Modeling the Impact of Complexity on Transportation

by

Jose A. Fernandez

M.B.A/M.S. Finance
Boston College, 2009

B.S. Business
ITESM (Mexico), 2003

and

Henry N. Okafor

M.B.A.
IE Business School, 2010

B.S. Geology
University of Ibadan (Nigeria), 2001

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Signatures of Authors..
Master of Engineering in Logistics Program, Engineering Systems Division
May 7, 2012

Certified by..
Dr. Chris Caplice
Executive Director, Center for Transportation and Logistics
Thesis Supervisor

Accepted by..
Prof. Yossi Sheffi
Professor, Engineering Systems Division
Professor, Civil and Environmental Engineering Department
Director, Center for Transportation and Logistics
Director and Founder, Master of Engineering in Logistics Program

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Abstract

This thesis aimed to understand the drivers of total transportation costs during supply chain complexity events, in particular new product launches, in a fast moving consumer goods company in the United States. The research specifically investigated which of the four key transportation cost drivers (line haul rates, length of haul, frequency of loads and regional factors) changed the most during a new product launch. The analysis showed that the main driver of transportation costs during a new product launch (for our case study) is the length of haul. This finding was used to further investigate how the allocation of transportation to factories within the distribution network affects the length of haul (and therefore total transportation costs) during a new product launch. The analysis also reveals that effective enforcement of line haul rates alone (with transport carriers) do not guarantee low transportation costs during new product launches. The total system transportation cost in 2011 was compared with the lowest cost mix of factories by transportation allocation. This cost comparison was done on the basis of the cost-to-serve each wholesaler in the distribution network. A model was then developed which can be used to predict the changes in transportation costs during supply chain complexity events, including specific variability. This research also revealed that total transportation costs (in the distribution network) increase significantly during complexity events and that the highest variability occurred in the high season for each launch location.

Thesis Supervisor: Dr. Chris Caplice
Title: Executive Director, Center for Transportation and Logistics

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- *Jose*

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1 INTRODUCTION

Companies in the fast moving consumer goods (FMCG) industry rely on a network of customers to distribute their products to the end consumer. It is therefore important that products are transported from the manufacturer's warehouses to these customers (typically via trucks) in a speedy and cost efficient way. This is especially difficult during unexpected fluctuations in the demand (for products) and supply (of transportation capacity). These unexpected variations (or complexity events) are characterized by more shipments and therefore more costs. Typical efforts by the transportation planning teams to minimize these costs (such as routing guide enforcement) may still not provide the optimal costs for the total transportation system.

In this thesis the complexity event being studied is restricted to a promotion or new product launch. During complexity events, the transportation departments of companies typically have very little time to react to a sudden spike in demand. This short notice can lead to less than optimal transportation capacity allocation decisions, such as selecting a more expensive transport carrier or servicing a customer from a more expensive factory location.

The changes in the total system transportation costs during a complexity event are driven by several factors. The goal of this thesis is to identify the principal drivers of these changes and to understand their behavior during complexity events. It also aims to propose criteria for making optimal transportation allocation decisions during complexity events. This thesis examines these issues from the perspective of CPGCo, a major player in the FMCG market in the United States.

1.1 Purpose and Motivation

Transportation costs constitute a major portion of the US economy and manufacturing business expenses. According to the 22nd Annual State of Logistics Report (2011), US business logistics systems costs accounted for up to 8.3% of national GDP in 2010, with annual transportation costs accounting for $760bn (or 5% of nominal GDP) and trucking accounting for up to 78% of these transportation costs (Wilson 2011). On average, FMCG manufacturers in the US spend up to 11% of their annual sales revenue to logistics and up to 42% of this is dedicated to outsourced logistics services (Cap Gemini 2010). In 2010, distribution costs were equivalent to about 5% of 2011 revenue at CPGCo in the U.S. However, with shrinking trucking capacity as a result of the 2010 recession (Wilson 2011) and forecasted 2012 gasoline and diesel price increases of 7% and 8% respectively (U.S. Energy Information Administration -March 2012), the cost of transporting FMCG products to consumers is expected to continue to rise.

As a result of this, companies like CPGCo will continue to explore ways to better manage their total transportation costs. Deciding the most optimal use of available transportation capacity on a day-to-day basis is a critical contributor to profitability and customer service. Caldwell & Fisher (2008) were able to identify potential cost savings of up to 4.1% through the modification of transportation business policies of manufacturing companies in the U.S. For a Fortune 500 company, such as CPGCo, every percentage point in cost savings counts.

1.2 Complexity and Total Transportation Costs

Supply chain complexity, and how it changes during new product launches, is extensively discussed in academic literature and often focuses on its impact on supply chain configuration (Graves and Willems, 2001), inventory management (Riggs and Tersine, 1978), retail order management (Shaojie Cui et al 2010) and innovative supply chain strategies (Yang and Yang, 2010) . Conversely, the impact of supply chain complexity on transportation carrier rates has been given much less coverage. This section covers the relevant and available material on supply chain complexity as a whole.

The term "complexity" in business has several definitions. It can be seen as a disruption, obstacle or complication in a business process. However, for this study, complexity is defined as any event that significantly changes the normal course of business, or status quo, in a supply chain process (in this case total system transportation cost behavior). This thesis categorizes complexity events at CPGCo into demand type events or supply type events. In general, demand type activities are caused by events that lead to a change in demand for trucking capacity by CPGCo and can include new product launches, promotions and product recalls.

Supply type events, on the other hand, limit the transportation carrier capacity available to CPGCo. Such events include seasonality, fuel price fluctuations, demand from competitors and macro-economic conditions. Even when carrier rates have been agreed on at the beginning of the year, these sudden events can make it more difficult for the carriers to honor these contracts. These events force shippers like CPGCo to look for alternative non-contracted carriers (usually from the routing guide) at often higher rates. Figure 1 below provides a pictorial representation of this relationship.

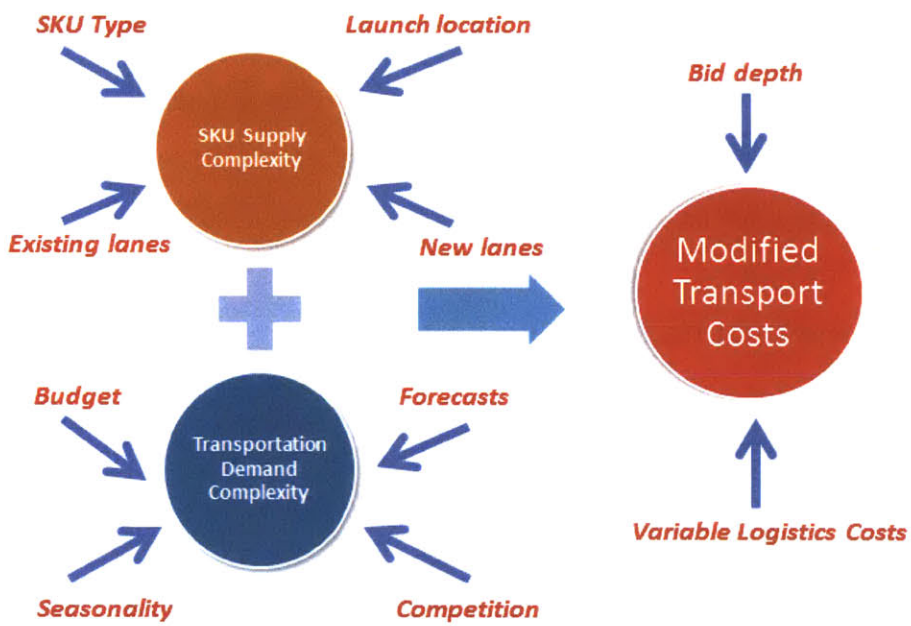


Figure 1.1: Transportation cost dynamics at CPGCo during new product launches

However, carrier rates constitute only one component of total transportation costs during a line haul move (straight line). Transportation costs in a line haul move from a warehouse to a customer are driven by four key factors:

- The rate charged per mile by the transport carrier for the line haul move
- The total distance covered during the line haul move
- The frequency or number of shipments
- Regional factors (movements between zip codes, forward move or backhaul move).

Some of these factors may also change with seasonality, such as the cost per mile or the regional factors.

Equation 1.1 demonstrates the relationship between the drivers which determine the total transportation cost (TTC):

$$TTC = \sum_{i=1}^{N} [(r_1)d_i + k_i] \qquad (1.1)$$

Where:

$TTC = Total\ Transportation\ Cost$

r_i = *cost per mile for load i (dollars per mile)*

d_i = *distance traveled on load i (miles)*

N = *number of loads*

k_i = *regional factor effect for specific origin and destination of load i*

i = *specific load from origin to destination*

Thus, any major change in total transportation cost during a supply chain complexity event is driven by a change in one or more of these variables. This thesis will focus on identifying and understanding which drivers most significantly affect the total transportation costs within the CPGCo distribution network during complexity events. It will also explore how this can help minimize total transportation costs during complexity events by optimizing the transportation capacity allocation between plants. As stated earlier, for the purpose of this study, complexity events will be reduced to new product launches which often result in an increase in demand for transport carrier capacity.

1.3 The CPGCo United States Distribution Network

The focus of this thesis will be on the CPGCo transport operations in the United States. CPGCo is a Fortune 500 company in the fast moving consumer goods industry. CPGCo also has global operations spanning over 20 major countries on each continent. In the United States, as of June 2012, CPGCo operates more than 10 plants producing over 100 million cases annually. These plants jointly produce up to 23 different global, multi-country and local brands for consumption within the United States. New product introductions also take place and are often produced by one or more plants at different times in the year. Imports of brands not locally produced can also be considered as new products.

Each of these new products was launched (or received) at one or more plants and re-distributed to any of the existing plants or directly to over 500 customers within the CPGCo distribution network.

The distribution value chain at CPGCo requires any of its plants to distribute directly to some or all its over 500 customers across the United States. Typically, the "primary source" of supply to a customer would be the closest plant. However, under certain circumstances (such as new product launches) some plants act as back up plants to the plant launching a new product. These "secondary source" plants ensure that the supply of mature products is maintained at these customers during the launch of a new product. During new product launches, the original primary plant may be responsible for supplying most or all of the customers within the distribution network with the new product.

Figures 1.2 and 1.3 illustrate the relationship between a "primary source" and a "secondary source" plant before and during a new product launch.

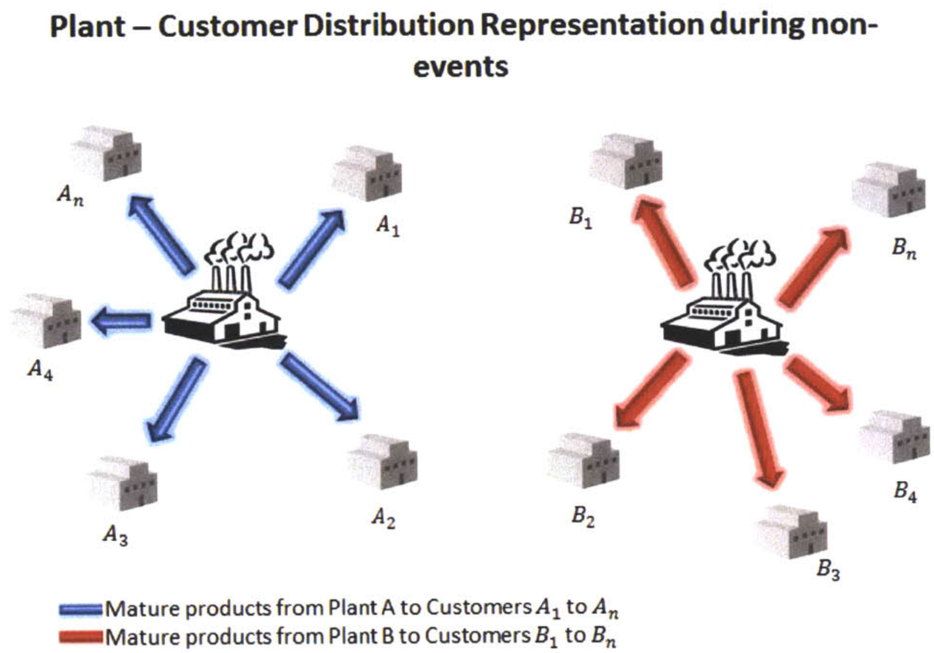


Figure 1.2: Distribution dynamics during a non-event (when no new products are being launched)

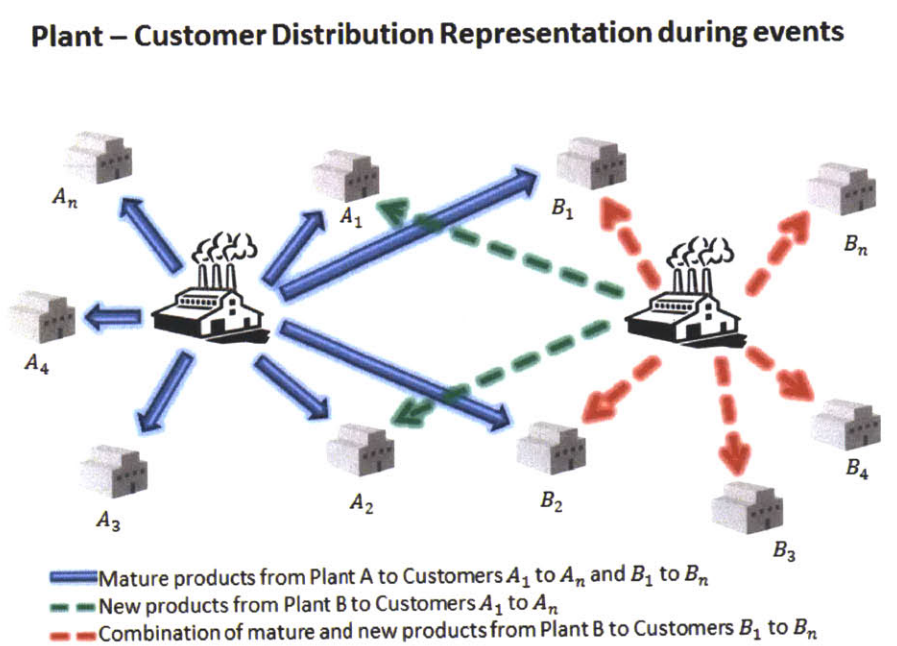


Figure 1.3: Distribution dynamics during an event (when a new product is being launched)

As can be seen in figure 1.2, during non-events (i.e. no new product being launched), plants within the CPGCo network concentrate on supplying a specific set of customers, usually the ones closest them. During, these occasions, a plant could also send products to another plant's customer, usually in a supporting capacity. However, during events (new product launches), as observed in figure 1.3, the dynamics change significantly. The launch plant supplies the new product to all the customers in the network. During this time, the launch plant allocates a portion of its mature product capacity to the new products. To fill the gap in supply to this plant's customers, other plants increase their supply of mature products to this plant's customers.

With over 20% market share of sales to retailers in the US, it is critical for CPGCo to distribute its products, new and mature, at the lowest possible costs. However, two conditions make this optimal cost planning particularly difficult during new product innovations:

i. New product innovations are usually initiated with very little notice to the transportation planning team (as little as 4 weeks).
ii. Contracted carriers may also be unable to honor requests to provide extra capacity or even agreed capacities, thus increasing the need for CPGCo to go deeper into the routing guide and use more expensive carriers.

1.4 Business Implication of this Study

With distribution costs over $400 million at CPGCo USA in 2011, savings in transportation costs from improved planning could significantly impact the bottom line. Another competitor in North America reported up to US$202 million in cost savings due to distribution related initiatives (such as centralized procurement of transportation services) and up to $73 million from other supply chain initiatives, such as data integration and improving forecast accuracy. Also, improved estimates of expected transportation costs can be used as input in selecting cost effective locations for new product launches, as well as for budgeting and planning. Better carrier management strategies could also be developed from the understanding of transportation capacity requirements during complexity events.

FMCG manufacturers depend on the relative stability of contracted lane-specific truckload transport rates for annual planning and budgeting purposes. These rates, derived through several carrier bidding mechanisms, may vary over the course of the year as a result of such factors as fuel price fluctuations, seasonality and regional factors. Overall, these oscillations are relatively well understood and expected by shippers and are factored into the final contract rates in one form or the other. But given the sharp increases or decreases which occur during complexity events, the total transportation cost to serve a customer within a company's distribution network can be difficult to predict. FMCG manufacturers can minimize the impact of these variations, through mechanisms such as routing guide enforcement, long term carrier contracts and preferential allocations to lower cost shippers.

However, during complexity events such measures may still yield costs that are less than optimal. The main reason for this is that freight rates are only one of the several factors that drive total transportation costs to serve a customer. This study examines freight rates and the other drivers of transportation costs with a view to understanding to what extent and to what manner they affect transportation costs. Braithwaite and Samakh (1998) identify transportation rates and distribution costs as one of the typical areas to examine in conducting a cost-to-serve analysis. They recommend unit calculations such as truckload equivalent units or truckloads in exploring the cost to serve. The unit explored in this study for cost calculations is the case. For the purpose of this thesis, a standard delivery truck is estimated to hold about 216.7 cases of FMCG liquid product.

