ABSTRACT

Title of Document: JOINT REPLENISHMENT AND SUPPLY CHAIN ACTIONS IN THE RETAIL GROCERY INDUSTRY: TWO ESSAYS

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This study investigated supply chain management practices in the retail grocery industry from two perspectives. First, the operational performance objectives were examined by developing and testing a periodic review, joint replenishment model and heuristic. Joint replenishment policies, designed to coordinate the ordering of multiple items, can reduce inventory costs by synchronizing transportation and replenishment decisions (Cetinkaya and Lee, 2000). A fully specified model was developed taking into account the cost disadvantage of over-declared shipments. Based on the performance of the Full model, a Truck heuristic was proposed to fill a truck with each order. By varying the model parameters, the study demonstrated the large impact transportation costs had on total inventory costs and the viability of the Truck heuristic, even for moderate differences in

transportation rates. A simulation study tested violations of the demand normality assumption and found the Full model suboptimized the order interval and base stock levels under non-normal demand conditions. The result was a 2 percent cost increase over the expected costs in the Full model. The primary cost drivers were positive or negative deviations from truckload shipments and higher than expected demand during the order interval and replenishment period.

The second essay examined the strategic objectives of the retail grocer using the Schumpeterian perspective to relate supply chain actions, market-based actions, and firm performance in a longitudinal study. A structured content method was used to code articles reporting on supply chain and market-based activities. The study found that higher levels of supply chain and market-based actions, a source of competitive advantage, resulted in higher sales growth. Unexpectedly, firms engaged in a broad range of supply chain activities realized a decline in sales, suggesting that a more narrow focus on specific supply chain programs provided greater financial benefits to firms in the retail grocery industry. An exploratory study using cluster analysis found grocery retailers used a variety of strategies. Larger firms were more likely to focus on market-based strategies and realized the largest sales growth. Smaller firms, on the other hand, tended to choose balanced or supply chain-focused strategies, while still realizing average sales growth.

JOINT REPLENISHMENT AND SUPPLY CHAIN ACTIONS IN THE RETAIL GROCERY INDUSTRY: TWO ESSAYS.

by

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Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2006

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Acknowledgements

I would like to thank Dr. Curt Grimm, Dean's Professor of Supply Chain and Strategy, University of Maryland, and Dr. Phil Evers, Associate Professor, University of Maryland, for guiding this research project. Their expertise was invaluable during each step of the process from narrowing the scope of the research to theoretical development and analysis. I am particularly grateful to Dr. Grimm and Dr. Evers for keeping me focused and on track, which was much more important than I would have thought. I would also like to thank my committee; their suggestions and insight throughout the process greatly improved this research.

I would like to extend special thanks to Mr. Ken Miller, Miller's Food Market, Inc., for his support of this research with inventory data and insight to industry practices. Mr. Miller and his store manager, Rusty Christman, were very helpful in explaining the ordering practices used by independent grocery retailers.

I am also grateful to Dr. Bill Cunningham, Professor of Logistics Management, Air Force Institute of Technology, who kept in touch over the past 10 years and encouraged me to seek this degree.

Finally, I am deeply thankful for my family's support and understanding. They made it possible for me to commit the time and energy necessary to succeed in this program. I particularly want to thank my husband for helping with the more tedious tasks related to data entry.

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Chapter 1. Introduction

The retail grocery industry is the second largest retail category in the U.S. (U.S. Census Bureau, 2005) with annual sales of $635 billion in 2004 (McTaggart and Heller, 2005). Yet, despite relatively stable sales growth (Agnese, 2005), intense competition and historically narrow profit margins (Frankel et al., 2002) describe an industry in continual flux with many firms examining the viability of their long-term strategic objectives (The Progressive Grocer, 2005). According to Kurt Salmon Associates, a leading industry consultant, emphasis in three fundamental areas – continued sales growth, differentiation strategies, and control of supply chain costs – will distinguish the leaders from the laggards over the next decade (Mathews, 2005).

This research examined the supply chain management practices in the retail grocery industry from two different perspectives. First, this research targeted the tactical-level inventory control decisions of the retail grocer seeking to improve the replenishment process and reduce total inventory costs. This effort examined one way firms can trim costs via inventory control by modeling the joint replenishment of multiple stock-keeping units at the store-level. Second, this research examined the strategic implications of supply chain activities that contribute to and enable sustained firm performance. Emphasis in only one area of the supply chain, such as inventory control, does not ensure success. Rather, firms develop multiple supply chain solutions, tailored for different products, different customers, and different channels. Therefore, this second research agenda examined the proposition that multiple supply chain solutions contribute to the firm's financial performance and that alignment of supply chain strategies with the overall business strategy is a key factor in sustainable financial performance.

This chapter continues with an overview of the retail grocery industry and the competitive landscape. The supply chain management practices within the industry are also discussed highlighting their importance in cost control, customer service, and financial performance. In chapter 2, the joint replenishment process is introduced and the joint replenishment models are developed. Chapter 3 introduces the methodology used to test the inventory models with the results presented in chapter 4. The broader implications of supply chain activities on firm performance are introduced in chapter 5 using a competitive dynamics framework. In this chapter, the hypotheses are developed relating market-based and supply chain actions to firm performance. Chapter 6 outlines the methodology using structured content analysis with the results discussed in chapter 7.

1.1. Overview of the Retail Grocery Industry

The retail grocery industry is dominated by the supermarket store format accounting for 72 percent, or $457 billion, of total annual sales in 2004. The remaining market is captured by wholesale clubs ($32.6 billion), convenience stores ($127.2 billion), and small grocery stores ($17.5 billion) (McTaggart and Heller, 2005). In 2004, there were approximately 34,200 supermarkets in the United States, operated by chain and independent retailers. The majority of these supermarkets were categorized as traditional supermarkets. Approximately six percent were categorized as supercenter store formats (e.g., Wal-Mart, Target, and K-Mart), selling grocery items along with general merchandise (Currie, 2005; McTaggart and Heller, 2005).

The supermarket store format is the focus of most industry analysis and academic research due to its dominance in the marketplace and the availability of detailed data for both public and private firms, as collected by trade associations and trade publications.

1.2. Competition in the Retail Grocery Industry

Although dominated by a few large national companies, the retail grocery industry is fiercely competitive (Whiteoak, 1999) and remains fragmented (Agnese, 2005), where supermarkets compete at the local level for the consumer's food budget. The competitive pressure is felt on two fronts: price competition from the proliferation of extreme-value store formats and strong growth by niche marketeers in areas such as high-end specialty stores, organic, or ethnic foods (Agnese, 2005).

Pressure on the low-cost front has been growing over the past decade with the expansion of the supercenter and warehouse club formats (Kinsey and Senauer, 1996). Between 1995 and 2002, the traditional grocery channel lost approximately 13 percent of grocery sales, most of which were transferred to supercenters. Indeed, the traditional grocery channel, which has historically penetrated 100 percent of U.S. households, lost 1 percent of shoppers in 2004 to other grocery channels (Currie, 2005). Despite these competitive pressures for the individual consumer dollar, concentration at the national level has increased. Between 1998 and 2004, the market share of the top five firms grew 18 percent (30.3% to 48.3%) (McTaggart and Heller, 2005).

The evolution of alternative food channels, coupled with changing consumer preferences, has prompted many innovations in the industry aimed at differentiation and cost reduction. From a business strategy perspective, innovations include home meal replacements, expanded deli and bakery sections, on-line shopping, home delivery, pharmacies, expanded private label lines, redefined store layouts, brand repositioning, and capacity expansion (Agnese, 2005; Currie, 2005; McTaggart and Heller, 2005; The Progressive Grocer, 2003). To complement innovative business strategies, firms within the industry are also focused on controlling supply chain costs, improving efficiency, and improving customer service (Butner, 2005). Indeed, supply chain management is an area that has received significant attention within the food industry with extensive sponsorship and analysis by industry trade organizations.

Supply chain efficiency is important at the store-level, where replenishment process improvements and customer service are immediately realized, and at the firm-level, where system-wide improvements are designed to meet strategic objectives. It is on these two levels where this research is anchored. The next section provides an overview of supply chain management initiatives within the industry, highlighting relevant research and trends.

1.3. Supply Chain Management in the Retail Grocery Industry

Efficient Consumer Response (ECR) was launched in 1992 by representatives of the food manufacturing and retailing sectors as a means to eliminate waste in the supply chain. ECR committees are sponsored by trade organizations, such as the Grocery Manufacturers Association (www.gmabrands.com) and Food Marketing

Institute (www.fmi.org), to provide analysis and recommendations on supply chain strategies to improve customer value and reduce costs. ECR addresses the "total supply chain – suppliers, manufacturers, wholesalers and retailers, working closer together to fulfill the changing demands of the grocery consumer better, faster, and at less cost" (Fernie, 1999). ECR emphasizes four key areas—product assortment, product promotion, new product development, and product replenishment—which are supported by enabling technologies (Copacino, 1997; Fernie, 1999). Many industry initiatives come together under ECR in order to improve material and information flow: category management, electronic data interchange (EDI), radio frequency identification (RFID), point-of-sale ordering, direct store delivery, cross-docking, continuous replenishment, collaborative forecasting, and activity-based costing (Whiteoak, 1999).

Despite the inferred benefits of ECR, evidence in the grocery industry points to a slow adoption due, in part, to the complexity of the supply chain, inexperience with new initiatives, and an uncertainty of the true costs. In a survey of Australian food retailers and manufacturers, Kurnia and Johnston (2003) found that a lack of understanding of ECR and a shortage of the requisite skills were the fundamental reasons for firms not adopting ECR initiatives. They also found that pressure from a dominant trading partner often drove ECR adoption. While similar barriers to ECR adoption may exist in the US market, there appears to be wider acceptance among US retailers. In the Progressive Grocers 70th Annual Report of the Grocery Industry (2003), nearly half of the top 25 programs retail grocers planned to initiate or expand during 2004 were supply chain related involving reductions in inventory, expanded use of electronic interchange data, collaborative forecasting, continuous replenishment programs, stronger relationships with manufacturers, and increased investment in information technology. In the Grocery Manufacturers Association 2005 Logistics Survey, driving down logistics costs remained a high priority in managing firm financial objectives (Butner, 2005).

The topic of supply chain management in a highly competitive environment is relevant on several fronts. First, supply chain management centers not on one well-developed plan within a single firm, but rather emphasizes efficiency at every level within the firm and between firms. Even so, efficiency at the lowest level is still essential. Therefore, this research develops an inventory model to improve the replenishment process at the retail store level. Second, "the implementation of SCM [supply chain management] enhances customer value and satisfaction, which in turn leads to enhanced competitive advantage for the supply chain, as well as each member firm" (Mentzer et al., 2001a). Therefore, adding to the body of empirical evidence, this research seeks to examine how supply chain activities can be an essential part of the overall business strategy in creating disequilibrium in the market place.

Chapter 2. Joint Replenishment with Transportation Costs

2.1. Introduction

With the continuous advances in information systems, the exchange of information along the supply chain has enabled more efficient solutions in inventory management. For example, electronic data interchange (EDI) and the availability of point-of-sale data facilitates more efficient centralized inventory solutions and automated replenishment programs (Ricks, 1997). This is particularly true in the retail grocery industry with an increased use of efficient consumer response (ECR) programs (Agnese, 2005; Kurnia and Johnston, 2003). However, even with the rapid growth of technology in the grocery industry, only 53 percent of grocery retailers use automatic replenishment (Bearing Point, 2003). Furthermore, many sophisticated inventory control programs require investment in information systems and infrastructure, an investment in which many small independent grocery retailers lag behind their large grocery chain counterparts. In a survey conducted by *The Progressive Grocer*, the average independent grocer was just beginning to invest in point-of-sale technology and often relied on their wholesaler for technology solutions (Tarnowski, 2005).

Even with a trend toward automated replenishment, the ordering process remains an essential element in maintaining customer service levels and controlling inventory costs. In a study of the root causes for out-of-stock items in the retail food industry, Corsten and Gruen (2003) concluded that for U.S. firms poor ordering practices at the store level accounted for 51 percent of the stockouts. Poor ordering practices can be the result of ordering too few items, ordering too late, or ordering based on a faulty forecast. This study examines the first two items, order quantity and order interval, in a single-retailer, single-supplier setting. Specifically, this study compared three multi-item periodic review inventory policies. This type of joint replenishment problem has been studied, but with limited attention given to transportation costs. Cetinkaya and Lee (2000) argued that substantial savings can be realized when transportation decisions are coupled with replenishment decisions. With rising transportation costs, the impact of transportation on optimal inventory modeling should not be ignored. The joint replenishment models developed in this research focused on near-optimal solutions for the retailer with limited technology to connect real-time consumer demand with back-end inventory systems, while considering transportation costs explicitly in the decision calculus.

The next section reviews the extant literature on joint replenishment policies. In section 2.3 the textbook approach is presented and a fully specified model is developed taking into consideration the impact of transportation costs on inventory replenishment decisions. A numerical example illustrates the differences between these two models and a heuristic is proposed based on the performance of the fully specified model. Chapter 3 develops the methodology used to test the impact of model parameters on inventory policy selection. The experimental design for a simulation study is also presented to test the normality assumption of demand. The results and managerial implications are presented in chapter 4.

2.2. Literature Review of Joint Replenishment Inventory Policies

Joint replenishment policies (JRPs) are designed to coordinate the ordering of multiple items in such a way as to minimize the number of orders placed, thereby reducing inventory costs. Most JRPs fall into the class of the periodic (R, T) policy, although variations for continuous review have been proposed. In the (R, T) policy, inventory levels for a group of items are reviewed every T units of time and a sufficient quantity is ordered to raise each item i up to the base stock level, R_i. Rao (2003) proved the convexity of the (R, T) cost function which permits optimal solutions for the parameters R and T. While optimal solutions are feasible, they require complicated searches. Therefore, near-optimal heuristics are often proposed. The joint replenishment models reviewed in this section are listed in table 1.

Table 1. Joint Replenishment Models in the Literature

JRP	**Description**	**Limitations**	**Author (s)**
Can-Order Policy (s, c, S)	• Continuous Review • Reorder point • Can-order point • Order-up-to level	• May not synchronize ordering of heterogeneous items • Parameters difficult to find	Federgruen, Groenevelt, & Tijms (1984)
Periodic Review (R, T)	• Fixed order interval • Synchronizes ordering	• Assumes independence between R and T	Atkins & Iyogun (1988)
Modified Periodic Review (R, T)	• Order interval varies by item	• Assumes independence between R and T	Atkins & Iyogun (1988)
Continuous Review QS	• Joint reorder point, order-up-to level	• May not trigger order when only a few items are short	Pantumsinchai (1992)
Periodic (s, S)	• Periodic Review • Reorder point, order-up-to level	• Does not synchronize transportation with replenishment	Viswanathan (1997)
Continuous Q(s, S)	• Joint reorder point, item reorder point, order-up-to level	• Does not synchronize transportation with replenishment	Nielsen & Larsen (2005)

One of the earliest joint replenishment policies proposed was the continuous review (s_i, c_i, S_i) policy, also known as the can-order policy. In this control policy, an order is triggered when item i in a family of items falls below its reorder point, s_i.

In addition, any other item j in the family at or below its can-order level, c_j, is also included in the order. All items k are ordered up to their base stock level, S_k. Federgruen, Groenevelt, and Tijms (1984) developed a heuristic for the can-order policy under Poisson demand and constant lead times. Across a wide range of inventory parameters, they demonstrated that a suboptimal can-order policy outperforms individually controlled order-point, order-up-to (s, S) policies. A limitation with the (s_i, c_i, S_i) can-order policy is its complexity, such that optimal parameters may be difficult to find (Nielsen and Larsen, 2005). Furthermore, when a group of items is relatively heterogeneous in terms of demand patterns or cost structure, the can-order policy may trigger an order when only one item falls below its reorder point and no other items meet the can-order rule. Thus, the policy may not necessarily synchronize ordering across multiple items (Cachon, 2001).

Atkins and Iyogun (1988) proposed two periodic variations of the (R, T) policy as alternatives to the can-order policy. The first policy was a periodic (P) heuristic and set the review period to the same length for all items in the family. The second policy was a modified periodic (MP) heuristic and took into account item-specific fixed cost differences such that the review period for each item was set to some integer multiple of the base period. Atkins and Iyogun (1988) demonstrated that the periodic review policies resulted in lower total inventory costs when compared with the can-order or individual (s, S) policies. Further, the MP policy performed slightly better than the P policy for medium range order costs, while the common order interval, P policy, resulted in lower total costs for both high and low order costs. In addition to total cost considerations, the periodic review policies are easier to understand and easier to implement than more complex (s_i, c_i, S_i) policies (Atkins and Iyogun, 1988).

Another approach to the joint replenishment problem is the QS policy, which sets a joint reorder point for a family of items. The QS policy is a continuous review control policy, such that when the combined inventory position for all items drops to a predetermined group reorder point, Q, each item, i, is raised to its respective base stock level, S_i. Comparing the QS, can-order, and periodic (P/MP) policies, Pantumsinchai (1992) found that no one policy was consistently superior. For example, the can-order policy tended to order more frequently and therefore performed well when order costs were low. On the other hand, the QS and MP policies tended to order less frequently and thus performed well when order costs were high. One disadvantage of the QS policy is the potential for one item in the group to run short, even when the group reorder point has not been reached, implying a homogeneous family of items might be more desirable.

Building on the robustness of the periodic control policies, Viswanathan (1997) developed a periodic (s, S) policy, denoted P(s, S), that takes into consideration the inventory position of each item at the time of the review. Similar to the P policy developed by Atkins and Iyogun (1988), the review period is fixed, but flexibility is added by including in the order only those j items at or below their order points, s_j. The result of the P(s, S) policy is a slight reduction in the total inventory cost over the MP and QS policies.

Finally, a continuous review Q(s, S) policy was proposed by Nielsen and Larsen (2005). Similar to the QS policy, an order is triggered when the total consumption since the last order equals Q. However, rather than a single order-up-to rule, the Q(s, S) policy includes an item-level reorder point, s_i. Under Poisson demand and constant lead times, they developed a dual search algorithm to find Q and the (s, S) parameters that minimize total costs. They demonstrated that the variable nature of the review period in the Q(s, S) policy adds flexibility and reduces total inventory costs in all cases when compared to the P(s, S) policy. Further, the Q(s, S) policy performed better than or equal to the QS policy.

In general, the continuous review joint replenishment policies perform better than the periodic review policies, as expected. Continuous review policies often result in near-optimal solutions and lower total costs. However, they also require constant monitoring of the inventory status, often with each transaction, and necessitate an automated inventory system. This may not be ideal for many small independent grocers, who may not connect point-of-sale scanner data with inventory ordering systems. In a periodic review policy, the inventory status is determined at fixed intervals, requiring less frequent oversight and often fewer orders. The trade-off is the potential for larger inventories to protect against stockout during the fixed review period and replenishment lead time. However, larger inventories do not necessarily imply higher costs. Considerable cost savings may result when inventory review is coordinated across multiple items (Federgruen et al., 1984) by reducing the labor required to monitor inventory levels and economizing on order costs. Furthermore, since periodic review policies tend to order less frequently than continuous review policies, transportation can be coordinated to improve utilization.

Cachon (2001) addressed transportation utilization in a joint replenishment problem where the retailer balanced inventory costs, transportation constraints, and shelf space constraints. He compared three policies with stochastic demand and fixed lead times. The first model was a variation on Pantumsinchai's (1992) QS policy, where the joint reorder point was determined exogenously as a fixed fraction of the truck capacity. The second model was a full service (R, T) model, where every T units of time, orders were shipped up to their base stock level, R_i, which was set equal to the shelf space constraint for the item. Finally, he considered a minimum quantity periodic review policy. In the minimum quantity periodic review policy, every T units of time, the inventory status was determined and orders were shipped such that the trucks had at least a minimum shipping quantity. While the continuous review policy, in general, resulted in lower total inventory costs, the periodic review policies performed nearly as well, particularly when the review period, T, was less than the average time for total demand to equal truck capacity.

This study develops a set of models for the multi-item problem similar to those proposed by Cachon (2001). However, the models developed here focus specifically on the differential in transportation shipping rates in determination of the order interval. Generally, inventory models seek to minimize costs by balancing the cost of holding inventory with the cost of ordering inventory. Transportation rates are either neglected or treated as constant, which can significantly distort the true cost of inventory. The next section develops the models for this study, presents a numerical example, and then recommends a simple heuristic based on the results of the example that is both practical and intuitive.

2.3. Joint Replenishment Inventory Model Development

In this study, a fully specified inventory control policy was developed for the joint replenishment of a family of items in a single-supplier, single-retailer setting. The fully specified model was compared with a textbook baseline (R, T) model resulting in the recommendation of a simple near-optimal heuristic. Most notably, the fully specified model included the cost of transportation as a key cost parameter.

