivery dates, and other information related to suppliers holding and shortage costs.

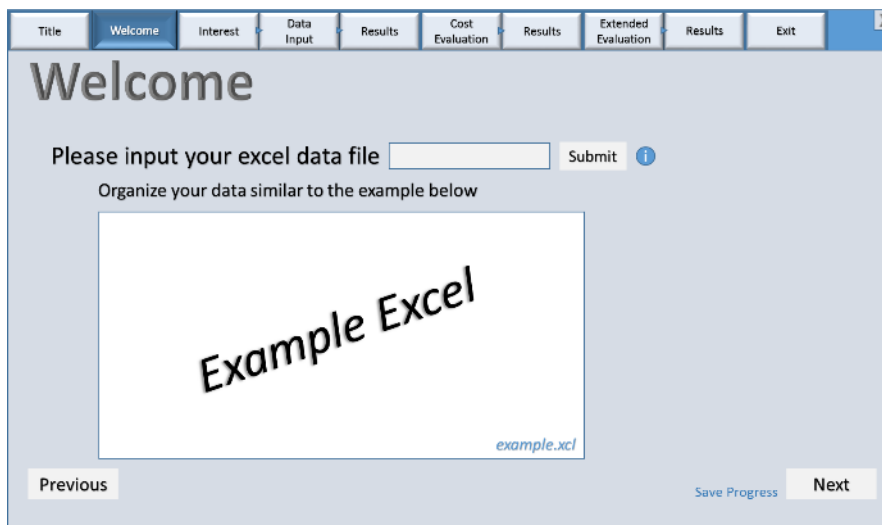


Figure 8.2 Welcome tab

After inputting the Excel© file, user chooses what they are interested in whether it was ranking all suppliers, or a certain percent of the underperforming suppliers, or just the status of a specific supplier. In addition, user specifies which criterion they would like to use in the calculation of the suppliers cost index: total quality cost, delivery time, or both.

The screenshot shows a software interface with a navigation bar at the top containing tabs: Title, Welcome, Interest (highlighted), Data Input, Results, Cost Evaluation, Results, Extended Evaluation, Results, and Exit. The main window content is titled "What are you interested in?" and includes the following options:

- Ranking of all suppliers
- Bottom [ ] percent of all suppliers
- Ranking of suppliers based on subcategory [ ]
- Bottom [ ] percent of suppliers based on subcategory [ ]
- Status of specific supplier [ ]

Below this section is another titled "Which criteria would you like to use?" with the following options:

- Total quality cost
- Delivery time
- Both, supplier's delivery time and quality cost

At the bottom of the window, there are "Previous" and "Next" buttons, and a "Save Progress" link.

Figure 8.3 Parameters tab

After choosing desired parameters, results can be derived. Many scenarios can be outputted based on the parameters. Below, are two scenarios depicting two different inputs.



Figure 8.4 Results tab (Scenario 1)

## CHAPTER 9

### CONCLUSION

Evaluating suppliers is a tough job that requires critical decision-making. When assessable, qualitative and quantitative figures help management monetize the possible alternatives at hand. The resultant decision-making strategy provides a more in-depth evaluation of suppliers that goes beyond management intuition.

Based on the literature review, it is evident that the main attributes implemented when assessing suppliers are the delivery time and delivered quality. Hence, the introduction of development for a future index founded upon these two attributes; recognized as the “Supplier’s Delivery Time and Delivery Quality Performance Index.” This index will be developed in future work to represent the performance of suppliers, and is necessary for further development into supplier evaluation. When faced with an underperforming supplier, management evaluates whether to switch their demand to a new supplier or to increase collaboration with the incumbent supplier, so that the current performance may be enhanced. This decision is primarily prompted by the cost of each alternative.

The current evaluation process norm is to study the alternatives and then make an “educated guess,” a decision primarily based on intuition. A more reliable evaluation system is possible by further assessment that includes cost models. Cost models for these

alternatives are deemed necessary for management to come to an informed decision, one to calculate the potential cost of switching suppliers and the other to calculate the potential cost of collaborative planning. These two models adjacent to the current cost would aid in the assessment of the alternatives: (1) switch supplier, (2) increase collaborative planning, forecasting and replenishment and (3) maintain the status quo.

This study provides a literature review comprised of a preliminary theoretical background and process, which serves as a basis for additional work to develop a thorough decision-making process for underperforming supplier assessment.

Evaluating suppliers is a tough job that requires critical decision-making. When assessable, qualitative and quantitative figures and numbers help management monetize the alternatives at hand, the resultant decision making strategy provides a more in-depth evaluation of suppliers that goes beyond management intuition.

Based on the literature review, it became evident that the main attributes implemented when assessing suppliers are the (1) delivery time and (2) delivered quality; hence, the development of an index founded upon these two attributes, which represent the performance of suppliers.

This study is part of a bigger picture where a detailed literature on current practices of supplier's assessment and valuation of decisions regarding underperforming suppliers was developed. A detailed research framework was developed based on this extensive literature. The first step of the framework is to identify the Supplier's Delivery Time and Delivered Quality Performance Cost Function based on a Markov chain model developed in this study. Based on the normalized Cost of all suppliers, suppliers are ranked in order to classify underperforming ones.

Two other cost models are to be developed in order to calculate supplier's switching cost and the cost of collaborative planning, forecasting and replenishment (CPFR). This will help decision makers chose to either switch supplier or increase collaboration.

In order to decide whether to switch suppliers, increase collaboration, or maintain the status quo, an analytical hierarchy process will be developed to choose between alternatives based on cost, feasibility, and management willingness .

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