1.5 Engineering Implication

This thesis identifies the right analytical tools and approach to deliver on the business objectives discussed above. Past research has been focused on inventory management strategies for managing unexpected demand, distribution network design to improve supply chain flexibility and strategic sourcing and postponement. This thesis attempts to cover the research gap in the area of transportation costs. By applying a similar scientific approach, this study aims to propose a working theory and model for understanding and predicting the behavior of total system transportation costs within a company's distribution network during complexity events such as a new product launch.

From an analytical perspective, this study presents some interesting questions. How do the main drivers of total system transportation costs change during complexity events? What would be a good rule of thumb for a transportation planner, in a company like CPGCo, to estimate the expected changes in transportation system costs during a complexity event? What is the optimal transportation allocation under specific time constraints (quarterly, monthly or weekly, seasons)? What criteria should be used in selecting the optimal "secondary source plants" during a complexity event? This thesis will attempt to provide a working model in order to answer these questions.

The remainder of this thesis is organized as follows. Chapter 1 provides the background, motivation, and value of this research. Chapter 2 provides a brief review of literature covering supply chain complexity and the various approaches that have been used to mitigate its effect. In Chapter 3 the analytical methodology and approach employed is explained; specifically the framework for predicting the change in total system transportation costs during complexity events. Chapter 4 presents the results of the data analysis and shows to what extent it supports the hypothesis on expected changes in transportation costs during complexity events. Chapter 5 concludes with strategic, operational and tactical recommendations for managing transportation cost changes during complexity events. Areas for further research are also included to refine the performance of the proposed framework.

2 LITERATURE REVIEW

The impact of supply chain complexity on operational performance is well documented in academic literature. However, the scope of previous research has been limited to the impact of supply chain complexity on inventory, production and customer service. Such research dates back to 1958 with the introduction of the concept of industrial dynamics (Forrester, 1958).

The specific impact of supply chain complexity on transportation costs has had much less coverage. The earliest literature coverage on the impact of demand amplification on transportation was found in 2007 (Potter and Lalwani, 2007). While the effect of a specific supply chain complexity event, such as a new product launch, has also been researched (Pero et al. 2010), work on its impact on total system transportation costs was not found.

This literature review examines existing relevant literature on supply chain complexity; the nature of new product launches and how they cause supply chain complexity; truckload transportation dynamics; and the behavior of transportation costs in response to sudden demand and supply variations. This overview provides the framework for developing the methodology and selecting the analytical tools in order to examine the behavior of transportation costs in response to new product launches.

2.1 Supply Complexity Overview

Supply Chain Complexity has been defined and examined in many different ways. Isik (2010) defines supply chain complexity as "quantitative differences between predicted and actual states which are associated with uncertainty and/or variety caused by internal and external drivers in a (supply chain) system."

Academics have also attempted to simplify the concept of supply chain complexity by identifying its characteristics and segmenting it into various categories. Frizelle and Woodcock (1995) segment supply chain complexity into two: structural and operational. Structural or static complexity deals with schedule variety; while operational or dynamic complexity deals with uncertainty or deviations from a pre-agreed schedule. Wilding (1998) describes the interaction between deterministic chaos, parallel interactions and demand amplification as "the supply chain complexity triangle". Milgate (2001) discusses the peculiar challenges in managing the three dimensions of supply chain complexity: uncertainty, technological intricacy and organizational systems.

The sources of complexity in the supply chain are diverse but all have the characteristic of being unpredictable. Arteta and Gachietti (2004) demonstrate that supply chain complexity arises from not only the size of the system but also from the interrelationships of its components and the emergent behaviors that cannot be predicted from these individual components. Christopher (2005) describes complexity as arising from connectedness and dependencies of supply chain actors across a supply chain network. He identifies eight types of supply chain complexity: Network, Process, Range, Product, Customer, Supplier, Organizational and Information complexity. This thesis studies the behavior of transportation costs during new product launches, where four of these complexity types overlap, namely range, network, supplier and information complexity.

Isik (2010) classifies supply chain complexity into two general categories:

1. Internal– Associated with material and information flows *within* a business partner of a supply chain, such as process deficits, material shortness, etc.
2. External– Associated with material and information flows exported by other business partners to a specific partner, potentially caused by globalization, technological innovation, customer demand variety, etc.

The behavior of transportation costs at CPGCo, which we will be studying in this thesis, has both internal and external components. Figure 2.1 below illustrates the interaction between the components of these categories:

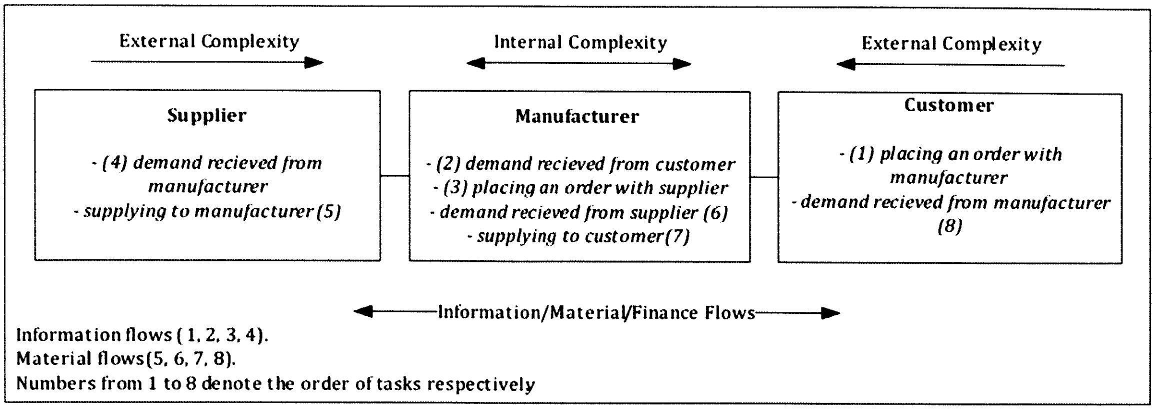


Figure 2.1: Sources of complexity in a typical supply chain (Source: Filiz Isik (2011).

After identifying the sources of supply chain complexity, it is equally helpful to identify its drivers. According to Reiss (1993), there are four drivers of supply chain complexity: size, diversity, variety of variability and uncertainty. Size includes the number of products, processes, partners, customers, goals, locations, etc. The higher the number of the systems' components, the higher the complexity. Diversity refers to a measure of the homogeneity or heterogeneity of the components. The more heterogeneous the components of a system are, the higher the degree of complexity. Variety or variability is associated with the variations of internal and external states, requirements and sources in the course of time.

Supply chain complexity is not always a negative thing. While stating that the best approach to dealing with the challenges of supply chain complexity is by building adaptability into the supply chain, Christopher (2005) notes that, it is still important for companies to have just enough complexity to remain differentiated in the market place. Fast moving consumer goods companies utilize product launches, among other strategies, to fight the intense growth in commoditization, while trying to keep costs low and improve service levels. Successful companies are those able to master this evolution by seeking an overall cost reduction while maintaining or improving overall efficiency. Therefore, supply chain complexity can actually improve a company's bottom line. It could help grow market share, enable flexibility and facilitate opportunities in completely new markets. High complexity confers key financial advantages, such as when the additional costs generated can be transferred to a customer who displays significant demand variability.

2.2 New Product Development (NPD) and the Supply Chain

New product launches introduce complexity into various components of the supply chain. According to Pero et al. (2010), supply chain management and new product development are related to each other since the supply chain produces and distributes the product, which is the output of the development process. Transportation is one of the key components of this supply chain.

Most research on the impact of new products on the supply chain has focused on their impact on inventory management at various stages of the product life cycle. A proposed solution for managing this complexity by Holmstrom et al (2006) concentrates mainly on using point-of sales and channel sell-through data to improve the forecasting process and hence associated costs, such as transportation costs. This has limited applicability in studying the behavior of transportation costs during a new product launch, as most of the transportation allocation decisions are driven by other factors such as the location of the product launch, the number of plants producing the new product and the proportion of production capacity allocated to the new product.

Cui et al (2011) suggest a systems dynamics modeling approach to deal with supply challenges during new product launches. Their model allows for launch scale adjustments to be made in response to various factors such as inventory management, pricing and distribution. While this may be directly useful for developing appropriate inventory management strategies there is limited applicability in managing transportation costs.

At the end of the 20th Century, leading manufacturing organizations have begun to realize that logistics costs account for an increasing share of total costs of new product development. Their focus is shifting to finding different ways to contain such costs while maintaining or improving customer service (Lee and Sasser 1995).

Zacharia and Mentzer (2007) have attempted to fill the existing literature gap with respect to the level of logistics involvement in new product development and organizational performance. Their analysis is based the resource dependence theory (RDT). This theory suggests that as a role becomes more relevant within a company and manages vital resources, the greater the likelihood it would be involved in important decisions and interests.

In order to reduce the impact of complexity events on cost and performance, the entire supply chain process (including transportation) must be involved in new product development activities as early as possible. Pero et al., (2010) propose a framework for managing the supply chain during new product launches, by focusing on aligning modularity, innovativeness and variety. Figure 2.2 below shows the components of this framework and the relationship expected between new product development and the supply chain process.

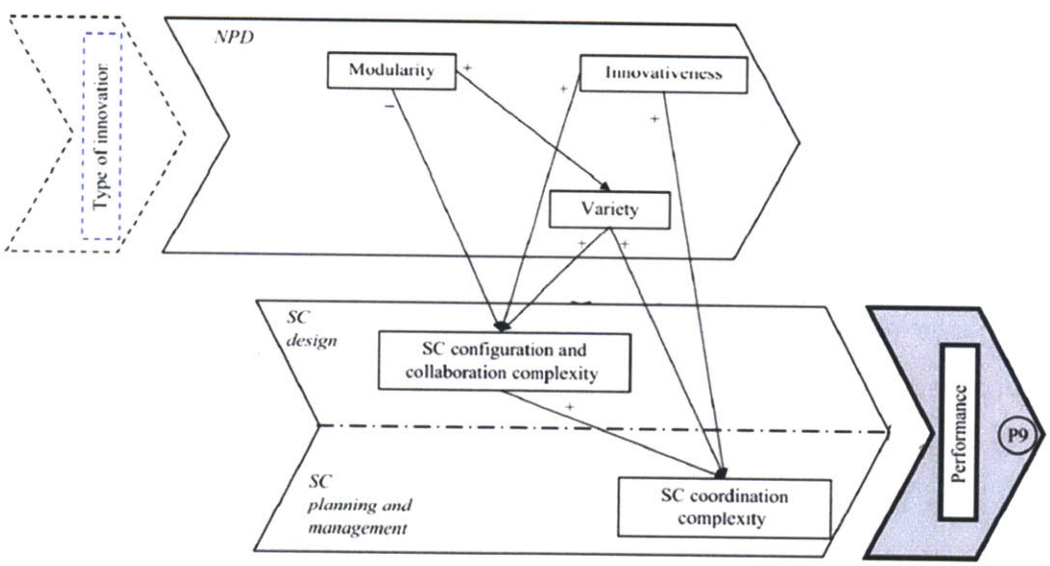


Figure 2.2: A framework for the alignment of new product development. Pero et al., (2010)

2.3 Managing Supply Chain Complexity In Practice

To get a clearer picture of how logistics and transportation planning professionals currently manage complexity events, external interviews were conducted with supply chain stakeholders in the following industries: Foods, Vision & Laser, Computerized Arcades, Aero manufacturing, and Confectionary & Tobacco.

Each respondent was asked questions about how their supply chain planning team manages supply chain complexity, especially new product launch events. The key questions asked where:

- How do new product launch events affect the transportation planning process in your company?
- What other types of supply chain complexity affects your company's transportation planning process?
- How does the supply chain department adjust to demand uncertainty in general?

The key types of supply chain complexity events faced by these supply chain managers were new product launches, sales cycle variability, unexpected increases in selling prices due to economic conditions, import/export issues, third-party freight handling constraints, unanticipated delays in suppliers' deliveries, extreme weather conditions and merchandise thefts. Most agreed that biggest challenge faced was due to variety and volatility in the supply chain (External Company Interviews 2012).

The main activities which were incorporated into the supply chain planning process include aligning key performance indicators across both logistics and other departments, shifting and overlapping sales and distribution cycles, actively seeking notifications of new product launches, improving forecast accuracy, working with large transport carriers who were most likely to absorb variability in demand from the companies, paying extra fees to carriers when the cost-value ratio favors their company and relying on larger and more trustworthy insurance companies to minimize the negative impact of these events (External Company Interviews 2012).

Similar interviews were administered at CPGCo to get a clearer of picture of their response to supply chain complexity events, specifically new product launches. A transportation planning manager in one of its US plants noted that while the transportation cost impact of new product launches was budgeted from the sales forecast annually, there were challenges with this. Some new product launches took place outside the normal planning cycles. In 2011, for example, 50% of launches from one US plant were unplanned (i.e. not included at the beginning of the budgeting cycle). The notice period varied depending on the type of launch. On average packaging changes were initiated and planned within 4 weeks while line extensions took between 2 and 3 months (Internal Company Interviews 2011).

CPGCo distributes its products through over 500 customers in the US market. Managing the availability of inventory and transportation is critical to ensuring product availability at these customers. Its transportation mix comprised on average of 40% dedicated fleet, 10% brokers and 50% over-the-road carriers. CPGCo encouraged direct loading (loading of trucks directly from palletizers to trucks) in all its factory locations. However, on some occasions floor-loading (loading from dedicated sections of the warehouse) occurred, which implied additional handling costs. In addition, the choice of a product launch site is very dependent on manufacturing set up requirements. When one or more factories are selected as launch sites they serve as the primary source of the new product to all customers in the CPGCo distribution network. Hence, launch factories would transport the new products directly to customers nationwide, including customers normally served by other factories. The responsibility of delivering mature products to a launch factory's customers was often taken up by one or more non-launch factories. During such occasions factories served as temporary distribution centers, i.e. relying on more floor-loading (Internal Company Interviews 2011).

2.4 Truckload Transportation Operations and Cost Behavior

For many FMCGs trucking spend accounts for a large portion of annual revenue. In 2010, motor carrier transportation accounted for up to $592 billion of total logistics costs in the US and experienced a growth of 9.2% (Wilson, R. 2011). At CPGCo North America, distribution expenses grew by 0.21% in 2011 despite shipment volumes decreasing by 3.2%. PepsiCo, another major US FMCG spends over $900m annually on truckload transportation, using over 500 different carriers, travelling over 800,000 lanes and carrying over one million loads (Hair et.al, 2012). A key means of controlling these expenses, according to PepsiCo, is the effective procurement and allocation of truckload transportation capacity.

Caplice (2007) describes how typical truck load capacity procurement takes place in the industry. He classifies this process into three stages: pre-auction, auction and post-bid stage (Caplice, 2007). He points out that while several methods, such as the winner determination problem (WDP) algorithm, helps shippers to pick the optimal carriers per lane; shippers maintain a series of alternative carries, due to high rejection rates (26%). Also the outcome of these auctions is not completely binding on any of the parties. Carriers are contractually obligated to provide capacity on the given lane they won, only to haul loads at the agreed rates. Carriers can reject loads for various reasons – lack of a continuous move (i.e. no follow on load), fuel rate hikes, etc. Also shippers are not contractually obligated to always provide loads on lanes. They simply have the option to request for capacity on the lanes the awarded to carriers during the bid. Rejection rates force shippers to resort to electronic catalogs (routing guides) and when this fails, exchanges (spot markets) usually at significantly higher rates. Despite these outcomes, the procurement bidding process using combinatorial auctions still remains popular. Combinatorial auctions have saved shippers between 3 - 15% of transportation costs while maintaining service levels (Sheffi, 2004).

Understanding the behavior of carrier rates under different conditions can help improve transportation planning especially in the fast moving consumer goods industry. Caldwell and Fisher (2008) studied the impact of lead time on truckload transportation rates in the spot market. They observe that the short lead times result in increased depth of the routing guide, increased load rejection and increased costs of shipment. They also observe significant variations in rates depending on the pickup and tender day of the week. In a white paper presented by CH Robinson (2010), their research shows that shippers always pay a premium over contract rates, whenever they resort to the spot market as a result of rejections. Even in the periods 2008 – 2009, at the height of the financial crisis, spot rates remained higher than contracted rates. This further highlights the need for both shippers and carriers to jointly examine shipping history to help optimize costs on specific lanes.

This thesis specifically studies new product launches, their impact on total cost, and attempts to develop a basis for making optimal transportation capacity allocation decisions during these type complexity event. Optimizing the total system transportation costs, while enforcing the contracted rates in the routing guide, will certainly be an important element in achieving this.

3 METHODOLOGY

Our approach to investigating this problem consisted of five sequential steps. First, we defined a working hypothesis statement, followed by a review of the data to identify key assumptions and decision filters. Then we conducted a statistical analysis to identify potential trends and to summarize the data. We also present an overview of software tools employed and sectors not covered in the analysis.

3.1 Hypothesis

The question this project attempted to prove is whether total transportation costs increase during a complexity event when compared to time windows when there are no complexity events taking place. The following is the hypothesis statement examined throughout the analysis:

a) Hypothesis null: total transportation costs increase during a complexity event.
b) Hypothesis alternative: total transportation costs do not increase during a complexity event.