2.3.1. Model Assumptions and Notation

1) The supplier has sufficient stock to satisfy all retailer orders.
2) Demand is $\sim N\left(\mu_{X_i},\ \sigma_{X_i}\right)$, independent and identically distributed, and uncorrelated across items.
3) Unsatisfied demand is backordered.[1]
4) The lead time, L, is a random variable $\sim N\left(\mu_L,\ \sigma_L\right)$
5) Demand and lead times are independent of each other.[2]
6) Sufficient capacity is assumed at the retailer location.
7) Holding and penalty costs are linear and all items incur the same order costs.
8) Except for the baseline model, the base stock level, R_i, and order interval, T, are dependent.[3]
9) Freight terms are FOB origin and the retailer is responsible for freight costs.

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[1] In a retailer setting lost sales may be more realistic and can be examined in future research. The fundamental difference between the backorder case and the lost sales case is the level of safety stock held and hence holding costs. However, the use of backordering over lost sales is not expected to significantly impact the analysis (Tersine, 1994).

[2] Independence between demand and lead time reasonably approximates reality (Silver and Peterson, 1979).

[3] Fixed order size models often assume independence between the reorder point and the order quantity. However, in an order interval model, demand uncertainty occurs not only during the replenishment lead time, but also during the order interval. Therefore independence between the base stock level and order interval is not a reasonable assumption (Tersine, 1994).

The JRP models developed in this study are variations on the standard economic order interval, or periodic (R, T) policy. The order interval, T, is calculated so as to minimize the expected inventory costs (transportation, ordering, holding, and shortage) during the lead time, L, and the review interval, T. In a periodic review policy, if an order is placed now at t_0, the next order cannot be placed until $t_0 + T$ and will not be available until $t_0 + T + L$. Therefore, the base stock level, R_i, protects against demand uncertainty during the order interval, *T*, and replenishment lead time, *L*. The joint replenishment inventory problem includes two types of order costs (Federgruen et al., 1984; Pantumsinchai, 1992). A major order cost is incurred anytime a review takes place (Viswanathan, 1997) and is associated with order placement. The major order cost also includes the cost to assess and update the inventory status. A minor order cost, or line-item cost (Atkins and Iyogun, 1988), is associated with each item included in the order to cover the cost of picking, packing, or other special handling required to process the item for shipment. In addition to being an effective control policy when continuous review of inventory is not possible, a periodic review policy allows for control over truck utilization, a possible source of cost reduction. Truck utilization can be improved by adjusting the order interval to coincide with a fixed delivery schedule, as studied by Cetinkaya and Lee (2000), or to maximize truck capacity, as studied by Cachon (2001) and in this research.

The first model presented is the baseline (R, T) model with which to compare the other models. The second model is a fully specified (R, T) model which includes all relevant inventory costs. Finally, the third model is a truckload (R, T) heuristic which is based solely on truck capacity. The notation used throughout this paper is listed in table 2.

Table 2. Notation

D_i	Annual demand for item i (units) $\sim N\left(\mu_{X_i},\ \sigma_{X_i}\right)$
$\bar{X}_i$	Average daily demand for item i (units)
P_i	Purchase cost of item i (\$/unit)
C	Major order cost (\$/order)
n	Number of joint items
c	Minor order cost associated with each individual item, line-item cost
$H_i = P_i F$	Annual holding cost for item i (\$/unit/year)
F	Holding fraction, percent of unit cost
K_i	Annual shortage cost per unit for item i (\$/unit)
R_i	Base-stock level for item i (units)
S_i	Safety stock for item i (units)
T	Order interval (years)
Q_t	Capacity of truck (units)
Q_k	Shipping quantity (units)
L	Lead time (days) $\sim N\left(\mu_L, \sigma_L\right)$
$\hat{X}_{(i)T+L}$	Expected demand during order interval and replenishment lead time for item i (units)
$\sigma_{(i)T+L}$	Standard deviation of demand during order interval and lead time for item i (units)
Z_i	Standard normal deviate for item i
$P\left(X_i > R_i\right)$	Probability of a stockout for item i
$E\left[X_i > R_i\right]$	Expected stockout quantity for item i
G_k	Unit shipping cost (\$/unit) associated with shipping quantity, Q_k
G_0	Truckload unit shipping cost (\$/unit)
G_1	Less-than-truckload unit shipping cost (\$/unit)

2.3.2. Base (R, T) Policy

The baseline (R, T) inventory policy (referred to as the Base model in remainder of the paper) is the textbook multi-item economic order interval inventory model. In this model, the order interval, T_{Base}, is selected to minimize inventory costs with respect to order and holding costs alone and does not consider the cost differential in truckload (TL) and less-than-truckload (LTL) transportation rates. In the Base model it is assumed that the base stock level, R_i, and the order interval, T_{Base}, are independent, which simplifies the calculation of T_{Base}. The total relevant cost function (TRC) is given in equation (1) and includes the annual order cost and holding cost for cycle stock. For simplicity, the summation limits were dropped. Summation occurs over all *i* items unless otherwise noted.

$$TRC = Annual\ Order\ Costs + Annual\ Holding\ Costs$$

$$TRC(T) = \frac{C+nc}{T} + \frac{TF}{2}\sum P_i D_i \tag{1}$$

Taking the partial derivative of equation (1) with respect to *T* and setting this equal to zero, the order interval, T_{Base}, is given in equation (2).

$$T_{Base} = \sqrt{\frac{2(C+nc)}{F\sum P_i D_i}} \tag{2}$$

The expected cost of safety stock equals the cost of holding safety stock plus the cost of shortages, given by $TC(S_i) = FP_iS_i + \frac{K_iE[X_i > R_i]}{T}$, where $S_i = Z_i\sigma_{(i)T+L}$. This leads to the total cost function for the baseline model in equation (3), where the transportation rate per unit, G_k, is the rate in the transportation freight schedule associated with the average shipping quantity $Q_k = T_{Base}\sum D_i$.

$$TC(T_{Base}) = \sum P_i D_i + G_k \sum D_i + \frac{C+nc}{T_{Base}} + \frac{T_{Base}F}{2}\sum P_i D_i + F\sum P_i S_i + \frac{\sum K_i E[X_i > R_i]}{T_{Base}} \tag{3}$$

The advantage of the Base model is that it is easy to understand and implement. The order interval can be found using only a calculator or simple spreadsheet and, therefore, can be easily adjusted as model parameters change. A limitation with this model is that it does not attempt to optimize the order interval with respect to the cost of transportation. In general, less-than-truckload shipping rates are higher than full truckload rates, sometimes with a substantial difference in price. In the 2005 Grocery Manufacturers Association Logistics Survey, transportation accounted for 62 percent of total logistics costs for those food manufacturers surveyed. Further, transportation costs per mile increased 23 percent between 2001 and 2004 due to high fuel prices and driver/capacity shortages. The rise in costs have resulted in a shift in modal choice toward higher volume/truckload shipments (Butner, 2005). To consider the impact of transportation costs on the order interval, a fully specified joint replenishment model was developed in the next section.

2.3.3. Full (R, T) Policy

The fully specified model (also referred to as the Full model) considers the trade off among all costs (transportation, holding, penalty, and order) in determining the order interval. The Full model was developed by making three fundamental changes to the Base (R, T) policy: 1) transportation costs were included as a major cost component, 2) holding costs were adjusted to include the unit cost of transportation, and 3) the assumption of independence between the order interval and base stock levels was relaxed.

A fundamental characteristic of the Full (R, T) model is the inclusion of a non-linear transportation function. The transportation function used in the Full model is similar to that used in the all-units freight discount problem; such that a single rate is applied to the entire shipment provided the appropriate rate breakpoint is attained. However, the transportation function, G_k, is defined to account for the indifference points in the rate schedule which leads to the practice of over-declared shipments. This is similar to the transportation function used by Russell and Krajewski (1991) in a lot sizing model for a single inventory item. They noted that phantom freight, or an over-declared shipment, occurs when the "actual shipping weight falls within a range that lies between the rate breakpoint and an indifference point which is a function of the particular freight rate schedule." This leads to a non-linear relationship between the shipping quantity and transportation costs and can be represented by two transportation functions; one that is applied for shipments between a rate break and the indifference point and a second function applied for shipments between the indifference point and the next higher rate break. Given the base truckload (TL) rate per unit, G_0, and the less-than-truckload (LTL) rate per unit, G_1, the transportation function, G_k, can be defined by equation (4), where Q_t equals the truck capacity in units and $Q = T\sum D_i$ is the shipping quantity associated with order interval T.

$$G_k = \begin{cases} \frac{k}{2}\left(\frac{Q_t}{Q}\right)G_0 & k = 2,4,6,... \\ \frac{k-1}{2}\left(\frac{Q_t}{Q}\right)\left(G_0 - G_1\right) & k = 3,5,7,... \end{cases} \tag{4}$$

Using the transportation function in equation (4) a transportation rate schedule can be constructed as shown in table 3. In this example, and truck capacity equals 50,000 pounds and all items weigh 50 pounds. Therefore, the unit capacity of the truck, Q_t, equals 1,000 units. The truckload (TL) rate is \$6.00 per hundred weight (cwt.), such that G_0 equals \$3.00 per unit, while the less-than-truckload (LTL) rate is

\$10.00 per cwt, where G_1 equals \$5.00 per unit. This results in an indifference point of 600 units below which the LTL rate applies.

Table 3. Transportation Rate Schedule

Order Quantity (units)	Transportation Rate (\$/unit)
1 – 600	$G_1 = G_1$
601 – 1000	$G_2 = \left(\frac{Q_t}{Q}\right) G_0$
1001 – 1600	$G_3 = \frac{Q_t}{Q}\left(G_0 - G_1\right) + G_1$
1601 – 2000	$G_4 = 2\left(\frac{Q_t}{Q}\right) G_0$
2001 – 2600	$G_5 = 2\frac{Q_t}{Q}\left(G_0 - G_1\right) + G_1$
2601 – 3000	$G_6 = 3\left(\frac{Q_t}{Q}\right) G_0$

The transportation rates and shipment costs are shown in figure 1 for shipments between 1 and 3,000 units. It can be seen that the total cost of transportation for a single shipment is the same whether 601 units or 1000 units are shipped, in this example. Thus, for a shipping quantity of 800 units, the shipper would over-declare the shipment as a full truckload and ship 200 units of phantom freight, rather than pay the higher LTL shipping rate.

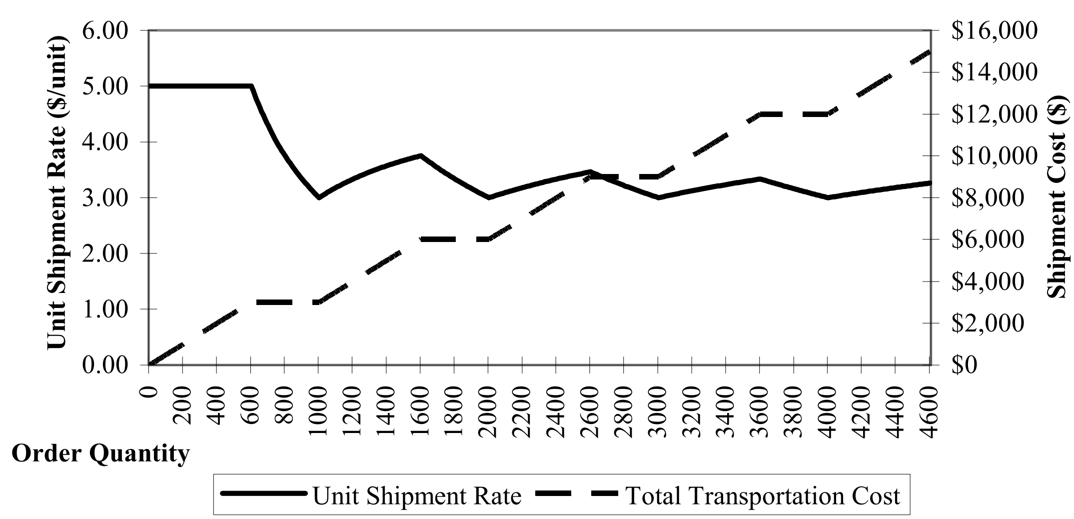


Figure 1. Shipment Rates with Phantom Freight

The total cost function for the full (R, T) policy is shown in equation (5) and includes the incremental unit cost of transportation in the holding costs as recommended by Buffa and Reynolds (1977) and Tersine (1994).

$$\begin{aligned} TC = &\ Annual\ Purchase\ Costs + Annual\ Order\ Costs \\ &+ Annual\ Holding\ Costs\left(Cycle\ Stock\right) \\ &+ Annual\ Holding\ Cost\left(SafetyStock\right) + Annual\ Shortage\ Cost \end{aligned}$$

$$\begin{aligned} TC\left(T\right) = &\sum P_i D_i + G_k \sum D_i + \frac{C + nc}{T} + \frac{TF}{2}\sum\left(P_i + G_k\right)D_i \\ &+ F\sum\left(P_i + G_k\right)S_i + \frac{\sum K_i E\left[X_i > R_i\right]}{T} \end{aligned} \tag{5}$$

The order interval, T_{Full}, is found by taking the first derivative of the total cost function in equation (5) with respect to T and setting this equal to zero. This leads to the solution in equation (6) and the first approximation for T_{Full}. The derivation of order interval is provided in appendix 1.

$$T_{Full} = \sqrt{\frac{2\left(C + nc + \sum K_i E\left[X_i > R_i\right]\right)}{F\sum\left(P_i + G_k\right)D_i - 2F\sum\left(P_i + G_k\right)\bar{X}_i}} \tag{6}$$

The solution to equation (6) is found using an iterative approach. However, before this iterative approach is presented, it is important to understand how the expected value and variance of demand during the lead time and order interval in a periodic review model differs from that in a typical lot sizing model.

First, consider $\hat{X}_{(i)T+L}$, the expected value of demand during the order interval and replenishment lead time in a periodic (R, T) policy. Recall that under a periodic review policy, the base stock level, R_i, must protect against demand uncertainty during the order interval and the replenishment lead time. Because both demand and lead time are stochastic, daily demand varies as does the length of the lead time. Conditioning is used to find the expected value of demand during the replenishment period and a variable lead time. For example, if one conditions on the lead time, L, when the lead time is known (e.g., $L = l$), then $E\left[X \middle| L = l\right]$ can be solved. By definition, $E\left[X\right] = E_L\left[E\left[X \middle| L\right]\right]$ where the outer expectation is taken with respect to the distribution of Y (Ross, 2002). It is further assumed that demand and lead time are independent, such that the expected demand during the T + L can be derived as shown in equation (7).

$$\begin{aligned} \hat{X}_{(i)T+L} &= E\left[X_{(i)T+L}\right] = E\left[\sum_{i=1}^{T+L} X_i\right] = E_{T+L}\left[\sum_{i=1}^{T+L} X_i \middle| T+L\right] \\ &= E\left[T+L\right]E\left[X_i\right] \\ &= \left(E\left[L\right]+T\right)E\left[X_i\right] \\ &= E\left[L\right]E\left[X_i\right]+TE\left[X_i\right] \end{aligned}$$

$$\hat{X}_{(i)T+L} = \overline{L}\overline{X}_i + T\overline{X}_i \qquad (7)$$

Where X_i is defined as the daily demand for item i, T (measured in days) is the order interval and treated as a constant, and L is the variable lead time.

Similarly, the variance of demand during the order interval and lead time is found by conditioning on the lead time, where the variance of the constant T is zero, $Var\left(T\right) = 0$, as shown in equation (8).

$$
\begin{aligned}
Var\left(X_{(i)T+L}\right) &= Var\left(\sum_{i=1}^{T+L} X_i\right) \\
&= E_{T+L}\left[Var\left(\sum_{i=1}^{T+L} X_i \middle| T+L\right)\right] + Var\left(E\left[\sum_{i=1}^{T+L} X_i \middle| T+L\right]\right) \\
&= E_{T+L}\left[(T+L)Var(X_i)\right] + Var\left((T+L)E[X_i]\right) \\
&= E[T+L]Var(X_i) + E[X_i]^2\, Var(T+L) \\
&= \left(E[L]+T\right)\sigma_{X_i}^2 + \bar{X}_i^2\left(Var(L)+Var(T)\right)
\end{aligned}
$$

$$
\sigma_{(i)T+L}^2 = \bar{L}\sigma_{X_i}^2 + T\sigma_{X_i}^2 + \bar{X}_i^2\sigma_L^2 \tag{8}
$$

Once the variance of demand during T+L is determined, the safety stock for item i, S_i, can be calculated if it assumed that $\hat{X}_{(i)T+L}$ is normally distributed. Therefore, $S_i = Z_i\sigma_{(i)T+L} = Z_i\sqrt{\bar{L}\sigma_{X_i}^2 + T\sigma_{X_i}^2 + \bar{X}_i^2\sigma_L^2}$, where Z_i is the standard normal deviate. The base stock level is then given by, $R_i = \hat{X}_{(i)T+L} + S_i$. Similarly, the expected stockout quantity, $E[X_i > R_i]$, equals $E[Z_i]\sigma_{(i)T+L}$, where $E[Z_i]$ is the expected quantity in the tail of the cumulative distribution function of Z_i.

It is now possible to find a first approximation of the order interval for the Full model using an iterative approach for convergence in R_i and *T*.

Iterative solution for T_{Full}, equation (6):

1) Compute T when the expected stockout quantity, $E[X_i > R_i]$, equals zero.

2) Use T to compute the shipping quantity, $Q_k = T\sum D_i$ and the appropriate shipping unit rate, G_k, given in equation (4).

3) Calculate the probability of a stockout, $P(X_i > R_i) = TF(P_i + G_k)/K_i$, which is the first derivative of the total cost function with respect to R_i (see appendix 1 for the derivation of the probability of a stockout).

4) Compute the base stock level, R_i, given by $R_i = \hat{X}_{(i)T+L} + S_i$.

5) Use $P(X_i > R_i)$ to find Z_i, $E[Z_i]$, and $E[X_i > R_i]$.

6) Recompute T using the new value for the expected stockout quantity, $E[X_i > R_i]$, found in step 5.

7) Repeat steps 2 through 6 until convergence in R_i and T occurs.

It should be noted that the expected stockout quantity, $E[X_i > R_i]$, is also a function of T, since $E[X_i > R_i] = E[Z_i]\sigma_{(i)T+L} = E[Z_i]\sqrt{\bar{L}\sigma_{X_i}^2 + T\sigma_{X_i}^2 + \bar{X}_i^2\sigma_L^2}$. However, $E[X_i > R_i]$ was treated as a constant in the derivation of the order interval in equation (6). This was done because the inclusion of the order interval, T, under the radical makes the total cost equation intractable. Therefore, the solution for T_{Full} given by equation (6) yields only a first approximation for the order interval. The optimal order interval can be found using an incremental search in T for the lowest total cost. This is a common approach in inventory modeling when the simplifying assumptions are relaxed.

2.3.4. Comparing Models: A Numerical Example

The Base (R, T) policy is compared with the Full (R, T) policy using a numerical example with the parameters listed in table 4. Consider a retailer managing two items. The annual demand for item 1 is 24,000 units and costs $45 per unit. The annual demand for item 2 is 22,000 units and costs $36 per unit. The remaining costs and problem parameters are the same for each item. Using these parameters, the order interval was calculated for the Base model.

Table 4. Numerical Example Parameters

		Item 1	Item 2
D_i	Annual demand (units)	24000	22000
σ_{X_i}	SD daily demand (units)	20	15
P_i	Item cost	45	36
C	Major order cost	100	
n	Number items	2	
c	Minor order cost	15	
F	Holding fraction	0.4	
K_i	Shortage cost	5	
L	Lead Time (days)	5	
σ_L	SD lead time (days)	1.5	
TL	Truck capacity (wt)	50000	
Q_t	Truck capacity (units)	1000	
G_0	TL rate ($/unit)	3	
G_1	LTL Rate ($/cwt)	5	
w	Item weight	50	

The first approximation for the order interval in the Full model was found using equation (6) and a search for the lowest total cost was used to find the optimal order interval as discussed in section 2.3.3. Table 5 compares the order intervals, demand during T+L for both items, and the total cost of inventory for each model.

In this example, the Full (R, T) policy led to fewer orders per year, a larger average shipping quantity, Q_k , and a lower total annual cost of inventory when compared to the Base (R, T) policy. Further, a 16 percent increase in the average shipment size (857 units in Base model and 1000 units in the Full model) had a relatively small impact on the traditional order, holding, and shortage costs (0.7% cost reduction), yet produced a large decrease in annual transportation shipping costs ($161,026 for Base model and $138,000 for Full model, or 14 percent).

Table 5. Inventory Model Comparison for Numerical Example

	Base Model	Full Model
Avg demand during L+T, $\hat{X}_{(1)T+L}$	779	854
Avg demand during L+T, $\hat{X}_{(2)T+L}$	708	776
Safety Stock, S_1	159	150
Safety Stock, S_2	150	143
Base Stock Level, R_1	937	1004
Base Stock Level, R_2	858	919
Expected stockout quantity, $E\left[X_1 > R_1\right]$	3.49	4.14
Expected stockout quantity, $E\left[X_2 > R_2\right]$	2.43	2.86
Shipment (Order) Quantity, Q_k	857	1000
Order Interval, T (in years)	0.01863	0.02174
Order Interval, T (in days)	6.80	7.93
Number order cycles per year (1/T)	54	46
Annual Purchase cost	$1,872,000.00	$1,872,000.00
Annual Shipping Cost	161,026.84	138,000.00
Annual Order Cost	6,976.53	5,980.00
Annual Holding Cost (Cycle Stock)	7,576.64	8,739.13
Annual Holding Cost (Safety Stock)	5,449.86	5,120.03
Annual Shortage Cost	1,589.47	1,612.56
Total Annual Inventory Costs	$2,054,619.34	$2,031,451.73

This is because with each shipment in the Base model, the shipper over-declared the shipment and sent phantom freight. This resulted in more frequent shipments and a higher "effective" transportation per unit rate. Thus, there was a cost disadvantage to sending phantom freight. On the other hand, the fully specified model optimized the order interval such that each shipment filled a truck (1000 units), taking advantage of the lowest transportation rate. This numerical example demonstrates that transportation costs are a significant part of total inventory costs and can result in much higher costs when excluded. While it appears that transportation is the major determinant of the optimal order interval, several different cost parameters were tested to determine if varying order, holding, and shortage costs might yield an LTL shipment size in the Full (R, T) model. Interestingly, the fully specified model optimized to a full truck, or integer multiple of a truck, for each scenario tested.

This led to a simple heuristic based on anecdotal evidence used in practice—that of higher volume shipments aimed at filling a truck with each order. Indeed, a retailer might be attracted to the lower shipping rate and want to improve truck utilization. A naïve approach sets the order interval as a function of truck capacity, taking advantage of transportation economies of scale. This heuristic is developed in the next section.

2.3.5. Truck (R, T) Heuristic

In this model the order interval, T_{Truck}, is determined exogenously as a function of truck capacity, Q_t, as shown in equation (9). In doing so, it is expected that, on average, the shipping quantity, Q_k, will equal the truck capacity, Q_t, and therefore take advantage of the lowest truckload shipping rate, G_0.

$$T_{Truck} = \frac{Q_t}{\sum D_i} \tag{9}$$

The total annual cost of inventory is given in equation (10) and includes the fully specified holding costs for cycle and safety stock. The Truck heuristic is a special case of the Full (R, T) policy where no phantom freight is shipped (see appendix 2 for a full discussion).

$$TC(T) = \sum P_i D_i + G_0 \sum D_i + \frac{C + nc}{T} + \frac{TF}{2} \sum (P_i + G_0) D_i + F \sum (P_i + G_0) S_i + \frac{\sum K_i E[X_i > R_i]}{T} \tag{10}$$

The Truck heuristic is intuitively simple and economizes on the lowest truckload shipping rates. Due to demand and lead time variability, a limiting factor with the truckload model is that the order quantity at each review will not be exactly a full truck load. Thus, when the order quantity, Q_k , is less than a full truck load, the retailer may simply ship the required amount at the corresponding shipping rate. Or, he may chose to increase the order size of some items to fill a truck. The disadvantage of the former option is a slightly higher shipping rate, while the risk in the later is higher holding costs. When the order quantity is greater than a full truck load, the retailer may, again, simply ship the required amount, paying the LTL rate for all items over truck capacity. Rather than paying a higher shipping rate, he might alternatively forgo ordering any quantity over Q_t and replenish each item to an equal fraction of the total requirement. With this allocation solution there is an increased risk of stockout. The choice of these options depends on transportation costs versus holding costs when $Q < Q_t$ and transportation costs versus shortage costs when $Q > Q_t$. As demonstrated, however, transportation costs dominate the inventory model. Therefore, this heuristic aims to fill a truck with each order with the expectation that actual demand does not vary significantly from the average.

The three periodic-review, multi-item inventory models were compared using the varying cost parameters listed in table 6. The resulting order interval, average order quantity, and total annual cost for each problem is listed in table 7.

Table 6. Numerical Example Problem Set

	Purchase Cost, P_1	Purchase Cost, P_2	Major Order Cost, C	Minor Order Cost, c	Holding Fraction, F	Shortage Cost, K_i
1	45	36	100	15	0.4	5
2	45	36	20	2	0.4	5
3	45	36	100	15	0.1	5
4	45	36	100	15	0.4	1
5	45	36	100	15	0.6	5
6	45	36	250	15	0.4	5
7	45	36	100	15	0.4	8
8	45	36	250	20	0.1	8
9	200	150	250	20	0.6	8
10	200	150	20	5	0.6	5

Table 7. Model Comparison with Varying Cost Parameters

	Base (R, T)			Full (R, T)			Truck (R, T)		
	T(days)	Q_k	Total Cost	T(days)	Q_k	Total Cost	T(days)	Q_k	Total Cost
1	6.80	857	$2,054,619	7.93	1000	$2,031,452	7.93	1000	$2,031,452
2	2.92	368	$2,116,890	7.93	1000	$2,026,576	7.93	1000	$2,026,576
3	13.60	1714	$2,042,324	15.87	2000	$2,019,307	7.93	1000	$2,020,349
4	6.80	857	$2,051,542	7.93	1000	$2,028,288	7.93	1000	$2,028,288
5	5.55	700	$2,097,333	7.93	1000	$2,038,167	7.93	1000	$2,038,167
6	9.98	1258	$2,056,602	7.93	1000	$2,038,352	7.93	1000	$2,038,352
7	6.80	857	$2,055,338	7.93	1000	$2,032,179	7.93	1000	$2,032,179
8	20.32	2560	$2,043,028	23.80	3000	$2,022,972	7.93	1000	$2,027,859
9	3.99	503	$8,418,467	7.93	1000	$8,330,788	7.93	1000	$8,330,788
10	1.28	162	$8,389,082	7.93	1000	$8,312,564	7.93	1000	$8,312,564

The results in table 7 show that the textbook approach in the Base (R, T) policy resulted in higher inventory costs, while the Full (R, T) policy produced the lowest annual cost. It is also evident that the Truck heuristic performed well for this numerical example in eight of the ten scenarios. Indeed, when the Full (R, T) policy optimized to a single truck, the Full model and Truck heuristic were equal. The performance of the Truck heuristic and Base model compared with the Full (R, T) model is the focus of this research. The methodology and experimental design for the proposed simulation study is detailed in the next chapter.

Chapter 3. Joint Replenishment Methodology and Experimental Design

This research had two main objectives. The first objective was to test the sensitivity of the two competing models (Base model and Truck heuristic) to changes in the model parameters when compared with the fully specified model. In particular, the aim was to more fully understand when the competing models would perform as well, or nearly as well, as the fully specified model, given a set of cost and demand parameters. To investigate this first objective, a test problem was developed in which the model parameters were varied. The three models (Base, Truck, and Full) were then compared based on the total annual cost of inventory.

The second objective of this research was to test the sensitivity of the fully specified model to non-normal demand. A fundamental assumption in the fully specified model is that demand is normally distributed. However, actual demand characteristics may, in fact, deviate from this normality assumption. To test this second objective, actual demand data was collected from a local grocer for use in a simulation study. This chapter describes the test problem and the data collection for the simulation study.

3.1. Model Sensitivity and Model Selection

Theoretically, the fully specified model will determine an order interval for the replenishment of multiple items resulting in the lowest total cost of inventory. However, this model is cumbersome to use as demonstrated by the iterative solution and final search in T described in section 2.3.3. For practical implementation, inventory optimization software would be required, particularly when the number of items in an order becomes large. Even when only a handful of items were considered, determination of the optimal order interval required some programming expertise within a spreadsheet tool. Therefore, it would be helpful to know when the fully specified model is most appropriate, given a set of model parameters. Equally, it would be helpful to know when the Truck heuristic or textbook approach yield acceptable results.

3.2. Model Calculations

Microsoft Excel 2003 (Excel) was used with the support of Visual Basic to quickly calculate the relevant variables in each model while enabling easy manipulation of the model parameters. An Excel worksheet was used to provide the input to the model. Input parameters included the model costs (e.g., major order cost, minor order cost, holding fraction, and shortage cost), the item characteristics (e.g., annual demand, average daily demand, the standard deviation of daily demand, item unit cost, and the average item weight), and the transportation parameters (e.g., TL and LTL freight rates, and truck capacity). A Visual Basic program was written to take the input parameters and calculate the order interval with resulting costs for each model. The Visual Basic code is detailed in appendix 3.

It should be noted that the accuracy of the calculations is limited by the precision imposed by the researcher and those inherent to Excel. First, the researcher rounded the order quantity to integer values once the order interval was calculated using equations (2), (6), or (9) for the Base, Full, or Truck models, respectively. This was done because, as this problem has been defined, the items held in inventory are discrete units. As such, the transportation weight breaks and subsequent unit breaks were determined based on whole units. Rounding ensured the order quantity fell within the defined transportation break points. The calculated order interval, however, was not rounded to the nearest integer value. If the calculated order interval was 3.74 days, for example, this value was carried through for all further calculations of the order, holding, and shortage costs. While it might be expected that actual orders would be placed every 4 days, in practice, for the purpose of model comparison, the calculated order interval was not adjusted to reflect whole days. The precision, with which the order interval was calculated, however, was set by the researcher to five decimal places. This was done to speed the computations and to ensure convergence during the iterative solution in the fully specified model. The level of precision was originally set to a higher level, but convergence was problematic in a few of the problems tested.

The level of precision for the calculation of the standard normal deviate, Z_i, and the expected stockout quantity, $E\left[X_i > R_i\right]$, in the fully specified model was also affected by the level of precision used by Excel to calculate the normal inverse function. In Excel 2003, the version used for this study, refinements were made to the computations of the standard normal distribution in the tail ends of the distribution to ensure accuracy to 14 or 15 decimal places (Microsoft, 2006), more than sufficient for this analysis. The normal inverse function was used to calculate Z_i, given the probability of a stockout $P\left(X_i > R_i\right)$, by returning the inverse of the normal cumulative distribution function with a mean of 0 and standard deviation of 1 $\left(Syntax: \;\; Z_i = NORMINV\left(1 - P\left(X_i > R_i\right), 0, 1\right)\right)$. The expected stockout quantity was found by multiplying the standard deviation of demand during the lead time and order interval with the expected value of Z_i, where $E[X_i > R_i] = \sigma_{(i)T+L} E[Z_i]$. Using the standard normal loss integral, the expectation of Z_i can be found by integrating the probability density function of the standard normal function (Keaton, 1994), resulting in $E[Z] = pdf(Z) - Z(1 - cdf(Z))$. While there is no closed form solution for the normal cumulative distribution function, the table look up function in Excel 2003 provides sufficient accuracy. The syntax used to calculate the expected stockout quantity in Excel is given by

$$E[X_i > R_i] = \sigma_{(i)T+L} E[Z_i] = \sigma_{(i)T+L} \left\{ NORMDIST(Z_i, 0, 1, 0) - Z_i \left(1 - NORMDIST(Z_i, 0, 1, 1)\right) \right\}.$$

3.3. Test Problem Description

The test problem was arbitrarily devised to consist of ten items with varying model parameters: major order costs (3 levels), minor order costs (3 levels), holding fraction (3 levels), shortage costs (3 levels), annual demand (3 levels), standard deviation of daily demand (3 levels), less-than-truckload freight rate (3 levels), and the average item weight (5 levels). Implementing a full factorial design, the total annual cost of inventory for the Base, Truck, and Full model was calculated in 10,935 (3x3x3x3x3x3x3x5) different problems. The model parameters are defined in table 8. The lead time parameters (mean and standard deviation), truck capacity, and truckload freight rate were held constant in all problems examined.

Table 8. Problem Factor Levels

Factor	Level 1	Level 2	Level 3	Level 4	Level 5
Major Order Cost ($/order)	20	300	600		
Minor Order Cost ($/item)	1	5	8		
Holding Fraction ($/unit/year)	0.2	0.4	0.6		
Shortage Cost ($/unit)	10	25	50		
Average Item Weight (lbs)	1.5	5	7	10	20
Annual Demand (units)	x1	x2	x3		
Standard Deviation of daily demand	x1	x2	x3		
Number of Items	10				
Average Lead Time (days)	4				
Standard Deviation of Lead Time (days)	0.5				
Truck Capacity (lbs)	40,000				
TL Freight Rate ($/cwt)	6.00				
LTL Freight rate ($/cwt)	8.00	10.00	14.00		

The demand characteristics for the ten items are given in table 9. In this problem, the average daily demand was determined by dividing annual demand by 365 days.

Table 9. Item Demand Characteristics

Item	Purchase Price	Annual Demand			Average Daily Demand			Standard Deviation of Daily Demand		
		Level 1	Level 2	Level 3	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
1	$15.00	4500	9000	13500	12	25	37	2.0	4.0	6.0
2	$12.00	2685	5370	8055	7	15	22	1.0	2.0	3.0
3	$25.00	1000	2000	3000	3	5	8	1.0	2.0	3.0
4	$18.00	5630	11260	16890	15	31	46	2.5	5.0	7.5
5	$10.00	5200	10400	15600	14	28	43	3.0	6.0	9.0
6	$16.50	8900	17800	26700	24	49	73	5.0	10.0	15.0
7	$23.00	2500	5000	7500	7	14	21	1.0	2.0	3.0
8	$27.00	4265	8530	12795	12	23	35	3.0	6.0	9.0
9	$19.00	3100	6200	9300	8	17	25	1.0	2.0	3.0
10	$12.00	1835	3670	5505	5	10	15	0.5	1.0	1.5

The total annual cost of inventory was used as the basis for comparison among the three models. For the purpose of meaningful comparison, the Base model was adjusted to reflect true inventory costs. Specifically, the holding costs in the Base model were adjusted to include the unit transportation rate, G_k, as shown in equation (11), in the same manner holding costs were calculated for the Truck heuristic and Full model.

$$TC(T_{Base}) = \sum P_i D_i + G_k \sum D_i + \frac{C+nc}{T_{Base}} + \frac{T_{Base}F}{2} \sum (P_i + G_k) D_i + F \sum (P_i + G_k) S_i + \frac{\sum K_i E[X_i > R_i]}{T_{Base}} \qquad (11)$$

In all 10,935 problems, the fully specified model resulted in the lowest total cost. Therefore, a firm wishing to ensure the lowest total cost would benefit from implementing the fully specified model. However, the Base model and Truck heuristic performed as well, or nearly as well, in many of the problems tested. To examine what levels of the model parameters resulted in adequate performance for these two competing models (Base and Truck), the difference in total cost with the Full model was calculated. A sub-sample of this cost comparison is presented in table 10.

Table 10. Test Problem Results – Sub-Sample

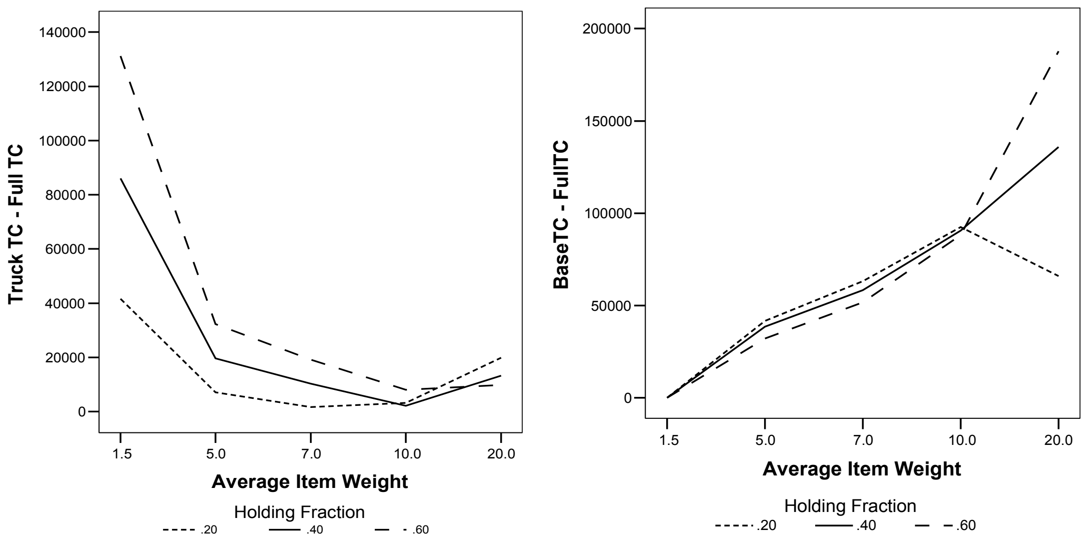
Sample Problem	Major Order	Minor Order	Holding Fraction	Shortage unit cost	Average Item Wt	TL unit Rate	LTL unit Rate	Full Order Qty	Truck Order Qty	Base Order Qty	Total Annual Demand	Truck TC - Full TC	Base TC - Full TC
1	600	1	0.2	50	5	0.30	0.40	8000	8000	3756	39615	$0.00	$78.10
2	20	1	0.6	25	7	0.42	0.70	704	5714	680	79230	$231.43	$4.11
3	300	1	0.6	50	10	0.60	0.80	4000	4000	1546	39615	$0.00	$97.33
4	300	5	0.4	10	20	1.20	1.60	2000	2000	2012	39615	$0.00	$97.01
5	20	1	0.2	25	5	0.30	0.70	8000	8000	833	39615	$0.00	$4,861.45
6	20	1	0.2	50	7	0.42	0.70	5714	5714	833	39615	$0.00	$3,985.58
7	300	8	0.6	25	10	0.60	1.00	4000	4000	2421	79230	$0.00	$28,203.25
8	300	8	0.2	10	20	1.20	2.00	4000	2000	2965	39615	$163.53	$9,844.39
9	300	8	0.6	10	1.5	0.09	0.15	2476	26667	2421	79230	$107,113.43	$6.41
10	600	5	0.4	10	5	0.30	0.40	2739	8000	2742	39615	$7,899.57	$0.01
11	300	5	0.4	50	7	0.42	0.56	2002	5714	2012	39615	$2,745.35	$0.17
12	20	5	0.6	25	10	0.60	0.80	741	4000	735	39615	$5,849.30	$0.29
13	600	8	0.2	10	20	1.20	2.00	4000	2000	3966	39615	$3,134.66	$408.13
14	600	1	0.2	10	10	0.60	1.00	8000	4000	6506	118845	$2,120.41	$15,952.13
15	600	8	0.2	10	10	0.60	1.00	8000	4000	6869	118845	$3,160.30	$11,507.87
16	600	5	0.2	50	20	1.20	2.00	6000	2000	5484	79230	$10,001.88	$8,891.76
17	600	5	0.4	10	20	1.20	2.00	4000	2000	3877	79230	$5,770.48	$3,017.43

In sample problems 1-4 from table 10, the Truck heuristic and Base model performed well and resulted in only marginal cost increases (ranging from 0.011 to 0

0.016 percent), over the total annual cost of the Full model. In sample problems 5-8, the Truck heuristic was the preferred model. In this sub-sample, the average item weight was larger making it easier to fill a truck, while lower holding costs allowed for larger orders without a significant cost increase. In sample problems 9-13, the Base model was the preferred choice, highlighting the impact of item weight on costs. In fact, for all problems tested, the Base model dominated when the average item weight was 1.5 pounds. Clearly, the more items required to fill a truck with each order, the higher the cost to hold this inventory, particularly when demand was low. Another indication in problems 9-13 that points to use of the Base model was the higher order cost, particularly the minor (per-unit) order cost, and higher holding costs compared to the first two sets of problems. Here, the classic approach to balance order and holding costs alone resulted in near-optimal solutions. Finally, in sample problems 14-17, the Full model resulted in the lowest total annual inventory costs and was preferred over both the Truck heuristic and textbook Base model. An interesting result for this sub-sample was that the optimal order intervals resulted in order quantities of multiple truckloads, 2 or 3 trucks, in this example. Generally, holding costs were low and annual demand was high to allow for such large orders.