3.2 Data Organization

3.2.1 Key Assumptions

After receiving CPGCo's U.S. transportation transactional data for 2010 and 2011, we proceeded to remove any records that contained missing, irrelevant or erroneous values, specifically when the records presented:

- Duplicate Load ID values.
- Blank load ID, origin city, destination city, distance traveled, SCAC code or line-haul cost fields.
- Destination located outside the contiguous 48 U.S. states and Washington DC.

- Rates per mile lesser than $0.50 or greater than $15, under the assumptions that they might include any credit outstanding values or that the figures were documented erroneously.

This practice shrunk the database by 22%, from a total of 1,546,222 records to 1,206,977.

3.2.2 Decision Filters

Due to the elevated overall increase in market or industry rates per mile observed in 2011 with respect to those of 2010 (52.4%), our study mainly focused on complexity events that took place in 2011. This procedure enables our final model to calculate projections with a significantly more accurate forecasting level. Our dataset shrunk by 48%, to 626,244 records.

Furthermore, due to different characteristics associated to utilizing dedicated and non-dedicated fleets, such as supervision and control, contracts in place and lanes covered, CPGCo suggested the analysis be restricted to those transactions operated by non-dedicated fleets.

Accordingly, we divided the database records into two large segments: (1) shipments performed by CPGCo's dedicated fleet, and (2) shipments completed by non-dedicated carriers. We analyzed average behaviors of segments covered by both the dedicated and non-dedicated fleets when a complexity event takes place. However, our study focused more on the non-dedicated section, as this could require the company to hire transportation suppliers on the spot market, where freight rates are not stipulated on previously negotiated contracts. This reduced our database to 384,490 transactions.

The following plants of CPGCo experienced at least one complexity event in 2011:

1) Factory 1
2) Factory 2
3) Factory 8
4) Factory 10
5) Factory 11
6) Factory 12

With the exception of Factory 10, the remaining five plants listed above presented at least one exclusive complexity event during 2011. (i.e. the product was launched by only one factory)

The following plants did not host any complexity event:

1) Factory 3
2) Factory 4
3) Factory 5
4) Factory 6
5) Factory 7
6) Factory 9

Subsequently, we separated the remaining transactions into twelve different segments, according to each plant's customer network. Having split the data, we proceeded to work with the following values:

Plant	Customer Locations	% of Shipments
Factory 1	36	1.9%
Factory 2	61	8.1%
Factory 3	124	10.7%
Factory 4	39	3.2%
Factory 5	127	14.3%
Factory 6	71	13.5%
Factory 7	64	14.7%
Factory 8	48	8.4%
Factory 9	25	1.9%
Factory 10	48	6.5%
Factory 11	83	9.1%
Factory 12	77	7.8%
TOTAL	**803**	**100%**

Table 3.1: Number of usable complexity events from 2011 dataset

3.2.3 Additional Variables Created

The following concepts were added to our database with the intension of providing a more in-depth analysis:

1) Line-haul cost per Mile:

With the intention of having a metric that would allow us to compare the different transactions on an average scale, we computed the following equation:

$$\text{Linehaul Cost per Mile} = \frac{\text{Linehaul cost per load}}{\text{Miles per load}} \tag{3.1}$$

2) Cost per Case:

This variable was added to compare CPGCo costs in selling units. The respective calculation can be explained using the following equations:

$$\frac{\text{Linehaul Cost}}{\text{Case}} = \frac{\text{Linehaul cost per load}}{\text{Cases per load}} \tag{3.2}$$

$$\text{Cases per load} = \left(\frac{ft.^3 \text{ per load}}{ft.^3 \text{ per case}}\right) = \left(\frac{4{,}044\ ft.^3}{18.7\ ft.^3}\right) = 216.7\ \text{cases/load} \tag{3.3}$$

3) Week Number:

This study required the organization of operations observed in time portions that would allow us to analyze the behavior of each complexity event in more detail. As a result, weekly groups were created to classify the different transactions according to departure time.

3.2.4 Geographic Distribution of Final Database

The map below shows how the dataset is distributed across all the regions of the contiguous 48 states and Washington, D.C.

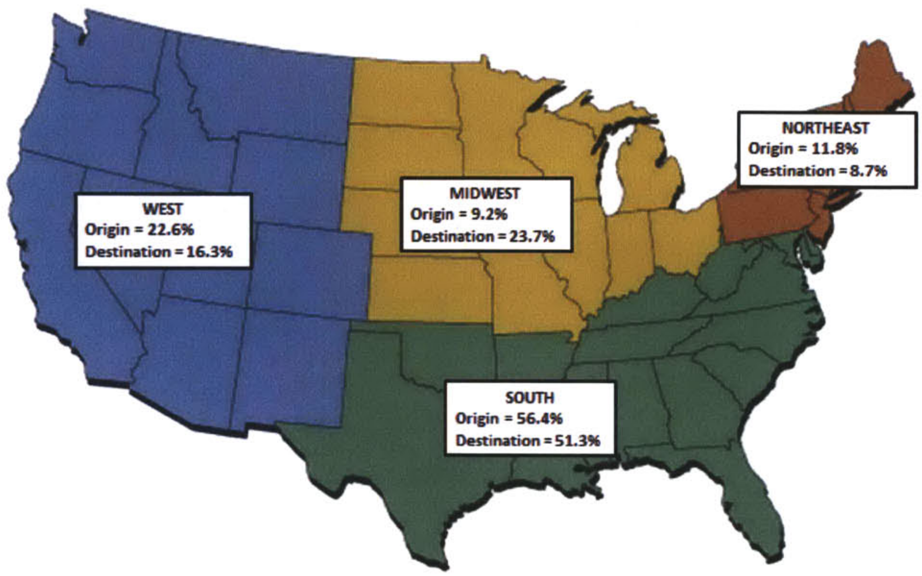


Figure 3.1: Distribution of shipments per geographic region

3.3 Statistical Analysis/Approach

3.3.1 Statistical Techniques

To get a preliminary sense of the impact that the different variables analyzed in our project have on the Cost-per-Case observed in our final database, we utilized the multiple linear regression model. This model assumes that there is a linear relationship between a dependent variable Y (in this case Cost-per-Load), and multiple independent variables $X_1, \dots, X_n$. This relationship can be stated in the regression linear equation:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \cdots + \beta_n X_{ni} + \varepsilon_i \quad (3.5)$$

Where:

$\beta_0 = Regression\ constant\ intercept\ coefficient$

$\beta_1, \beta_n = Regression\ coefficients\ assigned\ to\ independent\ variables\ to\ minimize\ the\ sum\ of$ *squared errors between each individual observation and the regression line.*

ε_i = *error term that captures the effect of factors ignored in the model.*

This model also provides a coefficient of determination R^2, which measures the extent to which the equation of the independent variables $X_1, \ldots, X_n$ successfully accounts for the variation in the dependent variable Y. This coefficient can be obtained using the following formula:

3.6

$$R^2 = 1 - \frac{residual\ sum\ of\ squares}{total\ variation}$$

This coefficient is then adjusted to reflect by how much the variability of the observations (n) is explained in the model, based on the number of independent variables included (p) and the respective degrees of freedom $(n - p - 1)$:

3.7

$$Adjusted\ R^2 = 1 - \left[\frac{n-1}{df}\right] * (1 - R^2)$$

The closer the coefficient of determination value is to 1, the more accurate the regression model is with respect to the data sample.

In addition, each independent variable coefficient is tested using a *t*-statistic to determine, with respect to a specific significance level (α), whether their true individual values are different from zero or not.

The following tables summarize the output of the regression model computed in our analysis:

**Note: Factory 1- Origin and Factory 1- Destination were excluded from the analysis to avoid over-specification.*

Concept	Value
R squared	0.59
Adjusted R squared	0.59
Significance Level (α)	5%
Degrees of Freedom (df)	350,734

Table 3.2: Multiple linear regression result summary

	Variable	Coefficient	Error	p-value
	Intercept	-10.15	3.31	0.0022
	Distance (miles)	1.09	0	<.0001
	Event	4.48	2.16	0.0376
Origin	Factory 2	269.32	3.32	<.0001
Origin	Factory 3	351.03	3.52	<.0001
Origin	Factory 4	760.93	6.03	<.0001
Origin	Factory 5	162.18	3.6	<.0001
Origin	Factory 6	112.19	3.92	<.0001
Origin	Factory 7	90.17	3.61	<.0001
Origin	Factory 8	743.42	4.33	<.0001
Origin	Factory 9	-245.26	5.86	<.0001
Origin	Factory 10	-47.84	3.47	<.0001
Origin	Factory 11	455.99	3.28	<.0001
Origin	Factory 12	191.56	3.29	<.0001
Destination Network	Factory 2	-81.57	2.87	<.0001
Destination Network	Factory 3	-112.16	2.77	<.0001
Destination Network	Factory 4	-403.98	4.46	<.0001
Destination Network	Factory 5	-20.96	2.92	<.0001
Destination Network	Factory 6	12.6	3.14	<.0001
Destination Network	Factory 7	111.3	2.94	<.0001
Destination Network	Factory 8	-355.71	3.45	<.0001
Destination Network	Factory 9	558.1	4.58	<.0001
Destination Network	Factory 10	350.71	3.09	<.0001
Destination Network	Factory 11	-247.97	3.05	<.0001
Destination Network	Factory 12	12.088	3.19	0.0002

Table 3.3: Multiple linear regression independent variable result summary

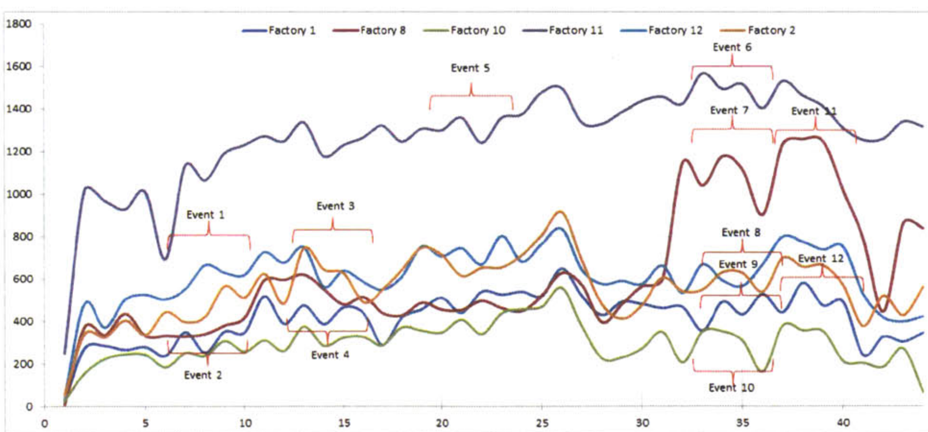
It can be observed that 59% of the behavior of the Cost-per-Load variable can be explained by the set of independent variables mentioned in the previous table. It is important to highlight that, according to this regression analysis, the Cost-per-Load would be $4.48 more expensive if it took place during a complexity event. In addition, all the coefficients associated to all the independent variables are statistically significant at a 5% significance level, as all of their p-values are lesser than 0.05.

3.3.2 Complexity Event Assumptions

The following are key assumptions specifically related to complexity events that were followed in our analysis:

1) Event Duration:

Guided by the chart below, which shows the number of shipments originated by each of the complexity participating plants, it was estimated that the impact of an event on shipping volume was observe in the first five weeks after each event's starting date. This time window covers the initial impact observed in the number of transactions generated by each plant.



**Note: Red Brace = 5 week span after event starting date.*

Figure 3.2: Snapshot of shipments showing peaks during complexity events (Adapted from Company Shipment data)

2) Event Scope:

During each event, we analyzed the shipments where the final destination was a customer within the event plant's network. This included shipments made by either the event plant or any other plant performing a backfilling operation.

3) Shipments filtered:

In some cases two complexity events took place during the same time frame. In such cases, the shipments originating from an event plant different from the event plant analyzed at that point in time were not included. Accordingly, the following numbers of records were excluded:

Event Plant	Omitted Records
Factory 1	130
Factory 2	583
Factory 8	389
Factory 11	190
Factory 12	598
TOTAL	**1,890**

Table 3.4: Records omitted from data analysis

4) Event Dimensions:

The following aspects were also taken into account during the study:

- Event's geographic extension:

Plant	Regional	Nationwide
Factory 1	1	4
Factory 2	-	1
Factory 8	-	1
Factory 11	-	1
Factory 12	-	2
Multiple Plants	2	1
TOTAL	**3**	**10**

Table 3.5: Scope of supply chain complexity event

- Event's Seasonality:

Each plant has a specific high and low season during the course of a year, which is determined by the company's transportation planning team.

Plant	High Season	Low Season	Mixed Seasons
Factory 1	3	2	-
Factory 2	1	-	-
Factory 8	-	1	-
Factory 11	1	-	-
Factory 12	1	1	-
Multiple Plants	-	-	3
TOTAL	**6**	**4**	**3**

Table 3.6: Seasonality variation at each event plant (Source: Company Planning Team)

- Number of events per plant

Plant	No. of Events
Factory 1	5
Factory 2	1
Factory 8	1
Factory 11	1
Factory 12	2
Multiple Plants	3
TOTAL	**13**

Table 3.7: Number of events at each event plant in 2011

3.3.3 Method Description

Each event studied was compared to how CPGCo serviced a specific event plant customer network during a non-event period. The most relevant metrics analyzed were:

1) Number of shipments.
2) Proportion of shipments originated at event plant and at backfilling or supporting plants.
3) Average cost per load.
4) Average cost per case.

The results of these metrics were then analyzed with the purpose of fulfilling each of the following tasks:

1) Determine whether the hypothesis null is correct or not.
2) Assemble a recommended cost matrix, which would include the different backfilling options' Cost per Case observed in 2011.
3) Build a Cost-to-serve model that will project the expected transportation costs of a complexity event, based on origin, volume, capacity dedicated and geographic range. This method projects estimated transportation costs during a complexity event on a weekly basis by providing a range around the mean equal to one standard deviation. Additionally, the baseline for these estimates is the behavior in transportation costs observed in the different plant-geographic extension – season combinations during 2011. It also incorporates an estimated growth rate in over-all system transportation costs.

3.4 Software Tools

During our analysis, we employed different software packages to organize and compute the data analyzed, and also to build our final model. The following list includes all the programs and tools employed:

1) Data organizing programs:
    - Access tools: external content linking, database joining, query building, report building.
    - MS Excel tools: pivot tables, charts, tables, conditional formatting.

2) Data computing programs:
    - MS Excel tools: Descriptive statistics.

3) Model building programs:
    - MS Excel tools: Activity-Cost analysis.
    - JMP Pro: Multiple linear regression analysis.

3.5 Sectors not covered in the analysis

The data set originally included shipments originated at locations other than plants (warehouses, distribution centers, etc.). These transactions were excluded from the analysis as the specific inventory shipped in a plant – warehouse – customer could not be tracked. Additionally, as mentioned previously, all the records from 2010 were disregarded due to substantial market or industry line-haul rate increments.

4 DATA ANALYSIS AND INTERPRETATION

This chapter presents the analysis conducted on the 2011 truckload shipment data at CPGCo USA to understand the transportation cost behavior during complexity events. The first section presents an overview of initial analysis that led to the selection of a launch plant as a test case for further analysis. The second section presents the results of this analysis and to what extent it explains the transportation cost behavior at the plant level. The next section analyzes rate behavior at all plants during complexity events in 2011, but this time focusing on specific lanes and carriers. This follows with a re-examination of our key assumptions with respect to the total transportation cost equation. This then is used to analyze the cost to serve each customer in the CPGCo distribution network regardless of which plant fulfills the order. This also leads to the development of a working model to predict the change in transportation costs during a complexity event.

4.1 Preliminary Data Analysis

In 2011, there were 15 new product launches (complexity events) at CPGCo USA which took place at 6 plant launch sites, namely: Factory 1, Factory 2, Factory 8, Factory 10, Factory 11 and Factory 12. Out of these launches, 10 were national launches and 5 were regional launches. National launches require the launch plant to send the new products to all the other plants and most of the customers in the CPGCo distribution network. Regional launches are restricted to the customers of the launch plant and those of one or two of the closest plants.

The new product launches took place between Weeks 7 and 36 in 2011. In some cases, new products were launched from multiple plant locations at a time. For example, in Week 36 the new product launch took place from 4 plant sites, in Week 12 from 2 plant sites and in Week 13 from 2 plant sites. Table 4.1 shows a summary of new product launch activity for the year 2011.