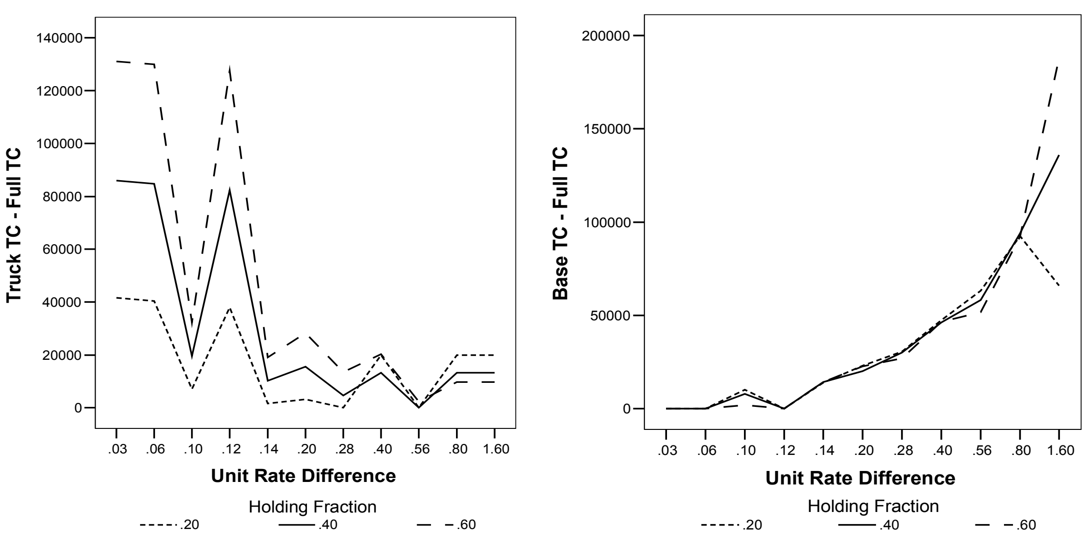
A general recommendation of one model over another is difficult to make simply by examining the results of the test problems individually. The interaction of the model parameters is complex. Figure 2 and figure 3 show how the difference in total costs varied in a non-linear manner. As the item weight increased, the difference in costs between the Truck heuristic and Full model (Truck TC – Full TC) became small, the magnitude of which varied depending on the holding fraction (see figure

2a). At the same time, however, the cost differential between TL and LTL shipping rates significantly affected the total cost in an irregular way. On the other hand, comparing the Base and Full models in figure 2b and figure 3b, the holding fraction had very little impact except for very heavy items.



(a) Truck Total Cost – Full Total Cost (b) Base Total Cost – Full Total Cost

Figure 2. Average Item Weight vs. Total Cost Difference by Holding Fraction



(a) Truck Total Cost – Full Total Cost (b) Base Total Cost – Full Total Cost

Figure 3. Unit Rate vs. Total Cost Difference by Holding Fraction

While some general statements could be made regarding the relationship between these model parameters and the total inventory cost, all model parameters interact, non-linearly, complicating model recommendations. Further, the impact of some parameters on total cost may be amplified depending on the level of another parameter. Upon closer examination of the problem set, however, four distinct categories emerged. The first category is depicted in sub-sample problems 9 through 13, where the Base model is recommended. In these problems Base TC – Full TC is significantly less than Truck TC – Full TC. Alternatively, the second category is shown by the sub-sample problems 5 through 8 in table 10. For these problems, Truck TC – Full TC is significantly less than Base TC – Full TC, leading to a recommendation in favor of the Truck heuristic. The third category favors the fully specified model, when both the Base model and Truck heuristic result in a significant increase in the total inventory cost over the Full model (see sub-sample problems 14 through 17). Sub-sample problems 1 through 4 demonstrate the forth category where the use of any of the three models would result in optimal or near optimal solutions.

3.4. Discriminant Function Analysis

With these four categories appearing to distinguish the problem set, discriminant function analysis was chosen as the appropriate statistical technique. Discriminant function analysis (DFA) allows one to examine a set of independent variables (in this study, the model parameters) and determine which variables help to distinguish or predict membership in a priori defined groups. Thus, the intent of the analysis was to identify which inventory policy was most appropriate given different levels of the model parameters. Specifically, DFA builds a linear combination of the model parameters and then determines the appropriate weight for these variables such that the variance is maximized between the groups relative to the within-group variance. The resulting orthogonal discriminant functions are then used to predict group membership. Discriminant function analysis can be interpreted in much the same manner as multivariate regression analysis. Indeed, a special case of discriminant function analysis is logistic regression where the categorical dependent variable is defined by only two groups (Hair et al., 1998). In this study, the predicted group is associated with an inventory model recommendation.

Variable Selection. The difference in the total cost of inventory between the Base and Full models, or the Truck heuristic and Full model, was useful in identifying the groups. When the cost difference is zero, the choice to implement an inventory model is simple – select the least complex model. However, when the cost difference is greater than zero, a decision must be made regarding the degree to which one is willing to accept the cost increase associated with the less complex model (Base or Truck). Equally, when the cost difference exceeds some acceptable tolerance level, the Full model would be the preferred choice. To clearly define these cut-points, the percent increase in total cost was selected as the metric to define group membership. This study examined three tolerance levels equal to 0.1, 0.5, and 1.0 percent increase in total cost over the Full model. First, the percent increase in total cost was calculated for the Base model and Truck heuristic as shown in equation (12), where m denotes Base or Truck, depending on which model was being compared to the fully specified model.

$$Percent\ Cost\ Increase_m = 100 \times \left(\frac{Total\ Cost_m - Total\ Cost_{Full}}{Total\ Cost_{Full}} \right) \qquad (12)$$

Comparing the Base and Full models, the percent cost increase ranged from 0 to 8.5 percent in the problem set. Comparing the Truck heuristic and Full model, the percent cost increase ranged from 0 to 19 percent. The percent cost increase, along with the tolerance levels, defined four mutually exclusive and exhaustive groups. These groups identified the inventory model most appropriate as measured by the total annual cost of inventory. Thus, when the 0.1 percent tolerance level was used, the model choice would be determined as shown in table 11. The groups were similarly defined for the 0.5 and 1.0 percent tolerance levels. The categorical dependent variable was defined as group number, 1 through 4, based on the grouping metric.

Table 11. Group Membership – Percent Cost Increase Over Full Model

Grouping Metric	**Recommended Model**	**Group Number**
IF $\%\ Cost\ Increase_{Base} \le 0.1$ AND $\%\ Cost\ Increase_{Truck} > 0.1$, THEN	Base	1
IF $\%\ Cost\ Increase_{Truck} \le 0.1$ AND $\%\ Cost\ Increase_{Base} > 0.1$, THEN	Truck	2
IF $\%\ Cost\ Increase_{Truck} > 0.1$ AND $\%\ Cost\ Increase_{Base} > 0.1$, THEN	Full	3
IF $\%\ Cost\ Increase_{Truck} \le 0.1$ AND $\%\ Cost\ Increase_{Base} \le 0.1$, THEN	Any Model: Base, Truck, or Full	4

It should be noted that the percent cost increase for either the Truck heuristic or the Base model was never greater than 1.0 percent in any of the 10,935 problems examined in this study. Therefore, when a 1.0 percent tolerance level was used to define group membership, group 3, which recommended use of the fully specified model, was not present. If the potential for a 1.0 percent deviation from the true cost of inventory is an acceptable margin of error, then at least one of the less complex models (Base or Truck) would be appropriate. This error margin, however, cannot be generalized beyond this test problem. Although the problem was designed to vary the model cost parameters and item-level demand characteristics, it is not known if more extreme variations in the parameters would yield the same 1.0 percent cut-point where group 3, which recommends use of the Full model, disappears.

The independent variables were selected from the model parameters in the total cost function. They included: major order cost, minor order cost, holding fraction, unit shortage cost, total annual demand, average item weight, and the unit rate difference. The average item weight and unit rate difference were chosen because they directly impact the transportation rate in the total cost function. The unit rate difference, LTL unit rate - TL unit rate, was chosen because, even when the TL and LTL freight rates were the same between two problems, the actual unit transportation rate varied depending on the average item weight. The results of the discriminant function analysis are discussed in chapter 4.

3.5. Simulation Study

A simulation study was designed to examine the sensitivity of the fully specified model to non-normal demand. Through a series of interviews and a site visit, actual item demand was collected from a local independent retail grocer, Miller's Food Market, Inc. This independent grocer operates a single store, supporting a local population of approximately 17,000 people. Miller's Food Market maintains approximately 15,000 items valued at $151,200 in 8,400 square feet of retail space. Inventory is replenished three times each week by a cooperative wholesaler and inventory orders are determined manually by assessing the inventory position for each item.

3.5.1. Data Collection

Weekly sales reports were collected from Miller's Food Market between January 1, 2005 and December 31, 2005. Sales data was used in this study as a proxy for demand. Demand, a function of the consumer's available budget and preferences, is often approximated based on historical sales data (Tersine, 1994). Based on interviews with the general grocery manager at Miller's Food Market, historical sales played a major role in the ordering process.

The weekly sales reports included sales data for 4,865 items sold in the general grocery, frozen, and dairy departments. The 52 weekly reports were combined and checked for consistency, removing duplicate entries, missing data, and outliers attributed to data entry errors. The average purchase price and profit margin were calculated, along with total annual demand. Using the random function in Excel, 100 items were selected.

Input Analysis: For each randomly selected item, a theoretical probability distribution was fit to the demand data using the Input Analyzer in Arena 9.0. The appropriateness of the theoretical distribution for the data was assessed using the Chi-squared and Kolmogorov-Smirnov (K-S) goodness-of-fit tests. Both tests have limitations. The Chi-squared test is highly sensitive to the number of intervals used to represent the data, greatly affecting the significance of the test statistic. However, the K-S test, while more powerful, is not valid for all distributions. The item-level demand characteristics, probability distributions, and cost parameters are listed in appendix 4. In many cases the goodness-of-fit tests were not statistically significant indicating the demand data was not well represented by the theoretical distribution function. Rather, the chosen distributions were the best choice, using the minimum mean square error as a metric, compared with all other possible distributions. The limitation of ill-fitted probability distributions was largely ignored in this study since the purpose was not to accurately model the original system, but rather to provide a representative sample of non-normal demands.

Cost Parameters: The purchase price for each item was taken as the average purchase price over the 52 weeks of data. The stockout cost was assumed to equal the profit margin lost for each stockout occurrence. The profit margin (in dollars) was averaged over all items to arrive at a common shortage cost. While shortage costs generally include the loss of goodwill, backordering costs, or costs associated with substitution, such costs are difficult to determine and were not available from Miller's Food Market. Consumers of retail goods, particularly groceries, are generally store-loyal and much more likely to substitute an item or delay the purchase than to switch to another retailer (Zinn and Liu, 2001). In this study, it was assumed that consumers forgo or delay the purchase of out-of-stock items. The major order cost was approximated using the labor cost of assessing inventory levels, determining order quantities, placing the order, and receiving/stocking inventory.

The major order cost was equal to $300.00 based on the labor requirements to prepare each order. The minor order cost associated with each line item was assumed to equal zero, since no such data were available from Miller's Food Market. The actual cost of holding inventory was unknown; therefore the holding fraction, F, was set to 0.4 percent per year. The average weight for all items was approximated to equal two pounds. The cost of transportation was taken from the literature (Russell and Krajewski, 1991) and was the same cost structure used for the test problem. The truckload transportation rate was \$6/cwt, while the less-than-truckload rate was set to \$10/cwt. It was not feasible to determine the actual cost of transportation from Miller's Food Market since transportation costs were included in the overall surcharge assessed for each order placed. This surcharge, however, was determined based on volume and similar to a transportation rate schedule.

3.5.2. Simulation Model

Two multi-item, periodic review inventory models were designed with Arena 9.0 simulation software using the logic depicted in figure 4. The only distinction between the two models was the demand characteristics. In the first model demand was assumed to be normally distributed using the mean, μ, and standard deviation, σ, for each item listed in appendix 4. The second simulation model used the fitted demand distributions derived from the historical data. Demand occurred daily with appropriate adjustments to the on-hand inventory levels for each item. Inventory holding costs and shortage costs were accumulated at the end of each day. As with the analytic model, daily demand was rounded to the closest integer following each draw from the probability distribution. Some distributions, such as the normal distribution, allow for negative values. Negative values were discarded and a new value was drawn.

The inventory review process occurred at equal intervals. The order interval, T_{Full}, and base stock levels, R_i, were calculated for the fully specified model using the Visual Basic program in appendix 3. The order interval was found to equal 18.58 days for the 100 grocery items. The lengthy order interval was due mainly to the small number of items and low item weight. At each review, an order was placed for all items with inventory positions below their respective base stock levels. The order quantities were aggregated and the unit shipping rate was determined using the rate function in equation (4). The purchase, transportation, and order costs were accumulated in every review cycle. The delivery lead time was set as a random variable with a mean of 2 days and standard deviation of 0.25 days. Upon receipt of each order, the on-hand inventory level and inventory position for each item was adjusted.

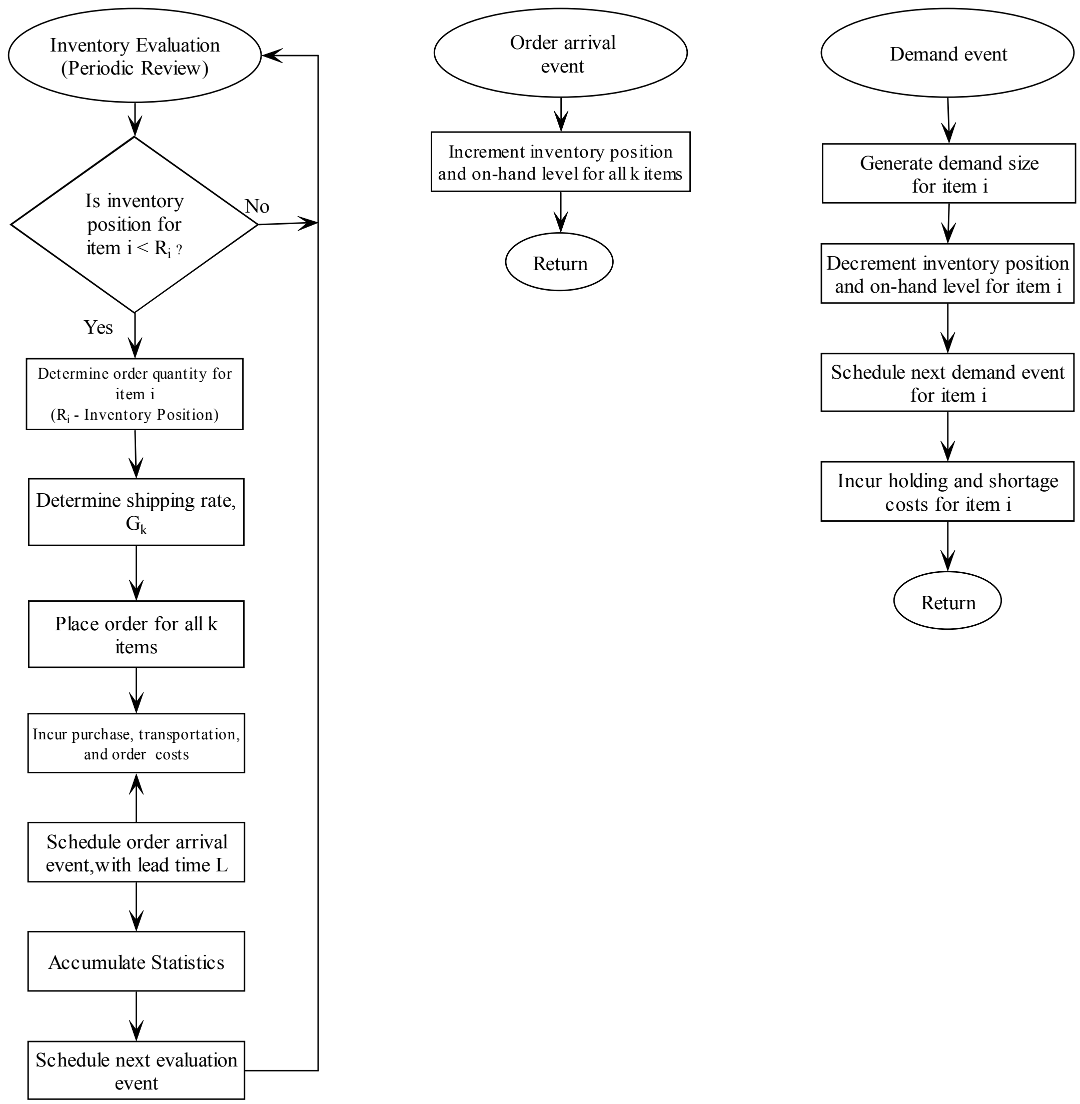


Figure 4. Simulation Flowchart

3.5.3. Model Measurement

The performance of the system was measured in terms of in-stock fill rates and total costs. The fill rate for each item was used to determine the steady state of the system, while the total cost of inventory was used to compare the models (normal demand and non-normal demand) with the calculated values. The fill rate for item *i* was defined as one minus the ratio of the average number of units short to total units demanded, shown in equation (13).

$$Fill\ Rate_i = 1 - \frac{Expected\ Number\ of\ Stockouts}{Total\ Number\ of\ Units\ Demanded} = 1 - \frac{E\left[X_i > R_i\right]}{Q_i} \qquad (13)$$

Ensuring steady state of the system is important to remove sample bias due to the starting conditions of the various model parameters. If the simulation output is dependent upon the initial values of the model parameters the true performance of the system cannot be accurately measured. Output analysis was used to eliminate or minimize sample bias arising from the initial conditions (Law and Kelton, 2000). This was done by identifying and eliminating the transient behavior in the item-level fill rates brought about by the starting inventory levels. The fill rate for 10 items was plotted against the simulation time to identify the transient period. The system was found to be in steady state after 200 days. This value was used as the warm-up period after which all statistical accumulators were reset to zero. The simulation run length was 365 days and the annual costs were calculated.

To ensure independence between each simulation run and eliminate autocorrelation, the random number stream was separated by 100,000 for each replication. Observations were collected by replicating the model 40 times. The results of the discriminant function analysis and simulation are discussed in chapter 4, to include recommendations and managerial implications.

Chapter 4. Joint Replenishment Results and Discussion

4.1. Discriminant Function Analysis (DFA)

The 10,935 test problems described in section 3.3 were randomly divided into two groups. Fifty percent of the problem set was randomly chosen to estimate the discriminant functions, while the remaining sample was used to validate the results. Because the four grouping categories (Base, Truck, Full, Any) were of unequal size, the estimation sample was randomly selected proportionate to group size.

For each tolerance level, the discriminant functions (DF) were estimated, group membership was predicted, and the overall fit of the DFs was assessed. For clarity in the discussion, DFA using 0.1 percent as the cut-point is labeled Analysis A, the 0.5 percent tolerance level is labeled Analysis B, and 1.0 percent is labeled Analysis C. Recall from section 3.4 that group membership represents the most appropriate inventory model given the model parameters. For example, if a test problem was predicted in the Truck category, then the combination of model parameters resulted in a cost increase smaller than or equal to the tolerance level when the Truck heuristic was used in place of the fully specified model. Similarly, a case in the Base group would indicate that the textbook approach would result in a cost increase over the fully specified model no greater than the tolerance level for the given model parameters.

Goodness-of-fit was evaluated first by testing whether the discriminant functions resulted in significantly different groups and second by assessing the accuracy of the predictions in the holdout sample. For Analyses A and B, three discriminant functions were estimated. Two discriminant functions were estimated for Analysis C, since only three groups emerged. In all analyses, the estimated discriminant functions were statistically significant, shown in table 12, indicating that the discriminant functions resulted significantly different groups. For Analyses A and B, the first two functions, X and Y, accounted for most of the between-group variability, 99.6 and 97.7 percent, respectively. Wilk's lambda tests the significance of the discriminant functions (DF). All DFs were statistically significant with p-values < 0.000.

Table 12. Discriminant Analysis Significance Tests

Discriminant Function	Eigenvalue	Cumulative % Variance	Canonical Correlation	Wilk's Lambda	χ^2	p-value
		Analysis A – 0.1%				
X	1.175	95.8	0.735	0.437	4531.98	0.000
Y	0.047	99.6	0.211	0.950	278.54	0.000
Z	0.005	100.0	0.072	0.995	28.53	0.000
		Analysis B – 0.5%				
X	0.613	82.2	0.617	0.546	3270.37	0.000
Y	0.116	97.7	0.322	0.881	685.22	0.000
Z	0.017	100.0	0.130	0.983	92.24	0.000
		Analysis C – 1.0%				
X	0.614	69.6	0.617	0.489	3865.96	0.000
Y	0.268	100.0	0.460	0.789	1281.47	0.000

Although the discriminant functions were statistically significant, prediction accuracy is not necessarily guaranteed. Prediction accuracy was assessed using the classification matrix and hit ratio. The classification matrix provides information on the actual groups to which observations belong, along with predicted group membership as calculated by the discriminant functions. The hit ratio measures the percent of observations correctly classified. Analysis A, with a tolerance level equal to a 0.1 percent cost increase over the fully specified model, had the highest hit ratio, shown in table 13. Accurate predictions were made for nearly 85 percent of the cases for both the original sample and holdout sample. With a very low tolerance for cost increases, Analysis A accurately predicted 86.6 percent of the Base models, 91 percent of the Truck models, and 84.1 percent of the Full models in the holdout sample. Of the misclassified cases, only those misclassified in the Truck group were problematic. In the holdout sample, 64 Full cases and 182 Base cases were predicted in the Truck group. For these misclassified cases, the Truck heuristic would actual result in a cost increase greater than 0.1 percent.

Table 13. Analysis A Classification Matrix – Cut-off = 0.1%

		Actual Group Membership	Predicted Group Membership BASE	TRUCK	FULL	ANY	Total
Original Sample	Count	BASE	1,423	192	63	0	1,678
		TRUCK	234	2,917	19	0	3,170
		FULL	0	49	313	0	362
		ANY	72	200	0	0	272
	%	BASE	84.8	11.4	3.8	0	100.0
		TRUCK	7.4	92.0	0.6	0	100.0
		FULL	0.0	13.5	86.5	0	100.0
		ANY	26.5	73.5	0.0	0	100.0
Holdout Sample	Count	BASE	1,486	182	48	0	1,716
		TRUCK	238	2,799	38	0	3,075
		FULL	0	64	338	0	402
		ANY	74	186	0	0	260
	%	BASE	86.6	10.6	2.8	0	100.0
		TRUCK	7.7	91.0	1.2	0	100.0
		FULL	0.0	15.9	84.1	0	100.0
		ANY	28.5	71.5	0.0	0	100.0
Correctly Classified				Original Holdout	84.9% 84.8%		

Analysis B, representing a 0.5 percent cost increase over the fully specified model was the next best predictive model (see table 14). The classification accuracy for the Truck heuristic and Base model was still high, although the accuracy dropped to 62.7 percent when classifying the fully specified model in the holdout sample. The percent of fully specified models misclassified in the Truck heuristic group also increased to 28.4 percent.

Table 14. Analysis B Classification Matrix – Cut-off = 0.5%

Actual Group Membership			Predicted Group Membership: BASE	TRUCK	FULL	ANY	Total
Original Sample	Count	BASE	1,358	9	17	77	1,461
		TRUCK	114	1,926	13	393	2,446
		FULL	0	25	38	12	75
		ANY	297	552	0	580	1,429
	%	BASE	93.0	0.6	1.2	5.3	100.0
		TRUCK	4.7	78.7	0.5	16.1	100.0
		FULL	0.0	33.3	50.7	16.0	100.0
		ANY	20.8	38.6	0.0	40.6	100.0
Holdout Sample	Count	BASE	1,449	18	10	83	1,560
		TRUCK	126	1,924	15	435	2,500
		FULL	0.0	19	42	6	67
		ANY	307	551	0.0	539	1,397
	%	BASE	92.9	1.2	0.6	5.3	100.0
		TRUCK	5.0	77.0	0.6	17.4	100.0
		FULL	0.0	28.4	62.7	9.0	100.0
		ANY	22.0	39.4	0.0	38.6	100.0
Correctly Classified				Original	72.1%		
				Holdout	71.6%		

As the tolerance level increased, the number of cases in the ANY category increased. When the tolerance level was set to 1.0 percent, in table 15, the FULL group disappeared. Specifically, if the potential for a 1 percent cost increase is acceptable, at least one of the less complex models (Base or Truck) could be implemented. In Analysis C, the predictive accuracy of the DFs dropped to 71.9 percent for the original sample and 70.3 percent for the hold-out sample. Analysis C also did a poor job in classifying the Truck heuristic model, with accurate predictions for only 47 percent of the cases.

Table 15. Analysis C Classification Matrix – Cut-off = 1.0%

Actual Group Membership			Predicted Grp Membership BASE	TRUCK	ANY	Total
Original Sample	Count	BASE	1,010	0	235	1,245
		TRUCK	17	760	777	1,554
		FULL	-	-	-	0
		ANY	247	244	2,118	2,609
	%	BASE	81.1	0.0	18.9	100.0
		TRUCK	1.1	48.9	50.0	100.0
		FULL	-	-	-	0
		ANY	9.5	9.4	81.2	100.0
Holdout Sample	Count	BASE	1,022	0	272	1,294
		TRUCK	22	759	831	1,612
		FULL	-	-	-	0
		ANY	253	264	2,104	2,621
	%	BASE	79.0	0.0	21.0	100.0
		TRUCK	1.4	47.0	51.6	100.0
		FULL	-	-	-	0
		ANY	9.7	10.1	80.3	100.0
Correctly Classified			Original	71.9%		
			Holdout	70.3%		

The discriminant loadings in table 16 allow for interpretation of the discriminant functions by identifying which model parameters contribute the most in defining group membership. In analysis A, transportation-related factors best describe the first discriminant function (DF X). As the average weight of the items increased and the difference between the truckload and less-than-truckload rates increased, the score on DF X increased. Recall that a score of 1 is associated with the Base model, 2 equals the Truck heuristic and 3 equals the Full model. When the discriminant function score equals 4, any model can be used. Therefore, as the transportation-related model parameters increase the score on DF X tends to predict the Truck heuristic or fully specified model. This makes sense since it is easier to fill a truck with heavier items without adversely impacting holding costs. Coupled with lower TL rates, inventory costs would be significantly reduced by filling a Truck with each order. Discriminant function X also had the greatest explanatory power of all other DFs, accounting for over 95 percent of the variability in the dependent variable (see table 12). This provides further support for the inclusion of transportation in the inventory model.

Table 16. Analysis A Discriminant Loadings

	Discriminant Function		
Model Parameter	**X**	**Y**	**Z**
Average Item Weight	0.780 *	-0.227	0.433
Unit Rate Difference	0.547 *	-0.484	0.152
Holding Fraction	-0.148 *	-0.129	-0.044
Major Order Cost	0.184	0.842 *	-0.297
Total Annual Demand	0.224	-0.163	-0.637 *
Minor Order Cost	-0.016	0.228	0.550 *
Unit Shortage Cost	-0.004	-0.032	0.279 *

* Represents largest absolute correlation between model parameter and discriminant function

The second discriminant function, DF Y, was most highly associated with the major order cost. As order costs increased, order frequency dropped resulting in larger orders. Thus, the Truck heuristic or Full model were predicted with higher scores on DF Y. Finally, annual demand and minor orders costs best described DF Z. As annual demand increased, the score on DF Z decreased in favor of the Base model (DF score = 1). This makes sense since high demand will tend to result in larger order quantities, thereby improving transportation utilization even when using the textbook approach.

In table 17 the descriptive statistics for each group (Base, Truck, Full, Any) further support model selection given the level of transportation-related factors, order costs, and annual demand. Except for the transportation-related factors, the average value of the model parameters was fairly consistent when comparing the Base model and Truck heuristic. The average item weight and difference in transportation rates (TL/LTL) were much larger for the Truck heuristic than for the Base model.

Therefore, the Truck heuristic is the appropriate model when the truckload transportation rate is sufficiently smaller than the less-than-truckload rate and the items are of medium weight. In practice, if a slight increase in the current shipment size would fill a truck, transportation rates should be the deciding factor when choosing between the Base and Truck (R, T) policies.

Table 17. Analysis A Descriptive Statistics

Model	Variable	Mean	SD
BASE	Major Order Cost	271.12	237.78
	Minor Order Cost	4.72	2.87
	Holding Fraction	0.43	0.16
	Unit Shortage Cost	28.04	16.43
	Average Item Weight	3.70	3.93
	Unit Rate Difference	0.14	0.20
	Total Annual Demand	70,424	31,674
TRUCK	Major Order Cost	287.18	229.16
	Minor Order Cost	4.60	2.89
	Holding Fraction	0.39	0.16
	Unit Shortage Cost	28.42	16.59
	Average Item Weight	10.48	5.48
	Unit Rate Difference	0.49	0.37
	Total Annual Demand	82,042	32,133
FULL	Major Order Cost	513.81	135.94
	Minor Order Cost	4.62	2.70
	Holding Fraction	0.32	0.15
	Unit Shortage Cost	27.24	16.39
	Average Item Weight	19.14	2.80
	Unit Rate Difference	0.86	0.49
	Total Annual Demand	100,132	24,865
ANY	Major Order Cost	395.44	245.65
	Minor Order Cost	5.47	2.58
	Holding Fraction	0.38	0.16
	Unit Shortage Cost	29.06	16.74
	Average Item Weight	8.04	3.46
	Unit Rate Difference	0.28	0.26
	Total Annual Demand	69,908	27,954

When high levels in the transportation-related factors were also accompanied by high order costs and large annual demand, the Full model minimizes inventory costs. This does not necessarily imply implementation of the Full (R, T) model whenever high levels of ordering and transportation costs are present. Recall from the sub-sample of test problems presented in section 3.3, table 10, the Full model resulted in the lowest total cost when the order quantity resulted in multiple truckloads. The Truck heuristic could be modified to calculate the total cost for multiple truckload shipments. For example, the order interval for two truckload shipments would equal $T_{2Truck} = 2Q_t \Big/ \sum D_i$. Comparing the single-shipment Truck heuristic with a modified multi-shipment Truck heuristic, the lowest total cost could be found.

Interestingly, the holding and shortage costs had very little impact on model selection. The average value for these costs was similar across all groups. Thus, the traditional approach of balancing ordering and holding costs may not be effective when faced with high or increasing transportation charges. Transportation can be a very large component of the total cost of inventory. Therefore, the Truck heuristic, or a modified Truck heuristic for multiple loads, is a reasonable and simple approach to cost minimization. The heuristic is easy to calculate and can be quickly adjusted to meet changing demand conditions. One disadvantage of the Truck heuristic, however, is the potential for larger inventories which may increase the risk of obsolescence. However, shipment frequency and volume in the grocery industry lends itself to truckload shipments.

The large impact of transportation-related factors on inventory costs shown in this study raises the question on whether the (R, T) policies discussed in section 2.2, are truly near-optimal solutions. The models in the extant literature may suboptimize the system by not considering transportation costs and limit their use in practice. Indeed, Silver (1981) questioned the practicality of inventory research and recommended the development of good rather than optimal solutions. Since optimal solutions are rarely easy to implement, the Truck heuristic was developed as alternative when considering all relevant inventory costs, particularly transportation. The results of the simulation study are discussed in the next section highlighting the impact of non-normal demand on inventory costs.

4.2. Simulation Results

The simulation study addressed a key assumption often made when developing analytic solutions to inventory models. Specifically, demand is assumed to be normally distributed. This assumption allows various model characteristics to be calculated, such as the demand during the leadtime and replenishment period, safety stock, the probability of a stockout, and stockout quantities. To examine violations of the normality assumption, two models were developed: one with normally distributed demand and one using non-normal demand distributions derived from industry data. Point estimates for the total cost of inventory were calculated for each model taking the average over 40 replications. A 95 percent confidence interval was constructed with which to compare the simulated costs with calculated costs, shown in table 18.

When demand was normally distributed, in model 1, the simulation produced results consistent with the calculated costs. The calculated total cost of inventory was $540,667 which fell within the 95 percent confidence interval for model 1. However, the total cost using actual demand (model 2) with varying demand distribution characteristics resulted in approximately a 2 percent increase over the calculated costs. The results suggest that the order interval and item base stock levels calculated when demand is assumed to be normally distributed were suboptimal for model 2.

This is shown by examining the various cost components in model 2. The transportation costs were higher than expected implying the shipment of phantom freight for some or all of the orders. Additionally, less inventory was held in model 2 than anticipated by the analytic model, since holding costs were lower. At the same time shortage costs increased indicating a higher stockout rate. The purchase costs were also higher in model 2 indicating the higher demand for and subsequent ordering of more expensive items. These results suggest that item heterogeneity may significantly affect the implementation of the simplified Truck heuristic (in lieu of the fully specified model) which is based entirely on truck capacity and annual demand.

The true cost, however, for this problem is unknown since the optimal parameters were not found. Indeed, the optimal parameters for the order interval and base stock levels would be impossible to determine analytically, given the variety of demand distribution patterns shown in appendix 4. The optimal parameters might be found using optimization and search techniques, but the computation effort would be significant and would only be applicable to this problem of 100 inventory items.

For an inventory manager, understanding how non-normal demand impacts the expected costs when calculated in the Full model or Truck heuristic is more useful from a practical perspective. The results of this simulation study indicate that the calculated costs in the Full model may represent a lower bound for total costs. True costs could actually be higher assuming actual demand deviates from normality.

Table 18. Simulation Output – Inventory Costs

		Annual Purchase Cost	Annual Trans Cost	Annual Order Cost	Annual Holding Cost	Annual Shortage Cost	Total Annual Inventory Cost
Calculated Costs		$481,454	$47,136	$5,892	$5,991	$193	$540,667
Model 1 Normal Demand	Avg	$480,807	$48,210	$5,700	$5,598	$289	$540,605
	SD	$1,478	$225	$0	$58	$24	$1,650
	95% CI Min	$480,335	$48,138	$5,700	$5,580	$282	$540,077
	95% CI Max	$481,280	$48,282	$5,700	$5,617	$297	$541,132
Model 2 Actual Demand	Avg	$490,101	$49,772	$5,775	$5,492	$529	$551,668
	SD	$3,942	$497	$132	$67	$53	$4,437
	95% CI Min	$488,840	$49,613	$5,733	$5,470	$513	$550,249
	95% CI Max	$491,361	$49,931	$5,817	$5,513	$546	$553,088

4.3. Discussion and Managerial Implications

The three multi-item inventory models developed for this research targeted the small retailer with limited order processing technologies. The objective of the fully specified model was to include the cost of transportation in determining the order interval and, therefore, more accurately evaluate the impact of ordering decisions on total costs. Building on the previous literature on joint replenishment programs, the Base (R, T) model was modified to include all relevant transportation costs and the possibility of shipping phantom freight. Specifically, the fully specified model included the cost disadvantage of less-than-truckload shipments, a factor not addressed in the extant literature on joint replenishment. Furthermore, the fully specified model was evaluated against the Base model and Truck heuristic over a range of varying model parameters. The results of the discriminant function analysis showed that transportation-related factors had the greatest impact on total annual costs in favor of the Truck heuristic. Further, modifications to the truck heuristic to calculate multiple truckload shipments could be easily implemented when ordering costs and annual demand are high. Indeed, an inventory manager would not need to implement the complex and difficult-to-calculate fully specified model. A comparison of the total cost for the Truck heuristic and modified Truck heuristic would reveal the cost minimizing solution.

When demand was not normally distributed, the fully specified model suboptimized the order interval. Specifically, deviations from a truckload shipping quantity increased costs. One approach might be to adjust the order quantities, either positively or negatively, in order to exactly fill a truck(s). In practice, such a policy would be easy to implement, adding or deleting pallets when needed.

4.4. Future Research

There are several extensions to the research that warrant further investigation. First, when demand was non-normally distributed the fully specified model resulted in a lower bound. Actual costs in the simulated model were 2 percent higher than calculated costs. A natural extension would be to find the upper bound of this cost increase. While an absolute upper bound may be difficult to calculate, it would be interesting to understand how varying model parameters affect total costs under actual demand conditions, particularly with respect to item heterogeneity. A study could be designed to vary both the probability distributions of demand and the variation of demand to better understand how demand patterns affect total costs compared with the calculated costs in the Full model. Such a study could examine whether items with similar demand patterns should be grouped together under a common order interval. Furthermore, variations in other cost parameters (e.g., transportation, order, holding, and shortage) might impact the total cost of inventory differently when demand patterns vary. For example, the calculated order interval was shown in this study to be suboptimal for non-normal demand. If, for example, the calculated order interval is smaller than the optimal order interval, more frequent orders would occur. Given high order costs, would the model with non-normal demand still result in a 2 percent cost increase? A simulation study with varying model parameters, similar to the test problem in this research, might provide useful information on an upper bound of the total inventory cost.

Second, it would be useful to test the affect of the allocation approach when order quantities deviate from a truckload shipping quantity. Given that non-normal demand actually increased costs, a simulation study could be devised to test whether strict implementation of the Truck or modified Truck heuristic helps to lower costs. For example, when the order quantity is less than truck capacity, $Q_k < Q_t$, the number of items ordered would be increased to exactly fill a truck(s). Similarly, when $Q_k > Q_t$, fewer items would be ordered. The objective of such a study would be to determine whether increases in holding and shortage costs using an equal allocation policy would outweigh the cost benefit of truckload shipments.

The third extension to this research would be to examine the impact on total costs when using an integer value for the order interval. For example, when the calculated order interval is 3.7 days, does underestimating the order interval at 3 days or overestimating at 4 days result in the smallest cost deviation? Furthermore, would an allocation policy to add or delete items, as needed, to fill a truck mitigate any cost increase associated with integer values of the order interval?

Finally, the characterization of the transportation function should be considered in future research. This study considered a weight-break transportation function and demonstrated that deviations from a full truck shipment raised inventory costs. Alternatively, Cachon (2001) treated transportation as a fixed cost per truck dispatch, such that the per unit transportation rate decreased hyperbolically up to truck capacity. This is not unlike the over-declared portion of the transportation function considered in this study. However, given a fixed cost per truck dispatch, shipping quantities slightly larger than truckload capacity substantially increase the per unit transportation cost and should have a similar impact on the order interval as shown in this study.

4.5. Limitations

The limitations of this study should be noted. The simulation study found that the true inventory costs were approximately 2 percent higher when demand was not normally distributed. This cost increase was measured with respect to the calculated expected costs in the fully specified model which assumed demand normality. However, for non-normal demand the optimal inventory policy may be very different from the one used in this study. Specifically, the order interval and base stock levels for each item in an optimal policy under non-normal demand will not necessarily be the same as when demand is normally distributed. The optimal inventory policy for non-normal demand was not found and was beyond the scope of this study. While an optimal policy would be limited to this problem, a comparison between the Full model and the optimal policy would be useful in understanding the extent to which the assumption of demand normality impacts the total cost of inventory.

Another limitation of this study which could impact inventory policy decisions was the assumption of unlimited storage space. Storage or shelf-space constraints can limit the ability to implement truckload shipments, particularly for small grocery retailers. For example, Miller's Food Market, the retail grocer interviewed for this study, placed three weekly orders. Each shipment was, on average, one pallet short of a full truckload. While cognizant that full truckload shipments could reduce costs, order frequency was driven primarily by storage space constraints at the store. While storage constraints would be a concern for any size retailer, this study provided evidence that transportation costs can outweigh holding costs, suggesting that expansion of backroom storage space might be a wise investment.

The applicability of the Truck heuristic to industries characterized by high shortage costs is another limitation to the study. Shortage costs in this study were shown to have very little impact on the total costs, even when these costs were varied. However, some industries might have very little tolerance for shortages. In such cases stockout costs could outweigh any cost savings derived by improved transportation utilization. Nevertheless, the fully specified model, would still be an appropriate inventory policy, assuming all costs are managerially relevant.

Chapter 5. Supply Chain Actions in the Grocery Industry

5.1. Introduction

Strategic management focuses on "the coordination and resource allocation both *within and across* firm boundaries" (Madhok, 2002). These internal and external management actions are of particular interest when examining firm performance in the context of supply chains. Supply chains are "links of partially discrete, yet interdependent, entities that collectively transform raw materials into finished products" (Hult et al., 2002). The strategic management literature informs us of the importance of the supply chain with an understanding of the determinants and consequences of vertical integration (Majumdar and Ramaswamy, 1994; Walker and Weber, 1984; Williamson, 1975), the market-based alternatives to vertical integration along the supply chain (Afuah, 2001; Gulati, 1998), and the benefits of cooperative buyer-supplier relationships (Bensaou and Anderson, 1999; Kotabe et al., 2003; Mudambi and Helper, 1998). Furthermore, there is growing attention regarding the impact of supply chain structure (in terms of upstream and downstream influences) on firm performance (Cool and Henderson, 1998; Randall and Ulrich, 2001). Yet, there remains a limited understanding of how the interdependence of firms along the supply chain impacts a firm's competitive strategy (Frohlich and Westbrook, 2001; Tan et al., 2002).

There are two dominant views of competitive strategy. From the vantage point of Porter's (1980) five forces model, competitive strategy is "aimed at altering the firm's position in the industry vis-à-vis competitors and suppliers" (Teece et al., 1997), where the firm's position is largely determined by barriers to entry/exit, industry concentration, and upstream/downstream dominance. On the other hand, the Schumpeterian perspective attends to a dynamic market process (Jacobson, 1992) and views competitive strategy as a "series of actions and reactions among firms" (Smith et al., 2001). The competitive dynamics research has studied this interdependence among rivals, demonstrating a strong link between firm actions, competitor actions, and firm performance. The actions among rivals emphasized in this stream of research centers on market-based actions, such as the pricing, marketing, and signaling activities of the firms. However, firms are also involved with coordinating their activities along the supply chain in order to enhance the performance objectives of the firm. These coordinating actions along the supply chain have not been considered in the competitive dynamics framework as a determinant of firm performance.

This research attempted to fill that gap by exploring a broader set of actions that may enhance a firm's competitive position; specifically, this research examined the supply chain actions of the firm and the impact these types of actions had on firm performance. This research addressed the following questions:

1) Is there a diverse portfolio of competitive moves in which firms engage to affect their competitive position? More specifically, does the quantity and diversity of supply chain actions positively impact firm performance?

2) Do supply chain actions moderate the relationship between market-based actions and firm performance?

3) Do certain types of supply chain actions align more closely with the firm's competitive strategy to enhance firm performance?