Date	Week	Comments	Location 1	Location 2	Location 3	Location 4
February 07, 2011	7	National	Factory 12			
February 07, 2011	7	National	Factory 1			
March 14, 2011	12	Regional Rollout	Factory 1	Factory 12		
March 21, 2011	13	Regional Rollout	Factory 1			
March 21, 2011	13	Regional Rollout	Factory 1			
March 21, 2011	13	Regional Rollout	Factory 1			
March 21, 2011	13	Regional Rollout	Factory 1	Factory 12		
March 28, 2011	14	National	Factory 12			
May 02, 2011	19	National	Factory 11			
June 06, 2011	24	National	Factory 1			
August 15, 2011	34	Seasonal Brand	Factory 1			
August 15, 2011	34	National	Factory 2			
August 29, 2011	36	National	Factory 1			
August 29, 2011	36	National	Factory 8	Factory 10	Factory 11	Factory 12
September 19, 2011	39	National	Factory 8			

Table 4.1: Summary of New Product Launch Activity in 2011

Based on the direct matching of launch dates in Table 4.1 and the observed fluctuation of shipments in Figure 8, Factory 8 was selected as a test case for further study of observed rate behavior. This plant showed a sharp increase in weekly shipments in Week 36 from 1328 shipments/week to an average of 2,270 shipments per week over the next 4 weeks. This coincided with a national launch in Week 36, which involved three other plants: Factory 10, Factory 11 and Factory 12.

Following from the literature review and interviews with internal and external transportation professionals, the following assumptions about the transportation cost behavior were tested on the Factory 8 shipment data:

i. There is an increase in weekly shipments from a launch plant during a new product launch

ii. The average cost per load will increase as the contracted carrier may not be able to meet the extra demand for transportation capacity at the pre-agreed rate. They may even turn down pre-agreed shipments because of their own capacity constraints.

iii. Each plant could resort to the transportation spot market to procure the extra needed transportation capacity; always at a higher rate.

iv. As each plant procured and managed transportation procurement independently, the behavior of transportation costs would be mainly driven by the effect of a new product launch at each plant location.

v. All components of the total cost per load (line haul cost, fuel surcharge, accessorial charge and stop charge) are considered to be equally important in driving costs during complexity events.

4.2 Plant Level Rate Analysis

Based on the dates in which new product launches (complexity events) took place in the Factory 8, in weeks 36 and 39; the analysis of rates and events for were conducted from weeks 31 to 40 to capture the impact of these overlapping events.

During this period a total of 43 new lanes were added to the existing lanes covered by the Factory 8 and accounted for up to 185 shipments in 2011. New lanes are added as a result of new products being distributed to customers not originally part of the Factory 8 network. Also during this period a total of 38 existing lanes were dropped from the Factory 8 network. Some existing lanes are dropped when Factory 8 allows another plant to supply mature products to its customers, usually to compensate for capacity diverted to the supply of new products to all customers in the CPGCo distribution network. During this period the average volume increase on old lanes is 225%. Table 4.2 summarizes these effects.

Event Summary 2011 - Factory 8	
No. of lanes	43
Total Volume on new lanes	185
Avg. Volume on new lanes	4.30
Number of old lanes dropped	38
Total Volume on old lanes	10,461
Avg. Volume per lane	176.39
Avg. Volume increased on old lanes	225%

Table 4.2: Summary lane behavior during event weeks 31 to 40 at Factory 8

4.2.1 Lane Level Analysis

A plot of the rate in dollars per mile at the Factory 8 in 2011 shows that average rate steadily decreases all through the year. Even in the period of weeks 31 to 40 when two product launches took place, there is no significant increase or decrease in the transportation rates at this plant. Transportation rates are calculated by dividing the total transportation cost for a shipment (in dollars) by the total length of hauls (in miles). The 2011 maximum and minimum rates of 5.66 and 3.79 dollars/mile do not take place during any of these weeks. Figure 4.1 illustrates this down trend in rates.

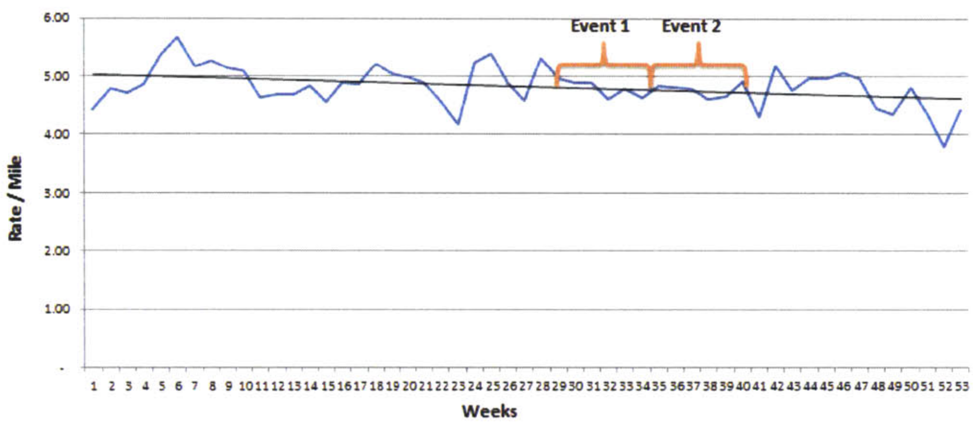


Figure 4.1: Average 2011 transport rate in dollars per mile at Factory 8

A further analysis of Factory 8 2011 data shows that there were a total of 200 lanes originating from Factory 8. Out of this number only 28% of the lanes showed any increase in average rates during an event. During Weeks 31 to 40, when there were two major events, only 42 lanes showed an increase in rates greater than 1%, 12 lanes showed an increase in rates greater than 5% and two lanes showed an increase in rates greater than 10%. Table 4.3 shows these results.

	RPM increase during events - lane analysis			
	Total lanes	Increase > 1%	Increase > 5%	Increase > 10%
Absolute	202	42	12	2
%	100%	20.80%	5.90%	1%

Table 4.3: Rate per mile increases at Factory 8 during event weeks 31 to 40

Further investigation was carried out on two sample lanes, to determine if there was a consistent change in rates during the event weeks. The lanes were selected as city to city origin-destination pairs for this analysis. The first lane examined was from Factory 8 to Location A. This showed an average increase of $1.20 during the two events (labeled as E1 and E2 in Figure 4.2) in weeks 31 to 40, as shown in Figure 4.2 and Table 4.4.

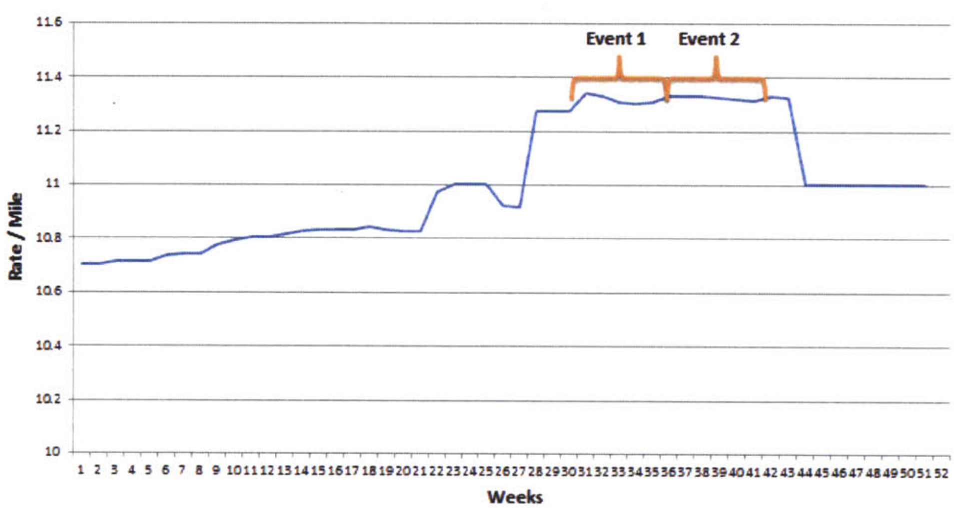


Figure 4.2: Lane level transportation rates at Factory 8 (in dollars/mile) showing an increase during events for the lane Factory 8 to Location A

	Total loads	Loads/ week	Distance	LOH (hrs)	No. of Carriers	Avg. RPM	Benchmark RPM
Pre - E1	1498	51.7	10	1	1	$ 10.87	$ 10.12
E1	292	58.4	10	1	1	$ 11.31	$ 10.12
E2	256	51.2	10	1	1	$ 11.32	$ 10.12
Post - E2	209	19	10	1	1	$ 11.26	$ 10.12

Table 4.4: Summary of lane level rate changes at Factory 8 (in dollars/mile) showing an increase during events for the lane Factory 8 to Location A

Note: LOH = length of haul and RPM = rate per mile. The benchmark RPM (rate per mile) in Table 4.4 indicates the expected average rate on this lane. This is calculated from the CPGCo 2011 routing guide as the weighted average contracted rate on this lane.

A similar analysis of another lane from Factory 8 to Location B shows no significant change in rate during the events in weeks 31 to 40, as shown in Figure 4.3 and Table 4.5.

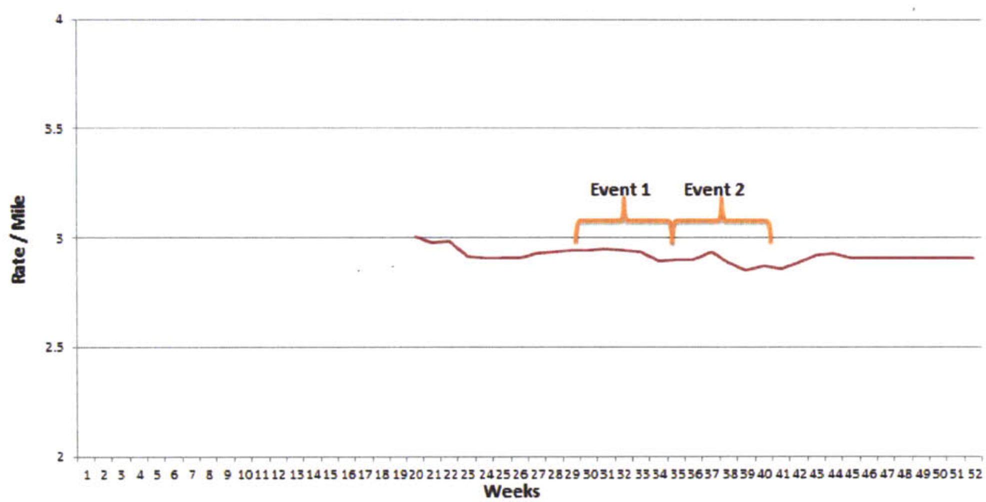


Figure 4.3: Lane level transportation rates at Factory 8 (in dollars/mile) showing no significant change during events – Factory 8 to Location B

	Total loads	Loads/ week	Distance	LOH (hrs)	No. of Carriers	Avg. RPM	Benchmark RPM
Pre - E1	678	67.8	384	9	4	$ 2.94	$ 2.38
E1	558	111.6	384	9	1	$ 2.92	$ 2.38
E2	698	139.6	384	9	2	$ 2.89	$ 2.38
Post - E2	388	32.3	384	9	2	$ 2.90	$ 2.38

Table 4.5: Summary of lane level rate changes at Factory 8 (in dollars/mile) showing no significant change during events – Factory 8 to Location B

These results seem to disprove the assumption that the impact of an event at a plant location would be reflected in the average carrier rates for moves originating from that plant. As can be seen, from this sample, there is no consistent downward or upward movement in rates during an event.

4.2.2 Carrier Level Analysis

To further explore how rate behavior could be affected by a complexity event, all the carriers operating from the Factory 8 were analyzed. The goal was to explore if any carrier characteristics such as relative size or proportion of the plant traffic had any effect on the rates. All 36 carriers operating from the Factory 8 were analyzed and their average rates compared in the event period (weeks 31 to 40) and the non-event period (weeks 1 to 30 and 41 to 52).

The results show a high amount of variability in the change in volume and carrier rates during events. The volumes show an average change of 353% during events with a standard deviation of 276%, while the change in volumes range from -52% to 1369%. The average rates (in dollars/mile) show an average rate change of 3% with a range of -15% to 44%.

The change in volume and change in rates during complexity events show very low correlation to each other (correlation co-efficient equal to 0.2624). The correlation coefficient of the five largest carriers (on the basis of shipments) is relatively higher at 0.6508. The change in volume and rates for the five smallest carriers by shipments returns a negative correlation of -0.66.

These results seem to verify our earlier lane level analysis that there is little relationship between the increase in shipment volume and the average rate change during events. As can be seen in Table 4.6 and Figure 4.4, there is no consistent pattern for the rate change during events.

However, for the top five carriers by volume, there is a stronger correlation between rates and volume (correlation coefficient equal to 0.6508). Nonetheless, the 2011 data set is not a satisfactory sample to base any conclusion on.

	Number of Shipments		Average Trips per Week		Average Cost per Mile			
Carriers	Non Events	Events	Non Events	Events	Non Events	Events	Volume Change	Rate change
C1	4	7	0.10	0.70	2.17	2.16	↑ 635%	↓ -0.4%
C2	7	13	0.17	1.30	2.39	2.22	↑ 680%	↓ -7.0%
C3	19	31	0.45	3.10	3.65	3.65	↑ 585%	↓ -0.2%
C4	26	3	0.62	0.30	2.20	2.99	↓ -52%	↑ 35.8%
C5	53	44	1.26	4.40	2.07	1.75	↑ 249%	↓ -15.3%
C6	58	21	1.38	2.10	2.09	2.07	↑ 52%	↓ -0.9%
C7	78	13	1.86	1.30	2.38	2.48	↓ -30%	↑ 3.9%
C8	86	122	2.05	12.20	2.06	2.05	↑ 496%	↓ -0.2%
C9	115	111	2.74	11.10	2.51	2.64	↑ 305%	↑ 5.4%
C10	132	104	3.14	10.40	3.58	4.21	↑ 231%	↑ 17.6%
C11	135	104	3.21	10.40	1.54	1.48	↑ 224%	↓ -3.9%
C12	143	500	3.40	50.00	3.43	4.94	↑ 1369%	↑ 44.1%
C13	156	91	3.71	9.10	2.17	2.17	↑ 145%	↑ 0.1%
C14	157	148	3.74	14.80	3.34	3.34	↑ 296%	↓ -0.1%
C15	169	114	4.02	11.40	2.11	2.07	↑ 183%	↓ -2.0%
C16	217	150	5.17	15.00	2.18	2.12	↑ 190%	↓ -2.6%
C17	308	476	7.33	47.60	2.55	2.54	↑ 549%	↓ -0.4%
C18	349	345	8.31	34.50	2.73	2.48	↑ 315%	↓ -9.3%
C19	388	207	9.24	20.70	2.23	2.21	↑ 124%	↓ -0.8%
C20	405	344	9.64	34.40	3.16	3.15	↑ 257%	↓ -0.4%
C21	426	534	10.14	53.40	3.97	3.97	↑ 426%	↓ -0.2%
C22	475	748	11.31	74.80	4.21	4.20	↑ 561%	↓ -0.1%
C23	489	170	11.64	17.00	1.80	1.77	↑ 46%	↓ -1.4%
C24	502	835	11.95	83.50	3.26	3.38	↑ 599%	↑ 3.6%
C25	544	390	12.95	39.00	2.54	2.53	↑ 201%	↓ -0.6%
C26	608	338	14.48	33.80	2.41	2.48	↑ 133%	↑ 2.8%
C27	612	840	14.57	84.00	4.21	4.20	↑ 476%	↓ -0.3%
C28	671	916	15.98	91.60	2.18	2.15	↑ 473%	↓ -1.4%
C29	762	1141	18.14	114.10	6.87	6.79	↑ 529%	↓ -1.1%
C30	810	1247	19.29	124.70	14.56	14.59	↑ 547%	↑ 0.1%
C31	816	1601	19.43	160.10	5.60	5.55	↑ 724%	↓ -0.9%
C32	1038	464	24.71	46.40	2.03	2.05	↑ 88%	↑ 1.1%
C33	1067	742	25.40	74.20	2.15	2.15	↑ 192%	↑ 0.0%
C34	1172	1594	27.90	159.40	2.28	3.23	↑ 471%	↑ 41.4%
C35	1766	2146	42.05	214.60	2.96	2.99	↑ 410%	↑ 1.0%
C36	12250	3807	291.67	380.70	6.06	6.21	↑ 31%	↑ 2.4%

Table 4.6: Summary of carrier level changes in rates and volumes during complexity events at Factory 8 in 2011.

Note: Red arrows indicate a decrease in rates while green arrows indicate an increase in rates during complexity events

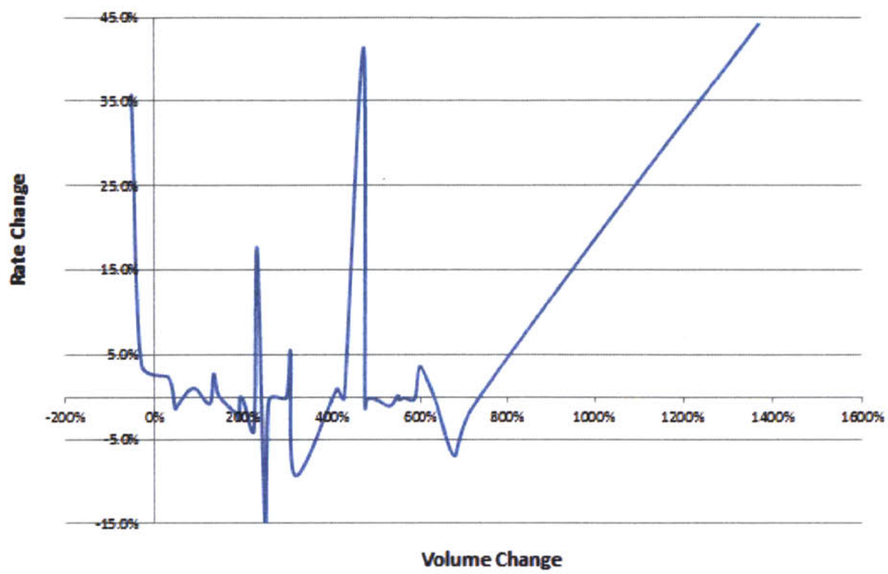


Figure 4.4: Carrier level changes in rates and volumes during complexity events at Factory 8 in 2011.