Drawing on the competitive dynamics and supply chain management areas of research, this research attempted to incorporate supply chain actions into the competitive action fold as a determinant of firm performance. This chapter begins with a review of the competitive dynamics literature, focusing on the relationship between firm actions and firm performance. Next, the supply chain empirical research is presented to uncover the types of supply chain actions that may impact firm performance. With this foundation, hypotheses are developed to relate actions with firm performance. Chapter 6 describes the data collection process and methods used to test the hypotheses. The analysis and results are presented in Chapter 7, to include a discussion of the key findings and managerial implications.

5.2. Theoretical Foundations: Competitive Dynamics

Competitive dynamics addresses a key area in the study of firm performance, that of firm behavior and conduct within an industry. While industrial organizational economics emphasizes the structure-conduct-performance (SCP) paradigm, industry structure remains the key determinant of performance. In contrast, the competitive dynamics research argues that beyond industry structure, actions and responses define the competitive strategies of the firm and directly influence performance (Smith et al., 2001). Competitive dynamics rests on entrepreneurial discovery and the dynamic market process of Schumpeterian economics (Jacobson, 1992) where firms search out opportunities to disrupt market equilibria (Grimm and Smith, 1997) and affect change within the industry. Many characteristics of firm actions have been studied, to include the impact of strategic versus tactical actions on imitation and the likelihood of response (Smith et al., 1991), the sequence or pattern of actions and reactions (Ferrier and Lee, 2002), action complexity and intensity (Smith et al., 2001), action timing (Ferrier et al., 1999), the timeliness of rival response (Chen and Hambrick, 1995; Smith et al., 1991), the number and diversity of actions (Ferrier et al., 1999), and the relationship between firm size and the speed and likelihood of actions and responses (Chen and Hambrick, 1995). The results of this research are largely consistent: aggressive competitive action (in terms of the number and intensity of actions) is positively related to firm performance and the persistence of market share leadership (Ferrier et al., 1999). Aggressive competitive action has also been linked with a first- and fast-second mover advantage (Lee et al., 2000), showing that lagging firms and late adopters of innovations accrue little, if any, competitive advantage (Ferrier et al., 1999; Smith et al., 1991; Smith et al., 2001).

The relationships between firm action, rival response, and firm performance are drawn mainly from the study of market-based actions. Specifically, market-based actions are those actions firms employ to capture customers. The types of market-based actions studied include pricing actions, marketing actions, new product actions, capacity- and scale-related actions, service actions, and signaling actions (Smith et al., 2001). In contrast, Shaffer et al. (2000) investigated the impact of non-market-based actions on firm performance, where non-market-based actions were defined as public policy- and governmental-related actions. This paper focuses on a different type of non-market-based action, specifically, supply chain actions.

5.3. Supply Chain Activities

Supply chains exist whether or not they are actively managed (Mentzer et al., 2001a). However, it is in the management of supply chains and supply chain activities that firms make decisions about the internal integration of processes and external integration with other organizations in order to facilitate the flow of material and information in support of the firm's strategic objectives (Houlihan, 1985; Mentzer et al., 2001a; Scott and Westbrook, 1991). This section briefly examines the supply chain literature to better understand the types of supply chain activities in which firms engage and how these activities relate to firm performance.

Supply Chain Material Flow. One of the fundamental reasons to manage the supply chain is to improve the flow of material to the end customer. Many areas of research focus on this issue, to include inventory management, just-in-time purchasing (Fazel, 1997), strategic supplier sourcing (Anderson and Katz, 1998), distribution and centralization, service quality, production, and new product development (Swink, 1999). Indeed, efficiency in material flow and improvements in cycle times are often driving forces in supply chain management. For example, in the furniture industry time compression strategies have been shown to positively impact firm performance (Vickery et al., 1995). Similarly, Stock et al (2000), found that operational improvements arise from improved material flow via integrated logistics activities within and between firms.

Supply Chain Information Flow. Coupled with material flow, information flow is essential to coordinate supply chain activities. A dominant theme in supply chain research is the reduction in information asymmetry along the supply chain. The exchange of information, particularly information concerning consumer demand, has been shown to reduce excess inventory (Lee et al., 1997), improve service quality (Mentzer et al., 2001b), and facilitate coordinated manufacturing processes via enterprise information systems (Rabinovich and Evers, 2002). Empirical evidence has shown that the efficient flow of information along the supply chain positively impacts firm performance. Droge and Germain (2000) found that electronic data interchange (EDI) capabilities reduced inventory investment and had a positive impact on financial performance. Similarly, effective knowledge transfer has been shown to improve supply chain performance, as measured by cycle time (Hult et al., 2004). One way firms affect the flow of material and information is through coordination with other firms. Coordination with supply chain member firms and the integration of processes with external organizations has empirically been shown to improve performance.

Supply Chain Relationships. The motives to collaborate within the supply chain are often driven by efficiency goals, scale economies, and quality improvement objectives (Tan et al., 1998). Supply chain collaboration can also provide greater access to resources (Gulati, 1998) and a competitive advantage (Ireland et al., 2002). The empirical research on supply chain relationships focuses on two fundamental issues—the determinants of supply chain relationships and the resulting benefits. Research examining the determinants of supply chain relationships is primarily grounded in transaction cost economic theory, particularly in the strategic management literature. For example, Bensaou and Anderson (1999) found that buying firms are more willing to initiate buyer-supplier relationships by committing relationship-specific investments when such relationships involve higher task complexity and technological uncertainty. Transaction cost economics views relationship-specific investments as idiosyncratic investments which cannot be re-deployable to another relationship, thereby creating bilateral dependency (Williamson, 1998). Williamson (1999) points to a large body of empirical research that supports a strong relationship between idiosyncratic investment and tighter governance of firm-to-firm relationships.

Benefits to forging tighter supply chain relationships are reduced costs and improved performance. For example, long-term buyer-supplier relationships have been shown to benefit supplier operational performance (e.g., product design, quality, and lead time) (Kotabe et al., 2003). Similarly, Shin et al. (2000) found that higher levels of supply management orientation (measured in terms of relationships, supplier selection, and supplier involvement) improved supplier and buyer quality and delivery performance.

5.4. Supply Chain Actions

The aforementioned supply chain literature and activities served as the basis for defining and operationalizing supply chain actions, the focus in this study. Supply chain actions were defined as documented supply chain activities relating to the flow of material, the flow of information, or supply chain relationships. As has been done in the competitive dynamics research (Ferrier et al., 1999), a supply chain action was defined as an instance in a published article that describes a supply chain activity in an associated pre-defined supply chain category. For example, an article describing the warehouse expansion for a firm would be classified as a supply chain action in the category identified as *Warehousing*. Similarly, an article describing changes in a vehicle fleet would be classified as a supply chain action in the category identified as *Transportation*. The supply chain categories related directly to material flow, information flow, and supply chain relationships were derived from the publication data source used in this research and described more fully in the methods section, chapter 6.

It is noted that some supply chain activities may not be readily observed or documented in a published source. While internal process improvements may support firm strategic goals, internal actions are less likely to affect the competitive landscape. The Schumpeterian perspective argues that actions must be observable to disrupt the status quo thereby signaling an intended course of action by the firm (Jacobson, 1992). Thus, while unobserved actions may indeed facilitate material and information flow along the supply chain, this study captured only observable actions that may be seen by rivals. The relationships between supply chain actions, market-based actions and firm performance are hypothesized in the next section.

5.5. Hypotheses Development

In The Competitive Advantage of Nations, Porter (1990) argues that competitive advantage is derived through acts of innovation. Further, once a competitive advantage is achieved, the firm must continually upgrade in order to sustain this advantage. Supply chain management is one way firms can reengineer processes within and across organizations and provide the basis for continuous improvement as raw materials are transformed into finished goods. That a competitive advantage must be continually upgraded and enhanced underlies the concept of first-mover and fast-second mover advantage (Lee et al., 2000).

Because supply chain management drives internal and external efficiencies (Mentzer et al., 2001a), some supply chain actions might be considered value-added actions (Hines et al., 1998) that are directed at improving the firm's resource position

(Grimm and Smith, 1997). For example, centralization of inventory at a distribution center may, in the short-run, reduce inventory investment and improve delivery efficiencies. However, in the long-run, such supply chain actions are geared toward more strategic goals of improved customer service, greater market share and higher firm profits (Wisner and Tan, 2000). Therefore, the following hypotheses were tested,

H1a: The total number of supply chain actions is positively related to sales growth.
H1b: The total number of supply chain actions is positively related to performance.

In addition to the relationship between the total number of supply chain actions and firm performance, it is expected that the positive relationship between market-based actions and firm performance will still be present, as strongly supported in the competitive dynamics literature. Therefore, the following hypotheses were tested,

H1c: The total number of market-based actions is positively related to sales growth.
H1d: The total number of market-based actions is positively related to performance.

Supply Chain Action Diversity: The competitive dynamics research has found a positive relationship between the complexity of the competitive action portfolio and sustained performance. Firms that relied on a narrow set of market-based actions were more likely to be out maneuvered by competitors (Ferrier et al., 1999), whereas firms that relied on a diverse set of competitive actions realized higher levels of performance than that of competitors. Consistent with the notion of action diversity, the supply chain management literature often considers the degree to which firms integrate their supply chains as a measure of their supply chain focus or external orientation. In a survey of 322 manufacturing firms, Frohlich and Westbrook (2001) investigated supply chain integration activities (e.g., joint EDI, customization, joint planning, information sharing) and found that firms characterized as outward-facing (integration with both upstream and downstream supply chain members) performed better than firms that were inward-facing or only focused effort in one direction (e.g., upstream or downstream, but not both). Further, inward-facing firms, those that engaged in limited supply chain integration activities, showed consistently lower performance than all other firms. In a similar study, firms that were more supply management oriented (with high coordination between buyers and suppliers) yielded higher operational benefits for both suppliers and buyers (Shin et al., 2000). Trends in the retail grocery industry suggest that the greatest benefits from Efficient Consumer Response arise when a wide variety of initiatives are implemented (Frankel et al., 2002). Therefore, it is suggested that firms that employ a more diverse set of supply chain actions will realize higher performance benefits than firms that engage in a narrow set of supply chain actions. Specifically, the following hypotheses were tested,

H2a: The greater the diversity of supply chain actions, the greater the growth in sales.

H2b: The greater the diversity of supply chain actions, the higher the performance.

Action Interaction: Logistics as a value-adding activity within the firm received momentum with Porter's concept of the value chain in the 1980's (Stock, 1997). It is widely held that the short-term objective of supply chain management is to increase productivity, reduce inventory, and improve cycle times, while the long-term, strategic goal of supply chain management supports the overall firm objectives of improved customer service, increased market share and higher firm profits (Wisner and Tan, 2000). Considering this view that supply chain actions support the strategic goals of the firm, the interaction of market-based actions and supply chain actions was test as it relates to firm performance. It was hypothesized that market-based actions when coupled with supply chain actions improved firm performance. Specifically,

H3a: The interaction of the total number of supply chain actions and the total number of market-based actions positively impacts sales growth.

H3b: The interaction of the total number of supply chain actions and the total number of market-based actions positively impacts performance.

5.6. Supply Chain Strategies

The competitive dynamics literature views strategy as action. Firms act in the marketplace, competitors react, and consequences are assessed in a cyclic manner. Thus, learning takes place through a feedback mechanism that enables future action (Grimm and Smith, 1997). Firm strategy is then revealed by discovering the types and patterns of competitive actions that firms enact. For example, price-cutting actions have been associated with low-cost strategies in the U.S. Airline industry, whereas airlines focused on differentiation strategies engaged in more marketing actions (Smith et al., 1997). The competitive dynamics literature characterizes the pattern of market-based actions as the competitive strategy of the firm.

Supply chain strategies have been investigated in the supply chain literature. In a survey of the grocery industry, Lynch et al. (2000) found that when a firm's logistics capabilities were appropriately matched with business strategies (cost leader or differentiation) performance was enhanced compared with firms that did not match capabilities with strategy. Similarly, manufacturing and business strategy alignment have been shown to enhance performance (Ward and Duray, 2000).

It might be expected that many combinations of supply chain actions and market-based actions are equally effective in achieving higher performance (Ward and Duray, 2000). For example, Morash (2001) found that demand-orientation (a customer focus) was highly correlated with the firm excellence. On the other hand, Tan (2002) and Tan et al. (2002) found that of 25 different supply chain activities, some were more highly correlated with firm performance than other activities. However, these studies failed to address other activities, such as the market-based actions of the firm, that impact performance. As a result, there is little consistency in the existing supply chain management research with respect to the types of supply chain activities that might have a greater impact on performance. Without a strong theoretical foundation to hypothesize which patterns of supply chain actions might be more likely to affect performance, an exploratory study was conducted to investigate the supply chain and competitive strategies of the firms in this study.

Using cluster analysis, this exploratory study attempted to uncover the patterns of actions that might characterize the firm's strategy in terms of supply chain and market-based actions at a more disaggregated level. Specifically, the exploratory analysis investigated the types of actions that were most prevalent in the sample data and whether the patterns varied based on organizational characteristics.

5.7. Research Setting

The retail grocery industry was selected for this longitudinal study during the period 2000 to 2004. A single industry was chosen because inter-industry effects can be directly controlled without the introduction of variables to account for varying degrees of capitalization, technological change, product introduction clock speed, scale economies, or other distinctive industry characteristics. The retail grocery industry, in particular, was selected because it met three basic criteria: 1) there was a high level of supply chain activity within the industry, 2) a large number of supply chain actions and market-based actions were visible and easily documented through trade publications, and 3) there was a sufficiently large sample size. Because of the first two points and the ability to collected data on over 1,100 firms in the industry, it was possible to capture many competitive actions in each year for a robust longitudinal study.

The grocery industry was also ideal because most U.S. firms were not diversified, although some firms were involved in the manufacturing of private label food products. The notable exceptions were Wal-Mart, K-Mart, and Target who operated predominantly in the discount general merchandise industry. Furthermore, the majority of U.S. retail grocery firms did not operate in foreign countries, with only a few minor exceptions (Gale, 2005). Therefore, the U.S. grocery industry might be considered a relatively closed system, in which investment in resources, supply chain advancements, and the competitive actions of firms were aimed primarily at markets within the U.S.

Defining the boundaries for this study, the data was collected using the North American Industry Classification System (NAICS) Code 44511, Supermarkets and other Grocery Stores. The industry defines a supermarket as a store with at least $2 million in annual sales carrying a full line of food and non-food items (Gale, 2005), and therefore this study did not include convenient stores or small grocery retailers. Warehouse clubs that sell directly to the public (e.g., Sam's Club or Cosco) were also excluded from the study since these types of firms fall under a different classification (NAICS Code 45291) and outside the scope of this study. Finally, supercenter-type firms (e.g., Wal-Mart, Target, and K-Mart), with a significant impact in the industry were included in this study. While NAICS 44511 is not the primary industry for supercenter-type firms, the grocery operations of these firms do fall under this industry classification. Therefore, a search in NAICS 44511 includes supercenter-type firms.

Chapter 6. Supply Chain Actions Data Collection and Methodology

The purpose of this research was to test the relationship between the various types of firm actions and performance in the retail grocery industry. Following the competitive dynamics literature, a content analysis method was chosen to document firm actions from the existing trade publications. This chapter discusses the data collection process, develops the regression model for hypothesis testing, and details the exploratory study using a cluster analysis methodology.

6.1. Structured Content Analysis

Structured content analysis is a useful method that can describe trends, identify intentions or characteristics of the communicator or subject and reveal patterns from the underlying data (Weber, 1985). This methodology was chosen to identify trends in supply chain actions by assessing the number and type of supply chain and market-based actions documented in the trade literature for the firms in the grocery industry. Based on these trends, inferences were drawn regarding the impact of competitive activity on sales growth and performance. Structured content analysis has been used in many fields of study (Jauch et al., 1980) and is a dominant method to measure competitive actions in the competitive dynamics literature. Content analysis rests on a classification procedure to analyze and code each article as recommended by Jauch et al.(1980). The content analysis classification schedule is much like a survey questionnaire where the objective is to measure specific variables of interest. The classification schedule used in this analysis was based on pre-defined categories into which supply chain and market-based actions were placed.

The next sections discuss the sources of data, the data collection process and the classification schedule used to categorize firm actions.

6.2. Data Sources

Action Articles: The supply chain and market-based actions were identified based on published news articles. The relevant publications for this study were identified by reviewing the retail grocery industry trade press, professional organization web sites, and industry newsletters. A list was compiled of the weekly and monthly publications that report both local and national news within the industry. This list was then compared to the publications contained in the Thomson Gale Business and Company Resource Center (BCRC). BCRC is a web-based archive of articles available by subscription through the University of Maryland Library. The BCRC database contained all of the publications on the original list and included a broad range of business, company and industry related content from a large list of academic and trade journals, trade newsletters, general national and local news sources, and company press releases. A full list of sources included in the BCRC database can be found at the Thomson Gale website, www.gale.com, while a short list of the relevant grocery industry trade publications are listed in appendix 5. A search procedure, described in section 6.3, was used to collect the articles from the BCRC database during the period 2000 to 2004. An overview of the number of articles collected is given in table 19.

Table 19. BCRC Articles by Year

	2000	**2001**	**2002**	**2003**	**2004**	**Total Articles**
Supply Chain Categories	667	883	1,234	1,742	1,173	5,699
Market Based Categories	3,813	4,325	6,185	7,006	6,068	27,397
Totals	6,480	7,209	9,421	10,751	9,245	33,096

Firm Data: The firm-level data and market characteristics were collected from two industry sources: The Marketing Guidebook: The Blue Book of Grocery Distribution and Market Scope: The Desktop Guide to Supermarket Share. These guides are published annually by Trade Dimensions International and The Progressive Grocer and contain detailed information on both public and private grocery firms. Trade Dimensions maintains store-level data compiled on every supermarket in the United States from which they produce company profiles and estimate firm sales and market share data. The data is compiled year-round via direct company contact (questionnaires and telephone calls) and maintained in the Trade Dimensions Retail Site Database (Currie, 2005). Fifty mutually exclusive market areas area consistently defined in both publications. The Marketing Guidebook, was used to collect market area demographics and aggregate sales. The firm-level market share data was extracted from Market Scope, a companion publication. Market Scope includes every firm operating within each market area, listing the number of supermarkets operated by the firm and the share of the market area supermarket sales.

The market share for supercenter-type firms was collected by Trade Dimensions in the same manner as traditional supermarkets through scanner data and direct company contact. The key difference was that only supermarket-type merchandise was used to estimate market share for supercenter firms. For example, 58% of the total sales were attributed to supermarket-type merchandise for Wal-Mart (Tarnowski and Heller, 2004).

6.3. Data Collection: Action Articles

The Thomson Gale Business and Company Resource Center (BCRC) was the sole source of news articles used to document the supply chain and market-based actions for the firms in this study. This on-line repository of business content is searchable by industry using the either the North American Industry Classification System (NAICS) or the Standard Industrial Classification System (SIC). The North American Industry Classification System (NAICS) was used for this study, specifically, 44511 – Supermarkets and Other Grocery (except Convenience) Stores. An initial search of BCRC under NAICS 44511 returned over 79,000 articles, as well as a list of subdivisions with which to narrow this broad search. These subdivisions served as the basis for the categories used for the content analysis classification.

6.3.1. Supply Chain Action Categories

The first content coding scheme was developed for supply chain actions. A first step in developing a comprehensive coding schema would be to examine the extant literature. However, taxonomies and inclusive functions of supply chain management vary from author to author (Mentzer et al., 2001a). Therefore, the starting point for this study was the pre-existing subdivisions in the Thomson Gale BCRC database. These pre-existing subdivisions, or categories, were selected consistent with the general definition of the supply chain management, specifically focusing on the flow of material and information (Houlihan, 1985; Mentzer et al., 2001a; Scott and Westbrook, 1991) and the interdependence, or relationships among firms along the supply chain (Hult et al., 2002). The BCRC categories relevant to material flow, information flow, and supply chain relationships are listed in table 20.

Table 20. BCRC Categories

Supply Chain Actions	Market-Based Actions	
Alliance	Acquisition	Marketing
Buildings and Facilities	Advertising	Marketing Agreements
Capacity	Competition	Mediation
Contracting	Design and Construction	Mergers
Customer Relations	Divestment	Negotiation
Distribution	Downsize	Organization Dissolution
E-Commerce	Endorsements	Organization Formation
Equipment and Supplies	Environmental Policy	Prices and Rates
Information Management	Facility Closure	Product Defects & Recalls
Inventory	Franchise	Product Discontinuation
Labeling	Green Market	Product Enhancement
Logistics	Growth	Product Introduction
Outsourcing	Innovation	Property
Packaging	Investment	Public Relations
Partnerships	Investor Relations	Remodeling
Product Development	Joint Venture	Renovation
Purchasing	Labor Relations	Reorganization
Quality Management	Licensing Agreements	Restructuring
Service Development	Location	Service Discontinuation
Storage	Market Research	Service Enhancement
Suppliers	Market Share	Service Introduction
Technology	Market Size	Target Marketing
Transportation		
Warehousing		

The use of pre-existing categories is advantageous because the classification of articles is consistent throughout the BCRC database and facilitates replication. One could argue that some supply chain management practices are absent from table 20. For example, common practices such as electronic data interchange (EDI), vendor management, continuous replenishment, radio frequency identification (RFID), category management, and efficient consumer response are not categories in the BCRC. However, upon review of the articles in the pre-existing categories, the supply chain management practices noted above were captured. The BCRC categories *Technology* and *Information Management* include articles on EDI and RFID programs. Similarly, the categories *Suppliers* and *Partnerships* include articles documenting continuous replenishment and vendor programs. It was therefore determined that the pre-existing categories in the BCRC were sufficient to capture the supply chain activities of grocery retailers.