4.3 Launch Plant Level Analysis

Based on the lack of conclusive results from studying complexity events at a plant level, the analysis was expanded to study transportation rate behavior when the plants are examined collectively. The purpose of this was to examine if the effect of a complexity event on transportation costs could be observed collectively. This analysis was conducted in two phases. First a comparison was conducted of long haul shipments with short haul shipments, Then another comparison was conducted by specifically examining shipments fulfilled by dedicated fleet.

4.3.1 Long haul versus Short haul Rates

Long Haul Rate Analysis

For this analysis long haul trips were defined as trips longer than 200 miles. Consequently, short haul trips were any trips shorter than 200 miles. Overall, long haul trips comprised mostly of out of state trips, while short haul trips were mostly intra-state trips.

An analysis of the trips originating from the 6 plants which launched a new product in 2011 was conducted. This involved comparing the relative changes in rates between non-events and events in 2011 on a quarter by quarter basis for each of the launch plants. Based on the limited data set of one year, it was difficult to find plants which launched a product in every quarter of the year. In neither the long haul nor short haul data could be found new product launches occurring in each quarter.

The analysis of long haul data showed some interesting results. Factory 1 plant which had events in all the first 3 quarters of 2011, showed increase in average transportation rates in the first two quarters (Q1 with 2.5% and Q2 with 14.2%) and a slight decrease in the 3rd quarter of 0.3%. Factory 12 plant also had events in the first 3 quarters of 2011. It showed similar results to Factory 1, with the first two quarters showing increases in transportation rates (Q1 with 18.4% and Q2 with 11.1%). The long haul transportation rates in the third quarter dropped more significantly in Q3 by -13.1% at the Factory 1 plant.

Factory 8 and Factory 11 plant had new product launches in two quarters only in 2011. Factory 8 had events in the 3rd and 4th quarters only, while Factory 11 plant had events in 2nd and 3rd quarters. At Factory 8 both quarters showed significant increases in rates, with Q3 rates increasing by 2.4% and Q4 rates increasing by 16%. At the Factory 11 plant there were both quarters showed decreased in rates -1.3% in Q2 and -1.4% in Q3.

The two other plants Factory 2 and Factory 10 had product launches only in the 3rd quarter of 2011. Factory 2 showed a slight increase in rates of 0.1% while Factory 10 showed a slight in decrease of -2.7% in Q3. A summary of all the rate changes in long haul rates in 2011 can be seen in Table 4.7.

	LONG-HAUL SHIPMENTS (Distance > 200 Miles)											
	QUARTERS											
	FIRST			SECOND			THIRD			FOURTH		
	Event	Non-Event	Delta	Event	Non-Event	Delta	Event	Non-Event	Delta	Event	Non-Event	Delta
Factory 1	$ 1.766	$ 1.722	2.5%	$ 1.988	$ 1.740	14.2%	$ 1.813	$ 1.820	-0.3%	NA	$ 1.888	
Factory 2	NA	$ 2.014		NA	$ 2.184		$ 2.076	$ 2.075	0.1%	NA	$ 1.960	
Factory 8	NA	$ 2.034		NA	$ 2.370		$ 2.646	$ 2.584	2.4%	$ 2.594	$ 2.236	16.0%
Factory 10	NA	$ 1.754		NA	$ 1.574		$ 1.711	$ 1.758	-2.7%	NA	$ 1.809	
Factory 11	NA	$ 2.674		$ 2.574	$ 2.609	-1.3%	$ 2.406	$ 2.441	-1.4%	NA	$ 2.276	
Factory 12	$ 2.168	$ 1.832	18.4%	$ 2.227	$ 2.004	11.1%	$ 2.004	$ 2.306	-13.1%	NA	$ 1.992	

** Assuming a 5 week duration per event*

Table 4.7: Changes in transportation rates of long haul shipments at all six launch plants in 2011.

Note: Red and Yellow indicate increases in average transportation rates while green indicates decreases in transportation rates. Blank cells indicate that no new product launch was conducted at that plant, thus no comparison was conducted.

While these rate analyses can be used to determine the average change in rates when products are launched from each of these plants, they do not show sufficient consistency across all plants as to be considered conclusive. Also, the changes in rates could also be largely explained by seasonality factors and not the presence or absence of a new product launch.

Short Haul Rate Analysis

A similar analysis of short haul trips was conducted on the same six plants. This also showed some degree of similarity with the results from the long haul analysis. In the Factory 1 plant, the short haul rates shows increases in all three quarters (Q1 to Q3) of 3.7%, 2.6% and 5.7% respectively. This differs from the long haul rates only in Quarter 3 where there was a slight decrease of -0.3% in long haul rates. There is a more glaring similarity in the short haul and long haul rate changes in the Factory 12 plant. The short haul rates show increases in Quarters 1 and 2 with a decrease in Quarter 3. This same pattern is repeated in the long haul rates.

Factory 8 also shows an exact match in rate movement for short haul and long haul rate change, with increases in both Q3 and Q4 when new products were launched.

However, the 3 other plants in the network Factory 2, Factory 10 and Factory 11 show direct opposite changes in rates for long haul and short haul rates. Table 13 shows a summary of the changes in transportation rates over short hauls in the quarters when new products were launched in 2011. Table 4.8 also shows a comparison of these transportation rate changes during short and long hauls.

	SHORT-HAUL SHIPMENTS (Distance < 200 Miles)											
	QUARTERS											
	FIRST			SECOND			THIRD			FOURTH		
	Event	Non-Event	Delta	Event	Non-Event	Delta	Event	Non-Event	Delta	Event	Non-Event	Delta
Factory 1	$ 3.507	$ 3.383	3.7%	$ 4.661	$ 3.699	26.0%	$ 4.401	$ 4.164	5.7%	NA	$ 4.217	
Factory 2	NA	$ 3.787		NA	$ 3.929		$ 3.892	$ 3.999	-2.7%	NA	$ 3.910	
Factory 8	NA	$ 5.548		NA	$ 5.939		$ 6.727	$ 6.247	7.7%	$ 6.684	$ 5.720	16.8%
Factory 10	NA	$ 8.307		NA	$ 8.507		$ 9.459	$ 9.107	3.9%	NA	$ 10.407	
Factory 11	NA	$ 5.792		$ 6.557	$ 6.408	2.3%	$ 6.129	$ 5.567	10.1%	NA	$ 5.718	
Factory 12	$ 4.059	$ 3.667	10.7%	$ 4.746	$ 4.279	10.9%	$ 4.182	$ 4.406	-5.1%	NA	$ 4.677	

** Assuming a 5 week duration per event*

Table 4.8: Changes in transportation rates of short haul shipments at all six launch plants in 2011.

	Quarter	Long haul	Short haul
Factory 1	1	Increase	Increase
	2	Increase	Increase
	3	Decrease	Increase
Factory 2	3	Increase	Decrease
Factory 8	3	Increase	Increase
	4	Increase	Increase
Factory 10	3	Decrease	Increase
Factory 11	2	Decrease	Increase
	3	Decrease	Increase
Factory 12	1	Increase	Increase
	2	Increase	Increase
	3	Decrease	Decrease

Table 4.9: Comparison of rate changes in six plants launching new products in 2011

Note: Red increases in average transportation rates while green indicates decreases in transportation rates. Table only shows the quarters in which new products are launched.

While the history of rates in each launch plant may be a useful guide in anticipating rate changes due to launch events, it appears it is not a conclusive method for predicting the total change in transportation costs during a new product launch. Additionally, it does not capture the full impact of seasonality on the transportation cost and it does not adequately take into consideration the difference in rate dynamics between dedicated and non-dedicated fleet.

4.4 Re-examination of Key Assumptions

These results challenge each of the initial assumptions made in Section 4.1 about the expected behavior of transportation costs during complexity events (in this case new product launches). A review of these assumptions shows the following:

i. *New product launch events are not always characterized by a significant increase in shipments from the launch plant*. On the contrary the number of shipments from the launch plant may remain relatively unchanged. This is because the capacity dedicated to new products is simply a portion of, and not an addition to, existing production capacity. During this time, the "lost volume" of mature products to the launch plant's customers is supplemented by deliveries from other plants in the CPGCo distribution network. Hence, a study of the impact of new products on transportation costs will have to take into consideration all plants, especially those not "back filling" for the launch plant.

ii. *The rates charged by each carrier for any lane is fixed throughout the year.* This is because CPGCo is particularly effective at enforcing agreed carrier rates. Hence, changes in total transportation costs during new product launches are not due to changes in rates but changes in carriers. Each plant simply increased routing guide depth to select a more expensive carrier once the previous carrier rejects the load.

iii. *None of the plants uses the spot market to source carriers in the course of the year.* All carriers are pre-selected annually and approached when needed over the course of the year.

iv. *Transportation costs in one plant are driven by the collective behavior of all plants in the CPGCo distribution network.* Total transportation costs at a plant can change for any of two reasons. On one hand, it may be launching a new product and supplying to customers outside its network. On the other hand, it may be supplying mature products to the customers of a plant launching a new product. Hence, transportation costs at CPGCo cannot be effectively studied at only the plant level.

v. *Only the line haul costs are relevant for analyzing the impact of new product launches on total transportation costs.* Other costs (accessorial charge, fuel charge and stop charge) are not directly affected by whether there is a new product launch or not. Line haul costs change because of the extra distance covered by a launch plant supplying all customers in the CPGCo distribution network and of other non-launch plants supplying customers outside their normal distribution network.

A re-examination of the transportation cost equation also reveals the relevant cost drivers that apply in the CPGCo distribution network.

$$TTC = N * [(Avg.CPM)(Avg.LOH) + Avg.REG] \quad (4.1)$$

Where:

TTC = Total Transportation Costs

N = Number of loads

$Avg.CPM$ = Average cost per mile

$Avg.LOH$ = Average length of haul per shipment

$Avg.REG$ = Average effect of regional factors (i.e. origin and destination)

From our analysis thus far can be observed the following from this equation:

- The number of loads while it is important in determining total costs at a plant does not change significantly during new product launches, when all plants are considered as a system.
- The average cost per mile changes only slightly as a result of a change in carrier mix. This occurs because during new product launches the relative ratio of carriers servicing each customer changes, and hence the rates they charge change as well. While there is usually an increase in average cost per mile, for some customers it could also decrease.

- The average length of haul per shipment increases significantly for all participating plants during a new product launch; both for the launch plant and the back filling plant.
- The effect of regional factors occurs when a trip involves movement across zip codes or states. This is already captured in some form during bid negotiations. Therefore, any change in regional factors is minimal during new product launches. They take place only when a shipment occurs on a lane that has not been covered in the past or has not been negotiated during the bids. Based on the interviews and the data analysis conducted, this scenario seems very unlikely.

Following from this, the primary focus of research for this thesis shifted to the impact of the changes in the average length of haul during a new product launch, and its impact on the average cost to serve each customer in the distribution network.

4.5 Cost-to-Serve Analysis

This thesis considers the cost to serve only from the point of view of transportation. The total cost to serve a customer typically includes allocated costs from all the members of the value chain such as procurement, planning, manufacturing, marketing, sales operations and transportation. As a result, the optimal cost to serve a customer, can only be effectively analyzed by examining all these costs at the same time. However, the interest of this thesis is primarily the impact of supply chain complexity on transportation costs. The cost-to-serve method provides an approach for analyzing this cost impact at the customer level.

The types of transportation companies working with CPGCo are divided into dedicated and non-dedicated carriers. Dedicated carriers allocate a certain number of transportation trucks to be used exclusively by CPGCo. Non-dedicated trucks are not allocated exclusively for use by CPGCo. They are part of the general pool of transportation capacity at a trucking company, and can be used by any company once they are available. The average cost per mile charged by a dedicated carrier is significantly higher than that for non-dedicated carrier. As a result of these differences, the dynamics of supply chain complexity can only be effectively seen in the transportation costs of non-dedicated carriers. It is for this reason that the analysis for the remainder of this chapter focuses on the transportation costs from dedicated carriers.

To correct for the effect of seasonality on the transportation rates in each plant, the analysis for each plant was conducted on the basis of whether it took place in the low season or high season. The high season for any plant is defined as a period of 4 to 10 months with consistently high number of shipments. A summary of the season for each plant in the CPGCo distribution network is listed below in Table 4.10.

Plant	Start	End	Duration
Factory 1	June	September	4 months
Factory 2	May	September	6 months
Factory 3	April	September	5 months
Factory 4	May	September	3 months
Factory 5	May	July	5 months
Factory 6	May	October	6 months
Factory 7	May	November	7 months
Factory 8	March	December	10 months
Factory 9	March	July	5 months
Factory 10	May	July	5 months
Factory 11	March	September	7 months
Factory 12	April	September	6 months

Table 4.10: High Season Period per plant location in the CPGCo Distribution Network

4.5.1 Supply Mix Fluctuation

To explore how the proportion of transport carriers serving a customer changes with a new product launch, a sample of one customer located within the Factory 12 network and for an event launched from the Factory 12 plant was analyzed. It shows that during the non-event period the primary source plant of supply for this customer is the Factory 12 plant, responsible for 46% of shipments to this plant. However, this plant also received products from 7 other plants in the distribution network. The main backfill plant during the non-event is Factory 7 with 29% of shipments during a new product launch.

During a new product launch this relative proportion changes. The proportion of shipments from Factory 12 plant drops slightly to 43%. While all other plants continue to supply this customer, Factory 7 is no longer the main backfill plant and in fact drops in proportion to 23%. The main backfill plant during new product launch events in 2011 became Factory 2 which grew in proportion from 19% to 38%.

A summary of these changes can be seen in Table 4.11 below.

Mix (%)	Non-Event	Event	Result	Delta	% Change
Factory 1	2%	3%	Increase	1%	88%
Factory 2	19%	38%	Increase	19%	96%
Factory 3	0.74%	0.89%	Increase	0.16%	21%
Factory 5	0.49%	0%	Decrease	-0.49%	-100%
Factory 7	29%	13%	Decrease	-16%	-55%
Factory 10	3.20%	1.79%	Decrease	-1%	-44%
Factory 11	0.18%	0%	Decrease	-0.18%	-100%
Factory 12	46%	43%	Decrease	-2%	-5%

Table 4.11: Summary of fluctuations in plant proportions during non-events

To examine this behavior more closely an analysis of all plants launching new products in 2011 was conducted. This was done for plants serving both as a "within network" or "out-of-network" plants during a new product launch.

4.5.2 Cost-to-Serve Sampling – Plant Level

For simplicity, the only plants selected for this analysis were those in which they were the only location where a new product was launched. For this reason, any new product launch in which 2 or more plants were simultaneously involved was not included. This reduced the impact of any possible data distortion. Five plant locations were analyzed, namely: Factory 1, Factory 2, Factory 8, Factory 11 and Factory 12.

The analysis involved calculating the average cost to serve a customer from a launch plant and any other backfill plant in dollars per case. This was done for plants in which the customer was part of the launch plant's distribution network and when it was not. Also for each customer, the cost-to-serve from the primary back fill plant (PBP) was identified and compared with the plant that was the least expensive option (PLEO).

Factory 1

Analysis of Factory 1 costs show that for a customer within the Factory 1 network, during a non-event, the primary backfill plant was Factory 12 even though the least expensive option was the Factory 10 plant by 1.4$/case. However, during an event the Factory 3 plant was correctly selected as the least expensive option.

For a customer in which Factory 1 was serving as a backfill plant on behalf of Factory 12, Factory 10 was the least expensive option during both events and non-events. It was cheaper than Factory 2 by 5.2$/case and Factory 7 by 8.1$/case during non-events and events respectively. Table 4.12 below summarizes these results.

Wholesaler (Within Network)	Factory 1 launch Feb-07-2011							
	$/Hl	Factory 1	Others	Average	PBP	PBP $/HL	PLEO	PLEO $/HL
WS No: 3	Non-Event	2.1	4.0	2.7	Factory 12 (19%)	4.6	Factory 10 (15%)	3.2
Point 3	Event	5.9	4.3	5.6	Factory 3 (17%)	4.3	Factory 3 (17%)	4.3

Wholesaler (Outside Network)	Factory 1 (Backfilling for Factory 12) Mar-28-2011							
	$/Hl	Factory 1	Others	Average	PBP	PBP $/HL	PLEO	PLEO $/HL
WS No: 4	Non-Event	2.8	1.5	1.5	Factory 2 (2%)	7.3	Factory 10 (0.4%)	2.1
Point 4	Event	3.6	5.6	5.0	Factory 7 (34%)	9.7	Factory 10 (33%)	1.6

Table 4.12: Dollar per case cost to serve during non-event and event for customers within and outside the Factory 1 network

Factory 2

For customers in the Factory 2 network, the Factory 11 plant served as the primary backfill plant even though Factory 6 was the lowest cost option both during events and non-events. For customers outside the Factory 2 network and within the Factory 1 network, the lowest cost back fill plant option was Factory 9 during non-events. However, during a new product launch from Factory 1, the primary back fill plant used was Factory 10 which was more expensive by 0.2$/case to 0.3$/case during non-events and events respectively. See Table 4.13 below.

Wholesaler (Within Network)	Factory 2 launch of Tilt Long Island Tea							
	Aug-15-2011							
	$/Hl	*Factory 2*	*Others*	*Average*	*PBP*	*PBP $/HL*	*PLEO*	*PLEO $/HL*
WS No: 7	Non-Event	3	3.7	3.3	Factory 11 (28%)	3.8	Factory 6 (13%)	3.1
Point 7	Event	3.5	3.3	3.4	Factory 11 (36%)	3.6	Factory 6 (19%)	2.7

Wholesaler (Outside Network)	Factory 2 (Backfilling for Factory 1)							
	June-06-2011							
	$/Hl	*Factory 2*	*Others*	*Average*	*PBP*	*PBP $/HL*	*PLEO*	*PLEO $/HL*
WS No: 8	Non-Event	10.3	5.1	5.3	Factory 10 (27%)	2.1	Factory 9 (6%)	1.9
Point 8	Event	14.6	5.8	6.7	Factory 10 (23%)	2.0	Factory 9 (4%)	1.7

Table 4.13: Dollar per case cost to serve during non-event and event for customers within and outside the Factory 2 network

Factory 8

For a customer within the Factory 8 network, the cost to serve it from Factory 4 was consistently lower, during events and non-events, than the primary backfill plant (Factory 5) used during an even in 2011.

In the case of a customer in which Factory 8 was a back fill plant, the more expensive plants, Factory 11 and Factory 3, were used during non-events and events respectively. However, Factory 7 (during non-events) and Factory 10 (during events) were cheaper by 2$/case and 1.7$/case respectively. Table 4.14 below shows an overview of these figures.

Wholesaler (Within Network)	Factory 8 launch							
	Sep-19-2011							
	$/Hl	*Factory 8*	*Others*	*Average*	*PBP*	*PBP $/HL*	*PLEO*	*PLEO $/HL*
WS No: 9	Non-Event	1.2	4.3	1.7	Factory 5 (10%)	4.2	Factory 4 (2%)	2.1
Point 9	Event	1.2	3.9	1.6	Factory 5 (11%)	4.2	Factory 4 (4%)	2.4

Wholesaler (Outside Network)	Factory 8 (Backfilling for Factory 2)							
	Aug-15-2011							
	$/Hl	*Factory 8*	*Others*	*Average*	*PBP*	*PBP $/HL*	*PLEO*	*PLEO $/HL*
WS No: 10	Non-Event	13.5	4.3	4.6	Factory 11 (25%)	4.3	Factory 7 (3%)	2.3
Point 10	Event	11.7	4.2	4.4	Factory 3 (30%)	5.0	Factory 10 (27%)	3.3

Table 4.14: Dollar per case cost to serve during non-event and event for customers within and outside the Factory 8 network

Factory 11

When the Factory 11 plant launched a product in 2011, Factory 2 plant was not the least expensive backfill plant. During both non-events and events, the lowest cost-to-serve plant option for a customer in the Factory 11 network was Factory 3. However, during an event Factory 2 was used instead (3.6$/case more expensive).

Factory 11 served as a backfill plant to Factory 2 during events and non-events, even though it was 0.2$/case more expensive than Factory 7 during events. Table 4.15 below shows a summary of these results.

Wholesaler (Within Network)	Factory 11 launch May-02-2011								
	$/Hl	*Factory 11*	*Others*	*Average*	*PBP*	*PBP $/HL*	*PLEO*	*PLEO $/HL*
WS No: 5	Non-Event	0.7	2.9	0.8	Factory 3 (2%)	2.2	Factory 3 (2%)	2.2
Point 5	Event	0.7	3.8	1.2	Factory 2 (5%)	5.8	Factory 2 (2%)	2.2

Wholesaler (Outside Network)	Factory 11 (Backfilling for Factory 2) Aug-15-2011							
	$/Hl	*Factory 11*	*Others*	*Average*	*PBP*	*PBP $/HL*	*PLEO*	*PLEO $/HL*
WS No: 6	Non-Event	2.4	2.5	2.5	Factory 11 (37%)	2.4	Factory 11 (37%)	2.4
Point 6	Event	2.6	2.1	2.3	Factory 11 (44%)	2.6	Factory 7 (2%)	2.4

Table 4.15: Dollar per case cost to serve during non-event and event for customers within and outside the Factory 11 network

Factory 12

For a customer located within the Factory 12 network, selected during a non-event and an event, the primary back fill plant was not always the least expensive option. For example, during a non-event the primary back fill plant was Factory 7, even though Factory 2 was the cheaper option by 0.1$/case. Similarly during an event, Factory 7 was a cheaper option than the primary back fill plant used by 0.1$/case.

When another customer is examined in which Factory 12 is serving as a backfill plant to Factory 1, the changes are much more significant. During non-events and events, Factory 12 is the primary back fill plant selected. However, in both cases there were much cheaper source plants by as much as 1.4$/case (during non-events) and 2.3$/case (during events). Table 4.16 summarizes these results

Wholesaler (Within Network)	Factory 12 launch Feb-07-2011							
	$/Hl	*Factory 12*	*Others*	*Average*	*PBP*	*PBP $/HL*	*PLEO*	*PLEO $/HL*
WS No: 1	Non-Event	1.8	2	1.9	Factory 7 (29%)	1.9	Factory 2 (19%)	1.8
Point 1	Event	1.7	1.7	1.7	Factory 2 (38%)	1.6	Factory 7 (13%)	1.5

Wholesaler (Outside Network)	Factory 12 (Backfilling for Factory 1) June-06-2011							
	$/Hl	*Factory 12*	*Others*	*Average*	*PBP*	*PBP $/HL*	*PLEO*	*PLEO $/HL*
WS No: 2	Non-Event	3.4	2.4	3.2	Factory 12 (34%)	3.4	Factory 9 (5%)	2.0
Point 2	Event	4.1	3.6	3.8	Factory 12 (28%)	4.1	Factory 9 (1%)	1.8

Table 4.16: Dollar per case cost to serve during non-event and event for customers within and outside the Factory 12 network

Note: PBB = Primary back fill plant and BLEO = Plant with the least expensive option.

4.5.3 Seasonal Changes in the Cost-to Serve

The cost to serve a customer also changes depending on whether a new product launch takes place in the low season or in the high season.

High Season

During the high season, the primary backfill plant used to serve customers during a product launch was not the lowest average cost option. While Factory 1, was the primary source plant during its own new product launch at 2.15$/case, in 2011 the lowest cost option for supply was Factory 9 at 1.91$/case. Yet on average, Factory 1 was responsible for 52.05% of shipments to its customers while Factory 9 was responsible for only 3.95%. The same situation occurs at Factory 11 with 82.96% of shipments at 2.49$/case even though the lowest cost option was Factory 3 at $2.34 which was allocated 4.83% of 2011 shipments.

However, during the high season Factory 2 and Factory 12 were the lowest cost option plants for supply whenever they launched new products and were correctly allocated the majority of shipments. Factory 2 delivered 46.76% of its shipments while Factory 12 delivered 62.78% of its shipments. Table 4.17 below shows a summary of these results

$/HL	HIGH SEASON Backfilling Factory											
Launching Factory	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Factory 1	2.15	11.67	2.84	N/A	8.51	9.73	9.15	15.53	1.91	2.06	7.26	4.46
Factory 2	N/A	2.00	3.15	18.38	5.76	2.57	2.35	11.65	4.48	3.22	2.61	3.25
Factory 11	3.33	3.38	2.34	N/A	3.01	3.32	N/A	15.27	N/A	3.96	2.49	4.91
Factory 12	2.88	2.35	4.42	N/A	10.70	9.83	2.21	N/A	3.71	2.31	8.67	2.05
Launching Factory												
Least Expensive Option												

2011 Shipment Proportion	HIGH SEASON Backfilling Factory											
Launching Factory	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Factory 1	52.05%	0.54%	11.32%	N/A	0.34%	1.02%	0.10%	0.05%	3.95%	22.05%	5.27%	3.32%
Factory 2	N/A	46.76%	6.05%	0.03%	0.17%	5.64%	14.90%	0.03%	0.03%	2.33%	20.07%	3.99%
Factory 11	0.64%	2.50%	4.83%	N/A	7.56%	0.17%	N/A	0.03%	N/A	0.88%	82.96%	0.44%
Factory 12	0.55%	13.37%	5.82%	N/A	0.11%	0.44%	12.65%	N/A	0.06%	4.16%	0.06%	62.78%
Launching Factory												
2011 Primary Backfill Factory												

Table 4.17: High season average dollar per case cost to serve and backfill plant mix.

Low Season

In the low season only three plants launched new products – Factory 8, Factory 1 and Factory 12. During the launches at Factory 8 and Factory 1, the greater proportion of supply was correctly allocated to the lowest cost plant of Factory 8 and Factory 10 respectively. However, in the case of Factory 12 launching a new product, the lowest cost plant of Factory 7, was not allocated the majority of supply. See Table 4.18 below for a summary of these figures.

$/HL	LOW SEASON Backfilling Factory											
Launching Factory	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Factory 1	2.94	9.57	4.14	N/A	N/A	10.32	7.34	18.01	2.21	1.84	6.72	5.60
Factory 8	7.66	7.10	N/A	3.18	4.04	5.28	N/A	2.70	9.09	4.77	7.45	9.89
Factory 12	2.36	2.11	4.25	N/A	13.67	12.58	1.77	N/A	N/A	2.23	6.50	2.15
Launching Factory												
Least Expensive Option												

2011 Shipment Proportion	LOW SEASON Backfilling Factory											
Launching Factory	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Factory 1	14.32%	0.66%	23.92%	N/A	N/A	2.23%	1.45%	0.13%	11.43%	35.74%	9.33%	0.79%
Factory 8	0.67%	2.07%	N/A	5.13%	31.35%	0.03%	N/A	59.51%	0.03%	0.05%	0.62%	0.54%
Factory 12	2.25%	10.64%	7.47%	N/A	0.05%	0.29%	15.23%	N/A	N/A	2.93%	0.34%	60.79%
Launching Factory												
2011 Primary Backfill Factory												

Table 4.18: Low season average dollar per case cost to serve and backfill plant mix.

Allocation Priority

On the basis of 2011 data, a priority allocation matrix can be generated for each plant as shown in Table 23 below. Although, the cost optimization process at CPGCo is conducted on a global basis and takes into consideration several costs (such as manufacturing, warehousing and procurement); these matrices present a guide for double checking decisions on transportation allocations.

The tables summarized below provide a ranking scheme on the basis of the cost to serve in dollars per case. So for example in Table 23(a), the Factory 1 plant is currently the lowest cost plant in the high season. Hence, it has a rank of 1. Also it is the 3rd lowest cost plant in terms of cost during the low season. After ranking, the cost to serve a customer in the Factory 1 network, the optimal score shows that Factory 1 is actually the 3rd lowest cost option in both the low and high seasons.

	Factory 1			
	High Season		Low Season	
	Current	Optimal	Current	Optimal
F 1	1	3	3	3
F 2	8	10	9	8
F 3	3	4	2	4
F 4	12	12	12	12
F 5	9	7	11	11
F 6	7	9	6	9
F 7	10	8	7	7
F 8	11	11	10	10
F 9	5	1	4	2
F 10	2	2	1	1
F 11	4	6	5	6
F 12	6	5	8	5

Table 4.19a

	Factory 2	
	High Season	
	Current	Optimal
F 1	12	12
F 2	1	1
F 3	4	5
F 4	9	11
F 5	8	9
F 6	5	3
F 7	3	2
F 8	10	10
F 9	11	8
F 10	7	6
F 11	2	4
F 12	6	7

Table 4.19b

	Factory 8	
	Low Season	
	Current	Optimal
F 1	5	8
F 2	4	6
F 3	11	11
F 4	3	2
F 5	2	3
F 6	9	5
F 7	12	12
F 8	1	1
F 9	10	9
F 10	8	4
F 11	6	7
F 12	7	10

Table 4.19c

	Factory 11	
	High Season	
	Current	Optimal
F 1	6	5
F 2	4	6
F 3	3	1
F 4	10	10
F 5	2	3
F 6	8	4
F 7	11	11
F 8	9	9
F 9	12	12
F 10	5	7
F 11	1	2
F 12	7	8

Table 4.9d

	Factory 12			
	High Season		Low Season	
	Current	Optimal	Current	Optimal
F 1	6	5	6	5
F 2	2	4	3	2
F 3	4	7	4	6
F 4	11	11	10	10
F 5	8	10	9	9
F 6	7	9	8	8
F 7	3	2	2	1
F 8	12	12	11	11
F 9	9	6	12	12
F 10	5	3	5	4
F 11	10	8	7	7
F 12	1	1	1	3

Table 4.19e

Table 4.19 (a - e): Allocation priority matrix in low and high season for 5 plants launching products in 2011

4.6 Modeling Variations in Transportation Costs

Using the shipment data from 2011, a cost to serve model was developed which predicts the expected change in transportation costs during a complexity event. This analysis was primarily conducted on events which took place at one plant location at a time. For illustration purposes, the same analysis is conducted on one multi-plant event.

Factory 1

At Factory 1 during a national event conducted during the low season, the average change in cost per case due to an event was 0.11$/case with an increase in standard deviation of 0.27$/case. Based on this data the total additional transport costs due to the Factory 1 plant launch was up to $113, 485 per week. For a 5 week surge in new products this could cause a transportation cost increase as much as $567, 426 from this launch alone.

During a low season regional launch in Factory 1, the increase in transportation costs was 0.29$/case with a standard deviation of 0.31$/case. The average weekly increase in transportation costs was as low as $4,911. For a Factory 1 national launch in the high season the change in transportation costs were as high as 0.14$/case with an increase in standard deviation of 0.40$/case. The average weekly increase in costs was as high as $206,658. A summary of these costs and changes can be seen in Table 4.20 below.

	HL/wk	Avg. $/HL	Std. Dev.	Range +- σ (Ev. Vol.)		Avg. Cost/wk (Ev. Vol.)
				From	To	
EVENT	1,026,291	$ 3.00	$ 1.75	$ 1,279,781	$ 4,874,776	$ 3,077,279
NON-EVENT	1,267,782	$ 2.89	$ 1.48	$ 1,445,383	$ 4,482,204	$ 2,963,794
DELTA (Value)	(241,490)	$ 0.11	$ 0.27	$ (165,602)	$ 392,572	$ 113,485
DELTA (%)	-19.0%	3.8%	18.4%	-11.5%	8.8%	3.8%

4.20a: Factory 1 national launch in a low season

	HL/wk	Avg. $/HL	Std. Dev.	Range +- σ (Ev. Vol.)		Avg. Cost/wk (Ev. Vol.)
				From	To	
EVENT	17,076	$ 3.48	$ 1.74	$ 29,789	$ 89,156	$ 59,472
NON-EVENT	23,331	$ 3.20	$ 1.43	$ 30,176	$ 78,947	$ 54,562
DELTA (Value)	(6,255)	$ 0.29	$ 0.31	$ (388)	$ 10,209	$ 4,911
DELTA (%)	-26.8%	9.0%	21.7%	-1.3%	12.9%	9.0%

4.20b: Factory 1 regional launch in a low season

	HL/wk	Avg. $/HL	Std. Dev.	Range +- σ (Ev. Vol.) From	Range +- σ (Ev. Vol.) To	Avg. Cost/wk (Event vol.)
EVENT	1,467,384	$ 3.04	$ 1.76	$ 1,879,930	$ 7,055,656	$ 4,467,793
NON-EVENT	1,493,236	$ 2.90	$ 1.36	$ 2,262,765	$ 6,259,503	$ 4,261,134
DELTA (Value)	(25,852)	$ 0.14	$ 0.40	$ (382,835)	$ 796,152	$ 206,658
DELTA (%)	-1.7%	4.8%	29.5%	-16.9%	12.7%	4.8%

4.20c: Factory 1 national launch in a high season

Table 4.20 (a - c): Factory 1 plant cost variations during complexity events

Factory 2

The only new product launch at Factory 2 plant took place during the high season. This led to an average increase in transportation costs of 0.10$/case with an increase in standard deviation of 0.24$/case. The average increase in costs to the whole system was up to $153,001 per week. These results can be seen in Table 4.21 below.