6.3.2. Market-Based Action Categories

A second coding scheme was developed for market-based actions. The previous competitive dynamics research has used categories such as pricing, promotion, marketing, and signaling to define market-based actions as shown in table 21.

Table 21. Market-Based Actions in the Literature

Market-Based Action Category	Examples	Study
Pricing	Price Cuts Fares	Ferrier, Smith & Grimm (1999) Shaffer, Quasney, & Grimm (2000) Chen & Hambrick (1995)
Mergers & Acquisitions		Shaffer, Quasney, & Grimm (2000) Chen & Hambrick (1995)
Services	New Service Service Improvement Change in Service Customer Loyalty Programs	Shaffer, Quasney, & Grimm (2000) Chen & Hambrick (1995)
Products	Airports Airline Routes New Products	Ferrier, Smith & Grimm (1999) Shaffer, Quasney, & Grimm (2000) Chen & Hambrick (1995) Lee et al (2000)
Marketing		Ferrier, Smith & Grimm (1999)
Promotion	Advertising	Chen & Hambrick (1995)
Market Expansion	Capacity Addition Vertical Integration Entry/Exits	Ferrier, Smith & Grimm (1999) Chen & Hambrick (1995)
Legal	New Legal Actions	Ferrier, Smith & Grimm (1999)
Signaling	Intentions to Act	Ferrier, Smith & Grimm (1999)

Signaling, as used in previous competitive dynamics research, focused on announcements made by a firm which may or may not actually transpire. The argument is that such overtures trigger a competitive response by rivals. A *Signaling* category did not emerge in this research. In its place, however, is the category

Competition. The BCRC categories used to capture market-based actions in this study are listed in table 20.

6.3.3. Extracting data from BCRC

Although the BCRC is a searchable on-line archive, the news articles cannot be directly downloaded to a usable format. Therefore, a web-crawler program, Visual Web Task 5.0, was used to extract the appropriate news articles from BCRC and convert the information to a format that could be easily manipulated in a Microsoft Access database. Visual Web Task (VWT) 5.0 takes user-defined criteria to search an internet website, maps the hyperlinks of the search, and then extracts the information to a user-defined format. With the BCRC as the target website, a program was built in VWT 5.0 using NAICS 44511 and the United States as top-level search criteria for the industry code and country. The inclusion of the United States narrowed the population of potential articles from over 79,000 to approximately 33,000 during the time period in this study. Next, the BCRC category and year of interest were included as variables to be changed each time the program was run. The articles were downloaded in groups of 300 articles or less due to design limitations of the VWT 5.0 software which distinguishes *active* and *inactive* hyperlinks. While this size limitation slowed the process, there were several advantages to extracting the articles in small groups. First, it was possible to assign each BCRC category the articles as they were downloaded. The categories could not be captured if all 33,000 articles were downloaded together. Second, accurate article counts could be maintained. On occasion, the Visual Web Task program did not execute properly, omitting several articles. This problem was addressed immediately.

Finally, and perhaps, most importantly, by extracting the articles in small groups it was possible to review the headlines (titles) and ensure the articles accurately reflected the category to which they were assigned.

The VTW 5.0 program extracted the article title, full text (when available), publication, publication date, and article number (a unique article identifier). Upon execution of each download, the applicable BCRC category and inclusive dates were entered. The inclusive dates were tailored to ensure at most 300 articles were returned. Once the VWT 5.0 program extracted the information, the file was saved in an ASCII text format. The program was run 374 times to download 33,069 articles reporting on supply chain and market based actions in the retail grocery industry.

Each of the 374 text files was prepared for direct import to a Microsoft Access database, removing stray formatting characters and adding tab delimiting brackets where needed to separate the information fields. Upon import to Microsoft Access, each file was reviewed for accuracy using a rigorous quality control process. The article count was verified and corrected when necessary. In some instances a whole article or groups of articles were omitted for unknown reasons. These were manually entered into the database using the cut/paste method. In other instances, only part of an article was extracted. This was evidenced when the Article Number, a unique number assigned by the BCRC, was dropped in the download process. Again, these problems were addressed by manually entering the information into the database using the cut/paste method.

6.3.4. Reliability

The content coding process detailed above relied heavily on electronic search, using key word parameters rather than an in-depth review of each article. While, content analysis often takes advantage of electronic search, a more active method of coding has dominated the competitive dynamics literature. However, due to the large volume of articles an in-depth review of each article was not possible. It was therefore necessary to assess the reliability of the coding process and ensure the categories assigned to each article in the keyword search accurately reflected the content of the article. There were essentially two steps in assessing the reliability of the article coding. The first step was ensuring consistency with which the articles were categorized in the Business and Company Resource Center. The Thomson Gale Business Development Group has a large editorial and technical staff that creates taxonomies and automated indexing tools in order to ensure accurate and relevant content. Therefore, there was a high level of assurance that the BCRC categories were consistently applied to the journal articles (Gale, 2006). The second step to ensure the BCRC categories accurately reflected the supply chain or market-based activities this study was designed to measure. As noted, the articles were collected incrementally which allowed for close scrutiny of the article content.

The article headlines were scanned during both the download and quality-control processes. For the vast majority of the articles an accurate category assignment was made based on the researcher's professional expertise in the field of logistics and academic studies. However, four potential problems were identified for resolution. First several articles were missing the full text. One hundred and fortyone articles contained no information beyond the title and 801 articles contained an abstract only. For these partial articles, the abstract or title were used to assign the article to a firm, when specific firm information was provided therein. The manual retrieval of the complete article is left for future research.

The second area of concern was the reliability of the supply chain category *Purchasing*. The intent of the *Purchasing* category was to capture the supply-side activities of the firm, such as vendor programs and other purchasing agreements between buyers and the suppliers of goods and services. However, upon review of this category of articles, it was determined that a majority of the articles did not document buyer-supplier activities, but rather acquisition-related activities, such as in the headline, "Kroger purchases 13 Food Town stores." Each of the 288 articles originally assigned to the *Purchasing* category was reviewed, resulting in the recategorization of 155 articles.

The next area of concern was the duplication of articles in redundant categories. While an article might be coded in multiple categories, it was necessary that the categories be unique and, in fact, document distinct activities of the firm. Through a series of queries to the database on the article number identifier, duplicate articles were identified and the categories to which they were assigned were reviewed. Two categories were deleted: *Distribution Agreements* and *Shipment Data*. The articles in these categories were completely documented in the category *Distribution* and determined not to be unique supply chain categories. All other supply chain and market-based action categories were evaluated and found to be unique, even when articles were classified in more than one category.

The final area of concern with the downloaded articles was the documentation of foreign activities of U.S. firms. A search of the database identified three U.S. grocery retailers, A & P, Safeway, and Wal-Mart, operating in foreign markets, specifically Canada, the United Kingdom, Mexico, and Japan. One thousand, two hundred and ninety-seven (1297) articles were marked as documenting overseas activities. Each article was reviewed and 1053 articles were deleted from the database.

6.4. Data Collection: Firm-Level Data

Firm-specific market share information, market area statistics, and regional statistics were collected from The Marketing Guidebook and Market Scope. Total population and total food sales were manually collected from The Marketing Guidebook for each market area and entered into a Microsoft Access database for each year in the study. The total food sales documented in The Marketing Guidebook, however, also includes food sales at small grocery and convenience stores. Therefore, supermarket sales as a percent of total food sales were collected from Market Scope. Supermarket sales were then calculated in each market area.

Detailed market share information for all supermarkets operating in each market area was collected from Market Scope based on check-out scanner data. The same market definitions are used in both The Marketing Guidebook and Market Scope, although Market Scope only publishes for the 48 contiguous markets. Therefore, this study excluded Alaska and Hawaii in the analysis. In each of the 48 contiguous market areas, the following firm-level data was collected from Market Scope for each year in the study:

1) Market share for each grocery retailer operating in each market area

2) The number of supermarkets each retailer operated in their respective area

3) The Supplier for each retailer

4) Advertising group market share[4]

6.4.1. Extracting data from Market Scope

The market share and number of supermarkets for each firm in Market Scope was published in tabular format, but not available electronically. Therefore the data collection process required significant effort to convert the data to a usable electronic format. To minimize errors in data entry, the process was automated to the greatest extent possible with rigorous screening for quality control. Each market area in Market Scope was electronically scanned using Readiris Pro 7.5 text recognition software. Readiris Pro 7.5 converted each scanned page for export directly to Microsoft Excel. While the accuracy of the converted text was very high, typographical errors were still present. Therefore, each Excel worksheet was carefully compared with the original, correcting typographical errors when needed. Additionally, the number of supermarkets and market share values were double checked for accuracy. With each Excel worksheet, the data was prepared for export into a Microsoft Access database, using Visual Basic to move data to a single row for each record. Further, the market share data was verified to ensure 100 percent in each market area. This process resulted in 240 Excel worksheets, one for each market

[4] Independent retailers may belong to a member-owned cooperative and operate under a common name for the purpose of advertising (e.g., IGA and Piggly Wiggly) (Trade Dimensions, 2005).

area (48) and each year (5) in the study. These Excel worksheets were imported directly to the Microsoft Access database.

6.4.2. Firm Names and Parent Corporations

With the firm-level information in the database, queries were used to aggregate the data for each firm and check for consistency across years. For example, “SaveRite” was changed to “Save Rite” in a particular year when all other entries included the space. These changes were only made when there was a very high probability that the entries referred to the same firm, such as when the firm location and market area of operation was the same across all years. Prudent judgment was also used to adjust firm names. For example, in 2000, “Lances New Market” operated 9 supermarkets in the Indianapolis market area. In 2001 through 2004, “Lances SuperValu Inc” operated 9 supermarkets in the Indianapolis market area. It was assumed that these entries reflect the same firm, particularly since the headquarters location was the same for both companies. Thus, the 2000 entry “Lances New Market” was change to “Lances SuperValu Inc." If there was any ambiguity in the firm name or doubt in ownership, further research was conducted before making adjustments to firm names. This was because many distinct firms have similar names in the retail grocery industry. For example, “Food Giant,” “Food Giant Inc,” and “Food Giant Supermarkets Inc” are all separate firms. Hoover’s was used to verify whether or not firms with similar names were distinct. By comparing the firm location and the operating markets with those published in the Hoover’s company profile, adjustments were made when appropriate. Company web sites were also referenced, when available. A majority of the similarly named firms were confirmed to be distinct. For the remaining few firms that could not be resolved the ambiguous entries were kept unaltered and treated as separate firms.

Another problem arose due to changes in ownership and brand name licensing. Through mergers and acquisitions, ownership of a firm may change without necessarily a change in the brand name. For example, Shaw's Supermarkets, Inc. was acquired by Albertsons, Inc in 2004, yet the Shaw's brand name was retained. It was therefore necessary to clarify changes in ownership in order to attribute sales to different parent corporations before and after the acquisition. Furthermore, some brand names are licensed or franchised, such as “Save-A-Lot,” “Cub Foods,” and “Piggly Wiggly.” Because these store names are licensed to many different owners, it would be incorrect to aggregate all sales under the “Piggly Wiggly” banner to one firm. To clarify ownership, the parent corporation was added to the database using a list of parent corporations and subsidiaries published in the Marketing Guidebook. This parent and subsidiary list was used to populate the database. In some instances Hoovers was used to validate the information. The firm-level data was aggregated to the corporate level when a clear parent corporation-subsidiary relationship existed. Data for firms with no parent headquarters (e.g., wholly-owned firms) was left disaggregated. This resulted in 1,164 individual organizations, though not all operated in each year of the study, as shown in table 22.

Table 22. Number of Grocery Retailers and Average Market Share by Year

Year	Number of Firms*	Average Market Share
2000	763	5.39
2001	783	5.23
2002	907	4.58
2003	836	5.00

*Note: Refers to Parent Corporations and Wholly-Owned Firms

6.4.3. Associating Articles with Parent Corporations

To determine the number of competitive and non-competitive actions enacted by each parent corporation or wholly-owned firm, each article downloaded from the BCRC was associated with each organization. A database query was used to search the text (or title when the full text was not available) of each article for reference to the parent corporation, its subsidiary, or each individual wholly-owned firm. Firm ownership was carefully tracked due to franchise licensing and acquisition without rebranding. For example, Fleming Co. and Kroger Co. both operated discount grocery stores under the "Food 4 Less" banner. Furthermore, rebranding did not always occur following an acquisition. For example, Hannaford Brothers was not rebranded following their acquisition by Delhaize America, Inc. Similarly, Albertson's, Inc. retained the Shaw's Supermarket brand name following the acquisition of Shaw's Supermarket Inc. Therefore it was necessary to distinguish between Parent A - Subsidiary A and Parent B – Subsidiary A by carefully constructing the search parameters using logic operators (e.g., AND, OR, NOT) in the SQL search statements. Article counts, by action category, were then assigned to each parent corporation or wholly-owned firm and used to calculate the action variables discussed in the next section. For simplicity in the discussion, parent corporations and wholly-owned firms are generically labeled *firm* in the remainder of the paper.

6.5. Model Specification and Variables

The hypotheses were characterized with direct relationships between the supply chain and market-based actions and performance. These relationships were tested using linear regression on the panel dataset shown in equation (14). The dependent, independent, and control variables are operationalized in this section.

$$\begin{aligned} Y_{i(t+1)} = \beta_0 + \beta_1 SCActions_{it} + \beta_2 MBActions_{it} + \beta_3 SDIV_{it} + \beta_4 SC_{it} MB_{it} \\ + \beta_5 Supermarkets_{it} + \beta_6 MktServed_{it} + \beta_7 Population_{it} \\ + \beta_8 Wt\_HHI_{it} + \beta_9 Year + \varepsilon_{it} \end{aligned} \tag{14}$$

The descriptive statistics and Pearson correlation coefficients for the key variables are in table 23 and table 24, respectively.

Table 23. Descriptive Statistics

	Mean	Std. Deviation	N
GROWTH	$2,641,564,755	$58,687,498,893	2964
ROE	-7.81	71.32	110
MB Actions	30.05	237.70	4128
SC Actions	11.20	70.47	4128
MBxSC	15,954.66	205,483.27	4128
SDIV	0.48	1.49	4128
Supermarkets	29.38	149.93	4128
MktServed	1.92	3.50	4128
Population	13,726,452	23,294,864	4128
Wt_HHI	1,402.13	563.72	4128

Table 24. Pearson Correlation Coefficients

	1	2	3	4	5	6	7	8
1 GROWTH								
2 ROE	0.04							
3 MB Actions	0.27 **	0.09						
4 SC Actions	0.24 **	0.13	0.93 **					
5 SDIV	0.16 **	0.11	0.55 **	0.65 **				
6 Supermarkets	0.31 **	0.18	0.80 **	0.80 **	0.54 **			
7 MktServed	0.42 **	0.20 *	0.64 **	0.71 **	0.55 **	0.76 **		
8 Population	0.38 **	0.19 *	0.61 **	0.69 **	0.55 **	0.73 **	0.96 **	
9 Wt_HHI	0.02	0.21 *	0.03 **	0.04 *	0.04 *	0.05 **	0.05 **	-0.01

** Correlation is significant at the 0.01 level (2-tailed)
 * Correlation is significant at the 0.05 level (2-tailed)

6.5.1. Dependent Variables

Firm performance is the primary outcome in this study. However, a significant number of firms in the sample were privately owned and profitability measures were not available. On the other hand, higher competitive activity has been shown to result in market share gains (Ferrier et al., 1999). In addition, grocery industry studies emphasize sales growth as a measure of success (Mathews, 2005). Therefore, the primary measure of performance in this study was growth, measured as the absolute change in sales. For a sub-sample of firms (N = 110), return on equity, ROE, was used as a financial performance measure. Return on equity, often used in the strategy research to measure profitability, was collected from COMPUSTAT.

Growth: Sales growth was measured as the absolute change in total annual firm sales across all markets the firm operated between time t and t - 1. Total firm sales was calculated for each year, t, by multiplying the firm's share in each market, *m*, with the total market area supermarket sales, aggregated over all markets in which the firm operated, $Total\ Sales_{it} = \sum_{m=1}^{M} \left(MS_{imt} \times SuperSales_{mt} \right)$. For parent corporations, total sales were calculated as the sum of all subsidiaries. Growth, or the absolute change in sales, was calculated as shown in equation (15).

$$GROWTH_{it} = Total\ Sales_{it} - Total\ Sales_{i(t-1)} \qquad (15)$$

6.5.2. Total Supply Chain and Market-Based Actions

The number of supply chain actions was defined as a count of articles published in each supply chain category by a firm during each year of the study. Therefore, S_{ijt} was defined as the number of supply chain actions for firm *i* in BCRC category *j* in year *t*. The total number of supply chain actions for firm *i* in year *t* is given by equation (16). A summary of the supply chain action categories by year is in appendix 6.

$$SCActions_{it} = \sum_{j=1}^{J} S_{ijt} \tag{16}$$

Similar to the total supply chain actions, the total number of market-based actions was measured by the aggregate of all BCRC market-based K categories carried out by firm *i* in year *t*, and given by equation (17). A summary of the market-based action categories is in appendix 7.

$$MBActions_{it} = \sum_{k=1}^{K} M_{ikt} \tag{17}$$

The interaction of market-based and supply chain actions was measured by multiplying the total number of supply chain actions with the total number of market-based actions for each firm.

6.5.3. Supply Chain Action Diversity

Supply chain action diversity was measured as the inverse of the action repertoire simplicity ratio used by Ferrier et al. (1999). Just as market-based action categories served as the dimensions of action diversity in their work, supply chain action categories were used in this study to capture the degree to which firms engage in a broad range of supply chain activities. The inverse of the Ferrier et al. (1999) measure was used because the intent was to capture diversity rather than simplicity. The variable was calculated by taking the squared ratio of the number of actions in each j supply chain category for firm i in year t and the total supply chain actions for firm i in year t, summed over all J supply chain categories, as shown in equation (18). By taking the inverse, larger values indicated that the firm engaged in activities in a larger number of supply chain categories during year t.

$$SDIV_{it} = \left[\sum_{j=1}^{J} \left({s_{ijt}}/{s_{it}} \right)^2 \right]^{-1} \tag{18}$$

The hypotheses predicted a positive relationship between the action variables and sales growth or performance. The actions taken by a firm in the year 2000 would then be associated with a growth in sales over the next year, between the years 2000 and 2001. Similarly, actions taken by the firm in year t were associated with return on equity of the firm in year $t+1$.

6.5.4. Control Variables

Firm size: Firm size has been shown to affect competitive action. Larger firms, with greater resource endowments, often have a stronger resource position with which to leverage competitive action (Grimm and Smith, 1997). However, inertial forces may also induce a large firm to be complacent (Hannan and Freeman, 1984) and hinder aggressive competitive actions. Chen and Hambrick (1995) found that, in the U.S. airline industry, small firms were faster to initiate market-based actions than larger firms. Whether this same relationship between firm size and propensity for action holds for supply chain actions is unknown. However, many supply chain actions involve large capital investment in infrastructure, equipment, and systems which might tend to favor larger firms. Therefore, it is expected that firm size is positively related to competitive actions and thus, firm performance.