	HL/wk	Avg. $/HL	Std. Dev.	Range +- σ (Ev. Vol.) From	Range +- σ (Ev. Vol.) To	Avg. Cost/wk (Event vol.)
EVENT	1,553,219	$ 3.00	$ 1.60	$ 2,176,549	$ 7,150,232	$ 4,663,391
NON-EVENT	1,493,236	$ 2.90	$ 1.36	$ 2,394,899	$ 6,625,881	$ 4,510,390
DELTA (Value)	59,983	$ 0.10	$ 0.24	$ (218,350)	$ 524,352	$ 153,001
DELTA (%)	4.0%	3.4%	17.6%	-9.1%	7.9%	3.4%

Table 4.21: Factory 2 plant cost variations during complexity events

Factory 8

Factory 8, which launched a new product in the low season, had an average weekly increase in transportation costs of 0.02/case with an average change in standard deviation of 0.11$/case. So during events in the low season the variability in costs actually reduced at the Factory 8. The increase in transportation costs due to this event was minimal at $28,471 per week. These figures can also be found in Table 4.22 below.

	HL/wk	Avg. $/HL	Std. Dev.	Range +- σ (Ev. Vol.) From	Range +- σ (Ev. Vol.) To	Avg. Cost/wk (Ev. Vol.)
EVENT	1,445,042	$ 2.91	$ 1.37	$ 2,228,547	$ 6,182,983	$ 4,205,765
NON-EVENT	1,267,782	$ 2.89	$ 1.48	$ 2,036,622	$ 6,317,426	$ 4,177,024
DELTA (Value)	**177,261**	**$ 0.02**	**$ (0.11)**	**$ 191,925**	**$ (134,443)**	**$ 28,741**
DELTA (%)	**14.0%**	**0.7%**	**-7.6%**	**9.4%**	**-2.1%**	**0.7%**

Table 4.22: Factory 8 cost variations during complexity events

Factory 11

At the Factory 11 plant which launched a new product in the high season, the average increase in transportation costs were up to 0.27$/case with an increase in standard deviation of 0.15$/case. The average cost increase came to $357, 914 per week. A summary of these figures follow in Table 4.23 below.

	HL/wk	Avg. $/HL	Std. Dev.	Range + - σ (Ev. Vol.) From	Range + - σ (Ev. Vol.) To	Avg. Cost/wk (Event vol.)
EVENT	1,326,507	$ 3.17	$ 1.51	$ 2,206,479	$ 6,213,434	$ 4,209,957
NON-EVENT	1,493,236	$ 2.90	$ 1.36	$ 2,045,334	$ 5,658,751	$ 3,852,043
DELTA (Value)	**(166,729)**	**$ 0.27**	**$ 0.15**	**$ 161,145**	**$ 554,683**	**$ 357,914**
DELTA (%)	**-11.2%**	**9.3%**	**10.9%**	**7.9%**	**9.8%**	**9.3%**

Table 4.23: Factory 11 plant cost variations during complexity events

Factory 12

The Factory 12 plant launched new products in both the low and high season. In the low season, the average increase in transportation costs were up by 0.13$/case with an increase in standard deviation of 0.30$/case. In the high season, the average increase in transportation costs went up by 0.26$/case with an increase in standard deviation of 0.26$/case. Weekly cost increases as the Factory 12 plant were as high as $149, 399 and $306, 921 in low and high seasons respectively. Table 4.24 below summarizes these results.

	HL/wk	Avg. $/HL	Std. Dev.	Range +- σ (Ev. Vol.) From	Range +- σ (Ev. Vol.) To	Avg. Cost/wk (Event vol.)
EVENT	1,107,684	$ 3.02	$ 1.78	$ 1,376,700	$ 5,319,787	$ 3,348,244
NON-EVENT	1,267,782	$ 2.89	$ 1.48	$ 1,560,013	$ 4,837,676	$ 3,198,844
DELTA (Value)	(160,098)	$ 0.13	$ 0.30	$ (183,313)	$ 482,111	$ 149,399
DELTA (%)	-12.6%	4.7%	20.3%	-11.8%	10.0%	4.7%

4.24a: Factory 12 national launch in a low season

	HL/wk	Avg. $/HL	Std. Dev.	Range +- σ (Ev. Vol.) From	Range +- σ (Ev. Vol.) To	Avg. Cost/wk (Event vol.)
EVENT	1,160,212	$ 3.17	$ 1.63	$ 1,789,158	$ 5,562,959	$ 3,676,059
NON-EVENT	1,493,236	$ 2.90	$ 1.36	$ 1,788,924	$ 4,949,351	$ 3,369,137
DELTA (Value)	(333,025)	$ 0.26	$ 0.26	$ 234	$ 613,609	$ 306,921
DELTA (%)	-22.3%	9.1%	19.4%	0.0%	12.4%	9.1%

4.24b: Factory 12 national launch in a low season

Table 4.24 (a & b): Factory 12 plant cost variations during complexity events

Multi-plant Launches

On four occasions a new product was be launched from two or more plants simultaneously. To understand how the observations from a single point plant launch differ from those in a multi-plant launch, a new product launch involving four plants was analyzed. The four plants involved were Factory 10, Factory 8, Factory 11 and Factory 12. This launch resulted in an increase in average weekly transportation costs of 0.05$/case and an increase in the standard deviation of 0.13$/case. Average weekly cost increased to $81, 848. See Table 4.25 below.

	HL/wk	Avg. $/HL	Std. Dev.	Range +- σ (Ev. Vol.) From	Range +- σ (Ev. Vol.) To	Avg. Cost/wk (Event vol.)
EVENT	1,753,840	$ 2.95	$ 1.49	$ 2,564,263	$ 7,785,377	$ 5,174,820
NON-EVENT	1,493,236	$ 2.90	$ 1.36	$ 2,704,235	$ 7,481,710	$ 5,092,973
DELTA (Value)	260,603	$ 0.05	$ 0.13	$ (139,972)	$ 303,667	$ 81,848
DELTA (%)	17.5%	1.6%	9.3%	-5.2%	4.1%	1.6%

Table 4.25: Cost variations during complexity events due to simultaneous new product launches at Factory 10, Factory 8, Factory 11 and Factory 12.

5 CONCLUSIONS AND RECOMMENDATIONS

As seen from the total transport cost equation, the behavior of the line haul component of transportation costs depends on four key variables - number of loads, cost per load, length of haul and regional factors. In the CPGCo distribution system the primary driver of transportation costs during new product launches is the average length of haul. The length of haul changes as a result of the backfill strategy, which is used to maintain deliveries to all customers in the network. Following are the key conclusions and recommendations from this study.

5.1 Conclusions

1. *The best way to study the cost impact of new product launches on transportation costs is to examine the "cost to serve" customers in the distribution network.* Initial attempts to analyze this cost impact by studying the changes in average rates at the lane, carrier and event level were inconclusive. Better results were obtained when the costs were examined as a whole for the system since all the actors involved participate in a new product launch, rather than just examining the new product launch location only. Thus, examination of rates and costs at the individual plant level does not show the whole cost picture.

2. *Transportation is not the top cost saving consideration in supply chain planning.* The analysis shows that the costs to serve each of the customers in the CPGCo network were not the lowest possible in each case. However, CPGCo currently conducts an optimization of all relevant costs before selecting the lowest overall cost option for delivering the product. It appears this optimization process currently favors other cost areas, such as manufacturing, inventory management or procurement, over transportation. Thus, the lowest total transportation cost plant option will not necessarily be part of the lowest total cost-to-serve option.

3. *An increase in supply chain complexity, adversely affects transportation cost performance*. This thesis observed that for all the complexity events that took place during 2011, there was an increase in average cost-per-case rates when utilizing non-dedicated fleet. This happened regardless of the origin, season, geographic extension or mix of plants during which the complexity event took place. The weekly cost increase ranged from 1.3% to 9.3% depending on these factors.

4. *The average transportation rate (dollars/mile) increases with an increase in the mix of carriers, despite strong rate enforcement at CPGCo*. CPGCo' s transportation management team performs a consistent and efficient implementation of contracted rates with individual carriers on most lanes. However, when there is a change in the relative proportion of carriers utilized for a specific origin-destination pair, especially during new product launches the company experiences a variation on average rate-per-mile observed. This also changes with the particular time horizon under consideration. (i.e. monthly or quarterly)

5. *Even a small percentage of new product capacity allocation in a plant, results in a significant increase in total system transportation costs*. A typical complexity event at CPGCo involved a re-allocation of existing production capacity, usually in the order of 0.2% to 3%. These small changes resulted in much higher transportation cost increases. Total transportation costs surged on average five-fold as a result.

6. *An increase in transportation costs is observable in the whole system and not only in the plant launching the new product*. Even though most of the complexity events were exclusively hosted by one location, the transportation costs impact of each event was absorbed by all the members of the CPGCo distribution networks, as the other plants fulfilled the task of backfilling. This backfilling strategy resulted in cost increases regardless of whether the launch was regional or national in scale.

7. *Complexity events impacts on transportation cost are much larger in the high season than in the low season*. In the cases analyzed in this project, we observed that the effect of launching a new product during what is considered the high season was double those which occurred during the low season.

8. *The plant launching a new product is not always the lowest cost option to supply customers within its network*. It was observed that in some cases it was less expensive to supply customers from a different plant rather than from the plant location closest to that customer. In some cases was observed up that it was up to 40% cheaper to serve the customer from an alternative further location.

9. *There is a noticeable increase in cost variability during new product launches*. During the high season there is an increase in variability of costs on average of 20% when non-events are compared to events. In the low season, this variability by almost half. It appears that new product launches in the high season have more impact on costs than in the low season.

5.2 Recommendations

At CPGCo and any other manufacturing company transportation costs is only one component of the total cost to serve a customer in the distribution network. Hence, any recommendation must bear this firmly in mind. However, acting strictly from the point of view of transportation planning and execution, this thesis suggests three types of recommendations, namely: strategic, tactical and operational.

Strategic recommendations are defined as long term (usually taking over 5 years) and will require large manpower and resources to execute. Tactical recommendations are seen as medium term (2 – 5 years execution window) and require much less manpower and resources to execute. Operational recommendations are seen as short term (less than 2 years, usually a few months) and should require only a team of one or two implement.

Strategic Recommendations

In the long term this thesis recommends a re-examination of the choice of backfill plant for a given customer. The current mix used in 2011 did not represent the lowest cost option strictly from a transportation cost point of view. One question to consider would be if the current backfill strategy is the best option for guaranteeing the lowest cost supply to all the customers in the CPGCo distribution network during NPDs. What would constitute the optimal number of plants to launch a new product from in order to minimize transportation costs? And does this change if the number of customers receiving these products changes as well?

Another long term issue to explore would be how to minimize the impact of low season and high season variability during new product launches. It is worth examining if it possible to incorporate this uncertainty in the bidding process. Can the current bidding algorithm be updated to capture this? Another key decision would be whether to share this information with all carriers involved in the bidding process. One approach would be to share this with only carriers with a national coverage who may thus be in the best position to leverage the potential cost impact of this information. Another approach could be to share this information only with carriers who have done business with CPGCo.

Tactical Recommendations

One possible approach that could be used in the transportation planning process could be scenario planning. Several transportation options could be developed assuming the best and worst case time and cost scenarios in terms of new product launches. This high level data should be shared with all actors in the supply chain planning process, preferably at the beginning of the year. Also a high level version of the same scenario could also be shared with preferred transport carriers in the CPGCo distribution system. For this to work this scenario plan would have to be updated and shared regularly, perhaps on an annual basis.

Another recommendation to CPGCo would be to consider collecting and including transaction level data on carrier load rejections to the existing transportation database. This can be useful for ongoing business intelligence on carrier behavior under different scenarios. This can also help determine on which lanes and at which times, the changes in carrier mix contribute to an increase in the average cost per mile.

Operational Recommendations

In the short term, we recommend comparing the transportation allocation priority, suggested in this thesis, with the system wide cost optimizer currently in place. This can be used to re-examine or update the constraints currently used in the optimizer. Another potential use of this information is in ensuring CPGCo builds carrier capacity on the lanes from the lower cost plants, according to the allocation matrix.

We also suggest exploring the option of varying the tender period on certain lanes to help minimize variability on these lanes. For example, the current practice of annual bid tendering may actually be increasing the number of load rejections, as carriers may not be able to commit resources over such a short time horizon. Our analysis shows that there are some lanes which are only used during new product launches. Is it possible to only request for the new product lanes (which show highly variable volume and costs) only when they are needed, for example, through quarterly bids? In the same way is it possible to lock in the more stable and predictable lanes over a 2 to 3 year period with national carriers to not only guarantee capacity but also provide economies of scale for the carriers and hence transferable cost savings to CPGCo.

5.3 Further Studies

There are certain areas which could not be explored due to time constraints and the scope of this study. This thesis would like to recommend the following possible areas for further exploration in the future at CPGCo.

First, this study can be expanded to examine what the number of optimal plants (launching a product) would be required to ensure the lowest possible overall transportation costs. While, this may not significantly change the current decisions being made from the optimization model employed at CPGCo during new product launches, it could be useful for long term planning of production capacity.

Secondly, the current study has been focused on studying the impact of a supply chain complexity event taking place within CPGCo. One area worth exploring would be the Examine impact on transportation costs at CPGCo when external complexity events take place. Such as , when a major competitor launches a new product or there are other external market disruptions such as oil price fluctuations or other economic factors.

Thirdly, the current study does not specifically explore the cost impact of a specific type of new product launch. Some launches involve minor packaging changes while others require more extensive packaging and product improvements. Each has its own unique impact on transportation costs. This is worth exploring.

Fourthly, this current study focuses on the impact of transportation costs up till the customer. For a more complete supply chain study it could be helpful to explore the impact of new product launches on second tier distribution. Can a customer be used as a test case to understand the dynamics after CPGCo supplies the new product? Is there any significant change as a result of the new product launch? Does this impact CPGCo in anyway?

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APPENDIX

A.1 Final Dataset Review

		FACTORY											
		1	2	3	4	5	6	7	8	9	10	11	12
	Non-Dedicated Linehaul Spend	$4,285,013	$15,805,080	$22.9MM	$8.7MM	$44MM	$28.7MM	$32.9MM	$22,337,555	$6.2MM	$14.4MM	$18,037,442	$12,390,687
Cost per Load	Mean	$ 643	$ 559	$ 612	$ 782	$ 877	$ 605	$ 637	$ 756	$ 956	$ 628	$ 568	$ 455
	Std. Dev.	$ 479	$ 351	$ 326	$ 514	$ 541	$ 423	$ 459	$ 723	$ 735	$ 533	$ 322	$ 326
	Min	$ 128	$ 3	$ 177	$ 100	$ 161	$ 185	$ 98	$ 229	$ 199	$ 119	$ 17	$ 123
	Max	$ 5,800	$ 4,798	$ 4,801	$ 7,902	$ 11,106	$ 5,413	$ 8,277	$ 4,013	$ 15,173	$ 7,148	$ 6,795	$ 4,692
	C. of Variation	0.74	0.63	0.53	0.66	0.62	0.70	0.72	0.96	0.77	0.85	0.57	0.72
Rate per Mile	Mean	$ 3.95	$ 1.87	$ 1.89	$ 2.57	$ 1.48	$ 1.75	$ 1.81	$ 3.74	$ 2.80	$ 6.59	$ 1.80	$ 2.49
	Std. Dev.	$ 2.40	$ 1.20	$ 1.08	$ 1.85	$ 0.71	$ 1.27	$ 1.05	$ 4.40	$ 1.00	$ 5.40	$ 1.40	$ 1.60
	Min	$ 0.80	$ 0.60	$ 0.55	$ 0.57	$ 0.50	$ 0.75	$ 0.70	$ 0.50	$ 1.06	$ 0.81	$ 0.50	$ 0.70
	Max	$ 31.50	$ 29.00	$ 14.13	$ 12.06	$ 10.06	$ 14.03	$ 14.80	$ 28.50	$ 14.96	$ 15.00	$ 34.10	$ 30.80
	C. of Variation	0.61	0.64	0.57	0.72	0.48	0.73	0.58	1.18	0.36	0.82	0.78	0.64
Cost per Hectoliter	Mean	$ 3.00	$ 2.58	$ 2.83	$ 3.61	$ 4.05	$ 2.79	$ 2.94	$ 3.49	$ 4.41	$ 2.90	$ 2.62	$ 2.10
	Std. Dev.	$ 2.20	$ 1.60	$ 1.51	$ 2.37	$ 2.19	$ 1.95	$ 2.12	$ 1.80	$ 3.39	$ 2.46	$ 1.50	$ 1.50
	Min	$ 0.60	$ 0.01	$ 0.82	$ 0.46	$ 0.74	$ 0.85	$ 0.45	$ 1.05	$ 0.92	$ 0.55	$ 0.08	$ 0.60
	Max	$ 26.70	$ 22.10	$ 22.15	$ 36.47	$ 51.25	$ 24.98	$ 38.20	$ 31.40	$ 70.02	$ 32.98	$ 18.50	$ 21.70
	C. of Variation	0.73	0.62	0.53	0.66	0.54	0.70	0.72	0.52	0.77	0.85	0.57	0.71

Table A.1: *Final Dataset Key Statistics*

A.2 System Backfilling Strategy Comparison Between Complexity Events and Non-Events Periods by Factory

A.2.1 High Season

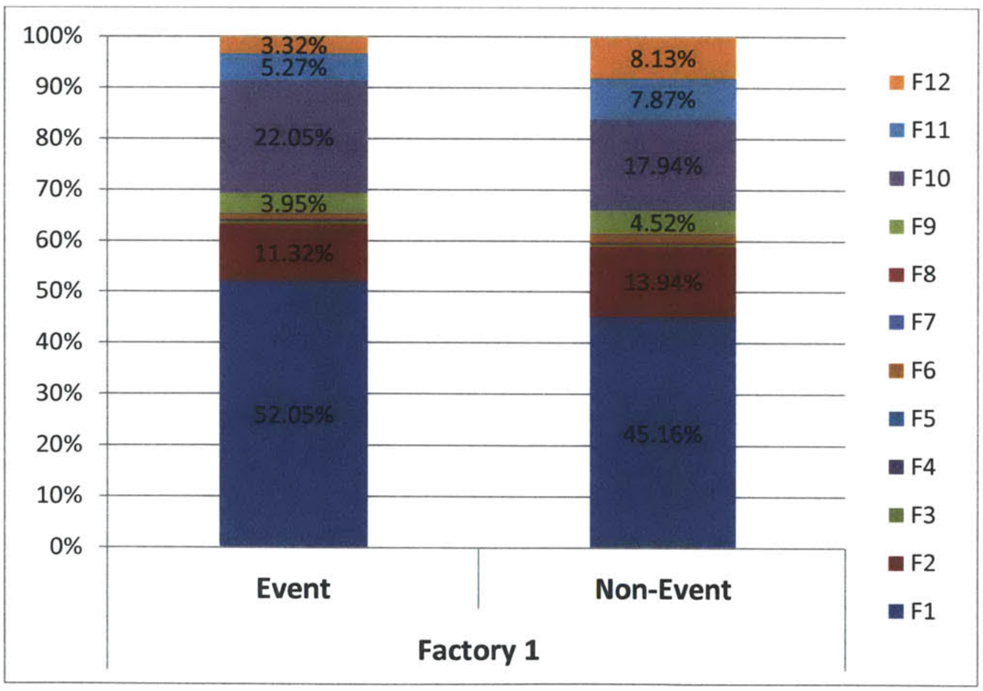

Figure A.2.1.1: *Factory 1 comparison between event and non-event periods during the high season*

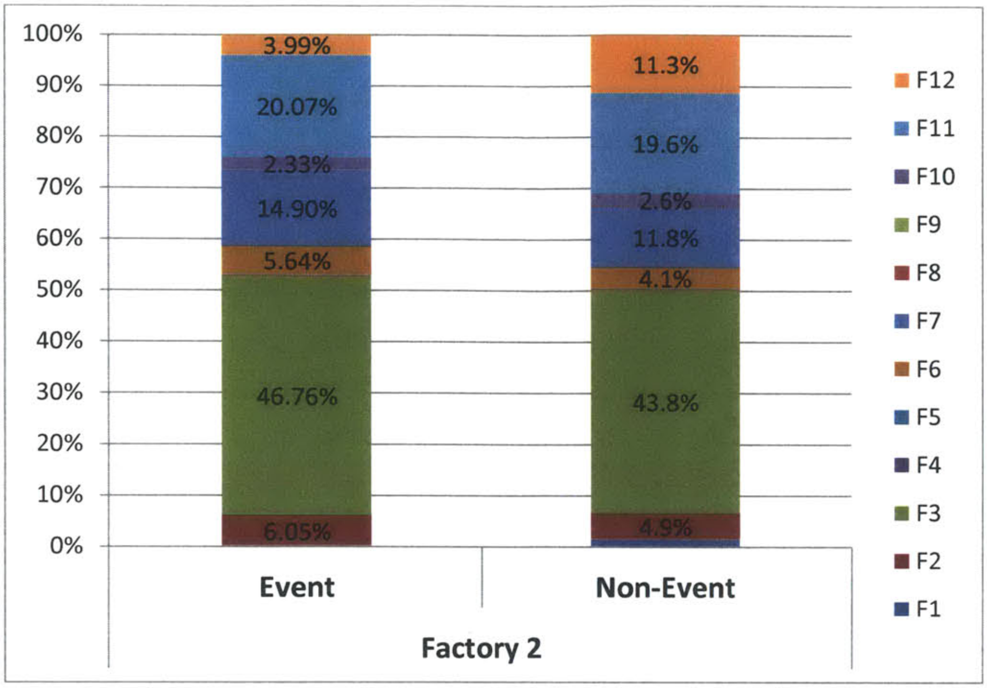

Figure A.2.1.2: Factory 2 comparison between event and non-event periods during the high season

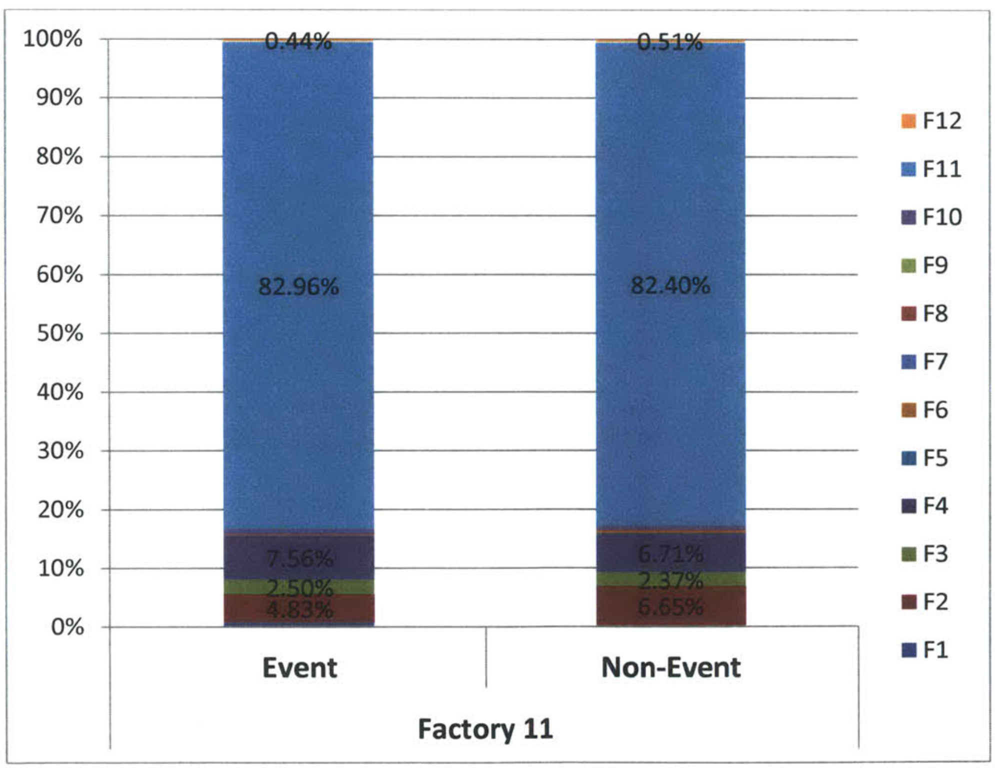

Figure A.2.1.3: Factory 11 comparison between event and non-event periods during the high season

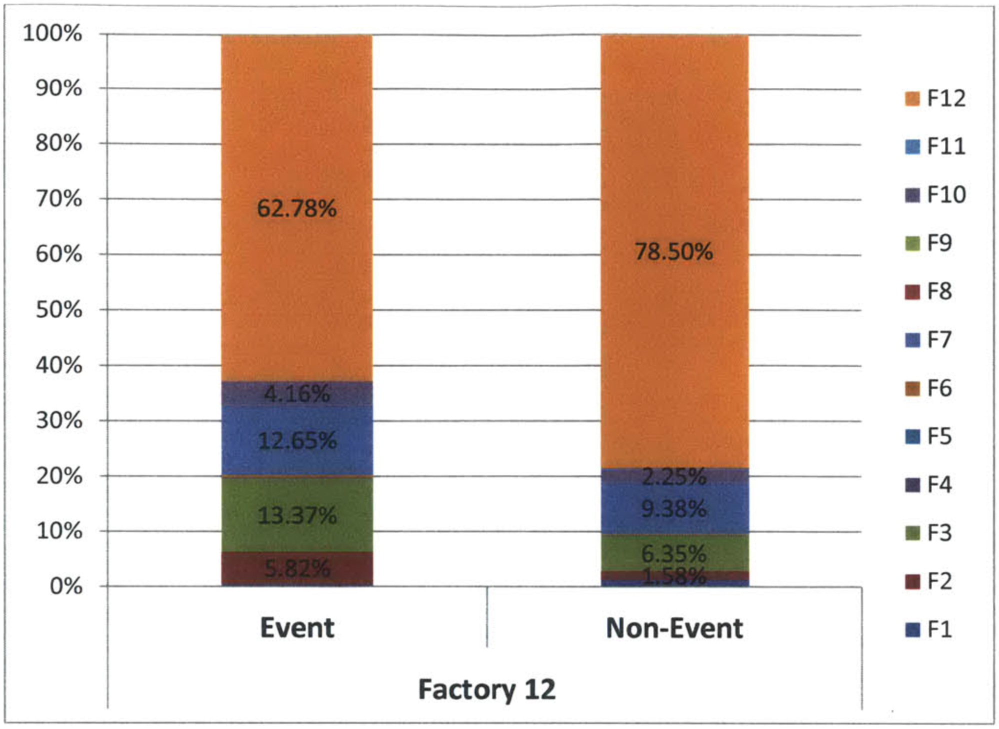

Figure A.2.1.4: Factory 12 comparison between event and non-event periods during the high season

A.2.2 Low Season

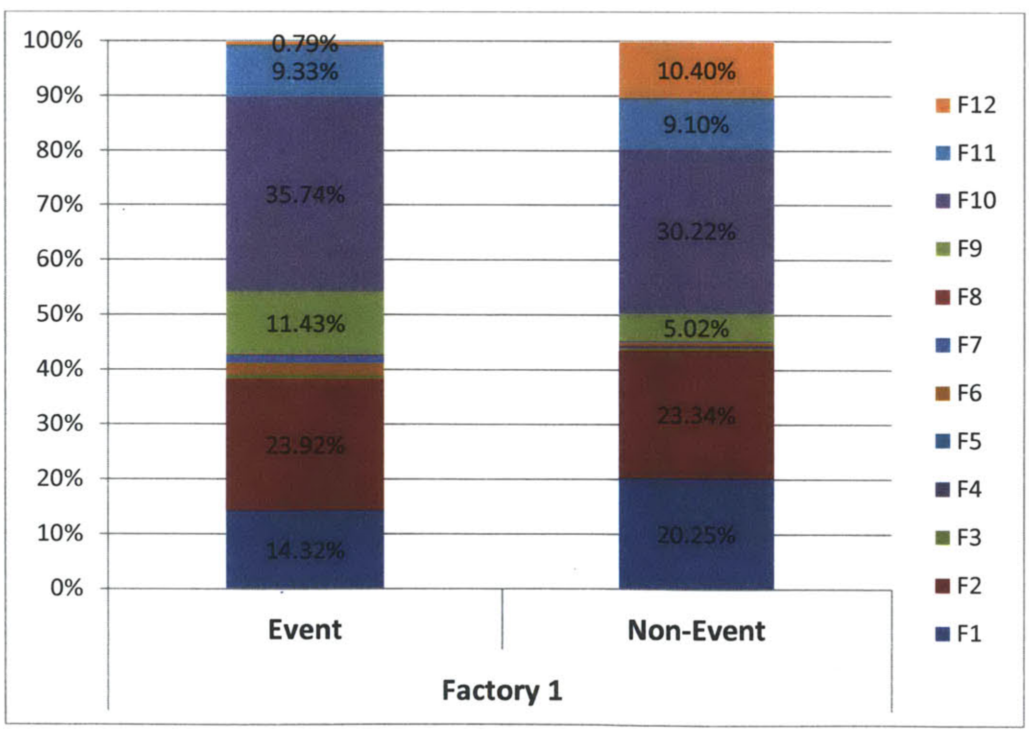

Figure A.2.2.1: Factory 1 comparison between event and non-event periods during the low season

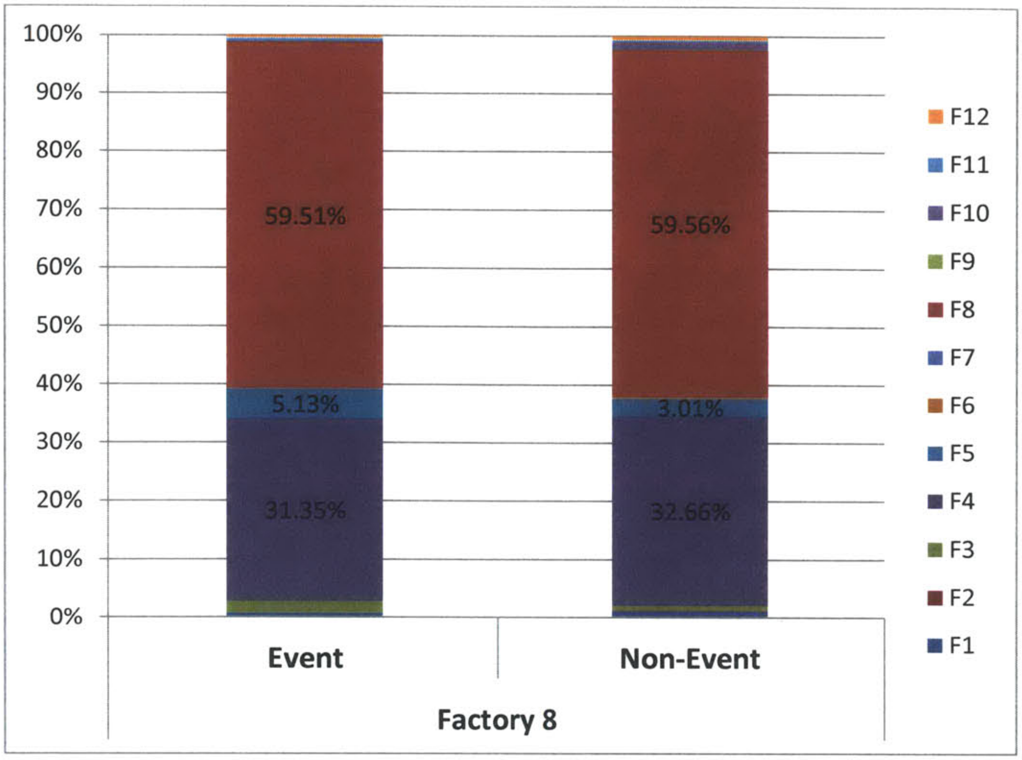

Figure A.2.2.2: Factory 8 comparison between event and non-event periods during the low season

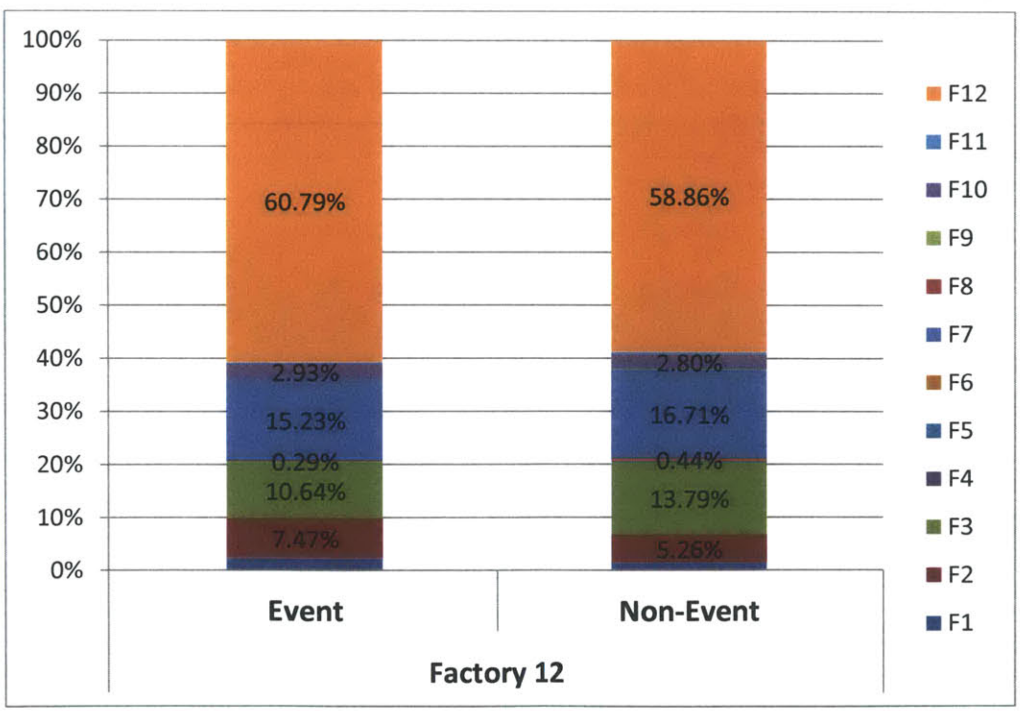

Figure A.2.2.3: Factory 12 comparison between event and non-event periods during the low season