Several different variables were considered to measure firm size. Total sales volume is often used in the management literature as a measure of firm size, but sales was already the main component of the dependent variable, GROWTH. Furthermore, total sales provide information regarding the volume and scale of operations, but not necessarily scope. The extent of operations between two firms, for example, may be very different even when the annual sales for both firms are equal. One firm may operate a few stores in several markets, while the other firm has greater penetration with many stores in a single market. A similar argument might be made for the use of total number of supermarkets, alone, as a measure of firm size, since this measure was highly correlated with total sales. Instead, the total number of supermarkets across all *m* markets and the total number of markets was used to better assess the footprint of the firm. The total number of markets was calculated, as shown in (19), where $MktServed_{imt}$ equaled 1 when firm *i* operated in market *m* in year *t* and 0 otherwise.

$$MktServed_{it} = \sum_{m=1}^{M} MktServed_{imt} \tag{19}$$

Market Area Characteristics: Market conditions have a significant impact on the structure of markets, the conduct of firms operating in that market, and performance. Market area population was used to measure market size, one market condition that affects the number of sellers. The total population potentially served by each firm was calculated by aggregating the population for each market the firm operated, as shown in (20).

$$Population_{it} = \sum_{m=1}^{M} \left(MktServed_{imt} \times Population_{mt} \right) \tag{20}$$

Market Concentration: Market concentration was calculated for each of the 48 market areas in this study. Competition among grocery retailers occurs locally and the 48 market areas used in this study were the most concise areas for which data was available. These 48 market areas were mutually exclusive and consistently defined across all 5 years in this study. The Herfindahl-Hirschman index (HHI) was calculated based on market share, *MS*, for each firm, *i*, in each Market Area, *m*, and each year, *t*. Concentration was calculated using a series of queries on the data extracted from Market Scope. First, the market share for each firm was aggregated within each market area for each year in the study. This was necessary because the data in Market Scope was listed by supplier. When a firm had multiple suppliers in a single market, the firm market share data was entered separately as it applied to each supplier. The HHI was then calculated for each market as in equation (21).

$$HHI_{mt} = \sum_{i=1}^{I} MS_{imt}^{2} \tag{21}$$

A total HHI could be calculated over all markets in which the firm operated, similar to total population, however, such a measure would not capture the relative importance of each market to the firm. Therefore, a weighted average of HHI was calculated as shown in equation (22) based on the firm's share in each market.

$$Wt\_HHI_{it} = \sum_{m=1}^{M} \left(MktServed_{imt} \times MS_{imt} \times HHI_{mt} \right) \tag{22}$$

6.6. Exploratory Analysis of Market-Based and Supply Chain Actions

The exploratory stage of the supply chain actions analysis investigated the structure of the data with particular emphasis on the types of actions firm employed. The objective of this investigation was to identify whether firms varied in the types of actions they enacted and if so, how the different market-based and supply chain action repertoires were related to firm characteristics such as firm size, growth, or performance.

A multivariate technique that can help uncover an underlying structure in the data is cluster analysis. The objective of cluster analysis is to classify objects, firms in this case, within the population based on pre-determined identifying characteristics. The result of the analysis is clusters of firms that exhibit greater homogeneity within each group than between the groups. Cluster analysis is exploratory in nature and therefore more descriptive than inferential. There is no statistical basis to compare one clustering solution with another. In fact, clustering solutions are not unique and highly dependent upon the clustering variables and cluster methods (Hair et al., 1998) even within the same dataset (Aldenderfer and Blashfield, 1984). Despite a lack of theoretical underpinnings, cluster analysis is a useful technique to uncover patterns that may later be used for more rigorous statistical analysis.

There are four essential components of the cluster analysis: 1) determining the clustering method, 2) defining the clustering variables which represent the characteristics on which firms are to be compared, 3) determining the appropriate similarity measure for which observations are compared, and 4) determining the number of groups to form that result in relatively homogeneous clusters.

Agglomerative Clustering Method: The clustering algorithm used to assign cluster membership was the hierarchical agglomerative Ward's method, where all observations begin in individual groups. In each step of the analysis, observations are permanently linked, based on the similarity measure, such that the within-group error variance is minimized. The step-wise approach continues until all observations are assigned to a pre-determined number of clusters (Hair et al., 1998). The hierarchical agglomerative method is the most frequently used clustering method and results in non-overlapping groups. Another clustering method is the non-hierarchical approach, but requires the number of groups a priori, and therefore, deemed not appropriate. One limitation of the hierarchical method is that once an observation is linked in a cluster the observation cannot be reassigned latter in the partitioning process (Aldenderfer and Blashfield, 1984). Thus, an observation that appeared very similar to other members in a group when it was originally assigned could, in fact, be very dissimilar to other cluster-members upon completion of the clustering procedure.

Clustering Variables: Central to cluster analysis is the cluster variate, the set of variables used to compare objects and determine group membership. In this exploratory analysis, the action variables form the cluster variate. The disaggregated categories used to identify supply chain or market-based actions were too numerous to effectively group firms. Therefore, these action categories were aggregated on two different levels. At the highest level of aggregation, the total number of market-based actions and supply chain actions served as the first cluster variate. The second level of aggregation formed a set of ten action categories, three supply chain categories and seven market-based categories. These ten action categories were essentially the same categories used to identify the relevant subdivisions in the BCRC database. The supply chain actions were categorized as those firm activities relating to the material flow, information flow, and supply chain relations as discussed in section 5.2.1 (see table 26) (Mentzer et al., 2001a; Scott and Westbrook, 1991). The market-based actions were categorized based on prior research in the competitive dynamics literature. The market-based action categories used in prior research include promotion, marketing, market expansion, pricing, products, services, and signaling (Ferrier et al., 1999; Smith et al., 2001). These same categories were used in this study, for the mid-level aggregation, with some minor adjustments. First, the number of actions in the *Product* and *Services* categories was relatively small compared to other categories. Furthermore, the actions identified as *Innovations* were also small in number (777 firm actions) and captured mainly product and service innovations made by the firms. Therefore, *Products*, *Services*, and *Innovations* were combined to form a single category. The second adjustment was to replace the *Signaling* category used in prior research with a category labeled *Competition*. The articles in this category documented various methods firms use to compete or leverage a competitive advantage. The last category added as a cluster variable was *Organizational Change*. This category included the internal actions of the firm associated with acquisitions, joint ventures, and restructuring. This category was delineated for two main reasons. First, the total number of market-based actions (124,045), which included those identified as organizational change actions (40,322), significantly out-numbered the total number of supply chain actions (46,250) carried out by the firms in the dataset (see table 25). Distinguishing *Organizational Change* as a separate category provided more balance among the clustering variables. More importantly, however, organizational theorists contend that organizational factors, such as decision-making and internal structure, are important determinants of firm performance and differ significantly among firms. It is such firm heterogeneity that provides the foundation for unique internal capabilities and helps explain differences in performance beyond industry and other economic factors (Hansen and Wernerfelt, 1989). The BCRC categories associated with each clustering variable are listed in table 26 along with descriptive statistics.

Table 25. Aggregate Action Categories

Clustering Variable	N	Min	Max	Total	Mean	SD
MB Actions*	655	0	3,195	83,723	127.82	389.62
SC Actions	655	0	1,360	46,250	70.61	164.73
Org Change Actions	655	0	2,160	40,322	61.56	204.59

* Market-based actions exclude organizational change activities

Table 26. Clustering Variables and Descriptive Statistics

	Clustering Variable	BCRC Categories	N	Min	Max	Total	Mean	SD
Market-Based Action Categories	Promotion	Advertising Endorsements Licensing Agreements Public Relations	655	0	125	2,956	4.51	15.51
	Marketing	Green Market Market Research Marketing Marketing Agreements Target Marketing	655	0	1,300	43,548	66.49	191.40
	Market Expansion	Market Share Market Size Growth	655	0	270	7,292	11.13	36.20
	Pricing	Prices and Rates	655	0	360	7,526	11.49	37.09
	Competition	Competition	655	0	360	6,469	9.88	33.74
	Product & Service Innovations	Innovation Service Development, Enhancement, Introduction Service Discontinuation Product Defects & Recalls Product Discontinuation, Development, Introduction Product Enhancement	655	0	230	4,888	7.46	24.92
	Organizational Change	Acquisition, Mergers Divestment, Downsize Joint Venture Organization Formation Reorganization, Restructuring	655	0	2,160	40,322	61.56	204.60
Supply Chain Action Categories	Materiel Flow	Buildings and Facilities Capacity Distribution Equipment and Supplies Inv, Labeling, Packaging Logistics, Transportation Warehousing, Storage	655	0	770	27,146	41.44	91.40
	Information Flow	E-Commerce Information Management Technology	655	0	175	5,721	8.73	22.13
	Relationships	Alliances, Partnerships Contracting, Outsourcing Purchasing Quality Management Suppliers Customer Relations	655	0	565	12,591	19.22	56.73

The clustering variables were measured as a percent of the total, rather than quantity, as shown in equation (23). This was done to shift the emphasis from the sheer magnitude of firm actions toward the relative combination of actions.

$$\%\_\,Action\ Category_{it} = \frac{Number\ of\ Articles\ in\ Action\ Category_{it}}{Total\ Number\ of\ Articles_{it}} \qquad (23)$$

Simply a function of size, larger firms with larger resource endowments tended to enact more competitive actions than smaller firms. The clustering variables measured as simple action counts only magnified this size effect. The objective of this exploratory study, however, was to examine the manner in which firms divide their effort among competitive and non-competitive activities. For example, two firms with a significant difference in the sheer number of actions, but yet, equally divide their activities between market-base and supply chain actions, would most likely be assigned different clusters. On the other hand, if the clustering variables were defined as the percent of market-based and supply chain actions, these firms have a higher probability of being grouped together identifying a balanced approach to competitive actions as the key clustering characteristic.

Table 27. Action Categories as a Percent of Total Firm Actions

Clustering Variable (Percent of Total Actions)	**N**	**Min**	**Max**	**Mean**	**SD**
MB Actions*	655	0	1.00	0.26	0.32
SC Actions	655	0	1.00	0.64	0.39
Org Change Actions	655	0	1.00	0.10	0.19

* Market-based actions exclude organizational change activities

Cluster Similarity Measure: In assessing the underlying structure of the data, cluster analysis techniques identify similar observations and place them into groups. Similarity between observations can be measured in terms of distance, correlation, or association. Distance measures assess the proximity of the observations in n-dimensional space and, therefore, are most often used when the magnitude of the clustering value is emphasized. Correlation measures of similarity examine the patterns, rather than the magnitude of the clustering variables. Using this type of similarity measure, the observations within each cluster would be more highly correlated than the observations in different clusters. Finally, association measures of similarity are used for non-metric variables.

In this analysis the Pearson correlation coefficient was used to assess similarity among the firms. A correlation measure was chosen over a physical distance measure for the same reason the clustering variables were measure as the percent of the total number of actions. A distance measure of similarity would emphasize the firm size effect rather than emphasize how the firms divide their efforts between the different types of activities.

Dataset: A sub-sample of the database was used in the cluster analysis which included only those firms with at least one action during the period of the study (N = 655). Cluster analysis was attempted on the entire dataset before deciding to limit the sample to only those firms with at least one action. However, the large number of observations with no action data tended to obscure the comparatively small number of observations with only a few actions.

Chapter 7. Discussion – Supply Chain Actions

7.1. Panel Data Regression Results

The results of the regression analysis and exploratory study are discussed in this chapter. With a cross-sectional time-series dataset, the assumptions necessary for ordinary least squares (OLS) are often violated. Nevertheless, OLS regression was performed with the inclusion of firm dummy variables and the key assumptions were tested. The model was statistically significant with an F test statistic of 4.121 ($p < 0.000$). The interaction term was tested by examining the incremental increase in R^2. While the change in R^2 was small, $R^2 = 0.001$, it was statistically significant at the 10 percent level ($p < 0.058$), providing support for inclusion of the interaction between market-based actions and supply chain actions (MBxSC) in the model. The results are reported table 28. Heteroskedasticity was detected in a scatter plot of the standardized residuals and standardized predictor variables. Attempts to transform the data failed to correct this heteroskedasticity. Additionally, negative autocorrelation was present in the dataset with a Durbin-Watson statistic of 2.58.

Classic OLS regression also assumes that the observed values of the regressor variables are determined independent of the dependent variable and thus uncorrelated with the error term. The potential for correlation between the regressor variables and error term is higher in a panel dataset due to multiple observations of the same firm. Further, variations within a firm over multiple time periods cannot be accurately captured in an OLS regression which only models between-group variations. The addition of firm dummy variables attempts to capture the unobserved firm heterogeneity, but may be inefficient. Therefore, fixed-effects and random-effects models were estimated.

The application of a fixed-effects or random-effects model depends on the assumptions made regarding the error term. With a fixed-effects model, the unobserved firm effect captured in the error term is assumed to be correlated with the predictor variables and time invariant. When the unobserved firm component in the error term is uncorrelated with the independent variables, the model can be specified with random-effects (Greene, 2003). Table 28 reports the results of the fixed- and random-effects models.

Table 28. Regression Models for Growth as Dependent Variable

	OLS[1]		Fixed-Effects		Random-Effects	
Growth	**ß**	**t**	**ß**	**t**	**ß**	**z**
SC Actions	1.13E+08	2.33 *	1.13E+08	2.33 *	-2.80E+08	-6.11 ***
MB Actions	4.54E+07	2.19 *	4.54E+07	2.19 *	4.87E+07	3.22 ***
MBxSC	3.36E+04	1.90 †	3.36E+04	1.90 †	46056.76	3.14 **
SDIV	-1.70E+09	-1.09	-1.70E+09	-1.09	-2.07E+09	-1.92 †
Supermarkets	2.97E+08	3.68 ***	2.97E+08	3.68 ***	-1.97E+07	-1.53
MktServed	9.10E+08	0.18	9.10E+08	0.18	1.18E+10	10.94 ***
Population	-9.54E+02	-1.23	-9.54E+02	-1.23	-5.30E+02	-3.48 ***
Wt_HHI	5.34E+05	0.10	5.34E+05	0.10	-1.72E+06	-0.90
yr2000	3.07E+08	0.12	3.07E+08	0.12	-5.08E+09	-2.01 *
yr2001	2.35E+09	0.91	2.35E+09	0.91	-2.06E+09	-1.03
yr2002	1.78E+09	0.74	1.78E+09	0.74	-1.19E+09	-0.48
Constant	-2.58E+08	-0.01	5.97E+08	0.06	-6.09E+10	-1.76 †
N		2964		2964		2964
R^2		0.67		0.06		0.21
ΔR^2		0.001 †				
F		4.12 ***		16.27 ***		
χ^2						629.79 ***
Durbin_Watson		2.58				

† < 0.1
* < 0.05
** < 0.01
*** < 0.001

1. OLS regression included firm dummy variables (not reported)

The Hausman specification test was performed to asses which model, fixed or random, was most appropriate for the data. The Hausman specification test specifies the null hypothesis as the difference in the coefficients from the fixed- and random-effects models with the assumption that the regressor variables and error term are uncorrelated. The test statistic, χ^2, was 1666.25 (p-value < 0.000), therefore the null hypothesis was rejected that the fixed- and random-effects models were equal, in favor of the random-effects model. The Beusch-Pagan Lagrange Multiplier test, however, still detected heteroskedasticity in the data. The null hypothesis of equal error variance (homoskedasticity) in the random-effects model was rejected with a χ^2 of 674.91 (p-value < 0.000).

To correct the problems with autocorrelation and heteroskedasticity, the model was transformed using generalized least squares. It was assumed that the structure of the error term across the panels was heteroskedastic (based on the Beusch-Pagan Lagrange Multiplier test) and uncorrelated (based on the Hausman specification test). Estimating the autocorrelation coefficient, ρ, based on the Durbin-Watson statistic, the transformed model was calculated taking the difference between each observed value and the once-lagged value multiplied by ρ, shown in (24), as recommended by Pindyck and Rubinfeld (1998). The resulting error term satisfies the assumptions of homoskedasticity with no autocorrelation.

$$y_{it} - \rho y_{i(t-1)} = \beta\left(x_{it} - \rho x_{i(t-1)}\right) + \left(\varepsilon_{it} - \rho \varepsilon_{i(t-1)}\right) \tag{24}$$

The results of the generalized least squares regression are in table 29. Observations (N = 156) with data in only 1 year were dropped from the estimation, since a lagged value could not be calculated. The model was statistically significant with a χ^2 test statistic of 884.49 (p-value < 0.000).

Table 29. Generalized Least Squares

	GLS – Growth[1]		GLS – ROE[1]	
Variable	**ß**	**z**	**ß**	**z**
SC Actions	7.08E+07	2.94 **	0.009	0.44
MB Actions	2.68E+07	2.62 **	0.003	0.43
MBxSC	-12.29E+03	-0.40	-6.02E-06	-1.00
SDIV	-2.05E+09	-16.11 ***	0.410	0.34
Supermarkets	-5.46E+07	-4.70 ***	0.005	0.62
MktServed	9.68E+08	4.10 ***	-0.711	-0.44
Population	-42.5	-2.45 *	1.10E-07	0.47
Wt_HHI	-3.73E+05	-3.52 ***	0.008	0.77
yr2000	-4.15E+08	-4.36 ***	5.731	0.79
yr2001	3.58E+08	4.46 ***	5.231	0.81
yr2002	3.58E+08	6.46 ***	5.466	0.94
yr2003			2.153	0.50
Constant	1.33E+08	0.54	-14.689	-0.84
N		2808		109
χ^2		885 ***		5.21
LL		- 64315		-464.6

* < 0.05
** < 0.01
*** < 0.001

1. 156 observations dropped with only 1 observation in the group

The first set of hypotheses predicted a positive relationship between the total number of supply chain and market-based actions and performance, as measured in terms of sales growth and return on equity (ROE). Hypothesis 1 was partially supported. The results in table 29 indicate that higher numbers of supply chain actions do result in higher sales growth (H1a) (p-value < 0.01), but not ROE (H1b). This supports an objective to reduce costs through supply chain management practices. In particular, the implementation of efficient consumer response programs by the grocery retailers in this sample was shown to positively impact sales growth. While there was no support for the positive impact of supply chain activities on profitability, this may be due to the small sub-sample of firms (N = 110) for which financial performance data was available. In fact, none of the hypotheses regarding the relationship between competitive or non-competitive actions and ROE were supported.

It was expected that aggressive market-based actions would be positively related to performance. Hypothesis 1c was supported; the higher the competitive activity of the firm, as measured in terms of the number of market-based actions, the greater the sales growth (p-value < 0.01). Thus aggressive competitive activity, such as marketing, pricing, and product/service innovations, can result in performance benefits even in a highly competitive industry like the retail grocery industry.

Hypotheses 2a and 2b predicted that firms engaged in a broader variety of supply chain activities would realize higher performance gains. Supply chain diversity (SDIV) was statistically significant (p-value < 0.001) for sales growth, but was in the opposite direction hypothesized. Higher levels of supply chain diversity resulted in a decline in sales or negative sales growth, for the firms in this study. This is inconsistent with a systems-view of the supply chain, where emphasis in only a few functional areas can result in suboptimization. This may suggest that investment in a wide range of supply chain activities is less effective in the retail grocery industry. Given the high level of competition and narrow profit margins that characterize the industry, grocery retailers may benefit more by focusing their efforts on a few cost saving supply chain activities rather than diversifying. This result, coupled with the strong relationship between the total number of supply chain actions and sales growth, suggests that heavy emphasis in a few key areas yields the greatest benefits. No support was found for performance benefits in terms of ROE (H2b).

Finally, hypotheses 3a and 3b predicted that the interaction of supply chain and market-based activities was positively related to sales growth (H3a) and ROE (H3b). Neither hypothesis was supported. While the OLS regression supported inclusion of the interaction term with a significant change in R^2, the percent of variance in the dependent variable attributed to the interaction term was very small ($\triangle R^2 = 0.001$). Thus, the impact of market-based actions on sales growth is not necessarily enhanced by higher levels of supply chain activity. The inclusion of the interaction term in the model does, however, alter the interpretation of the coefficients for the supply chain and market-based actions. That is, with the interaction term included, the coefficient for supply chain actions estimates the conditional relationship with sales growth when market-based actions equal zero, and visa versa. Omission of the interaction term did not change the overall results, but did strengthen the main effects for supply chain (p-value < 0.001) and market-based actions (p-value < 0.001).

7.2. Cluster Analysis Results

The exploratory study examined whether different sets of actions can be attributed to higher performance. A sub-sample of the database was used which included only those firms with at least one action during the period of the study (N = 655). Cluster analysis was attempted on the entire dataset before deciding to limit the sample to only those firms with at least one action. However, the large number of observations with no action data tended to obscure the comparatively small number of observations with only a few actions.

To move away from the size effect in which no distinguishing strategies emerged, the percent of the total number of actions in each action category was used to cluster the observations.   Three sets of clustering variables were used, each on the sample subset of firms with at least one action during the study period (N=655).

Analysis A) Percent market-based actions and percent supply chain actions.

Analysis B) Percent of the total in each action category:

- Percent promotion actions
- Percent market expansion actions
- Percent product and service innovation actions
- Percent marketing actions
- Percent pricing actions
- Percent competition actions
- Percent relationship actions
- Percent materiel flow actions
- Percent information flow actions
- Percent organizational change actions

Analysis C) Percent market-based actions (re-specified to exclude organizational change actions), percent supply chain actions, and percent organizational change actions.

7.2.1. Cluster Analysis A and B

The first two approaches are shown in figure 5 and figure 6. In analysis A, the clustering variables were the two main actions categories, market-based and supply chain, measured as a percent of the total number of actions for each firm, in each year. In analysis B, the clustering variables were the ten action categories defined in Table 26, also measured as a percent of the total number of actions for each firm, in each year.

Analysis A and B demonstrate that group profiles are dependent upon the cluster variate. In Analysis A, group A1 is the largest group with 374 observations (see figure 5). These firms focused nearly all of their effort on supply chain activities. On the other hand, for the next largest group (A2) approximately 80 percent of the actions were market-based with some emphasis on supply chain activities. The last group, A3, was balanced between market-based and supply chain actions. When the cluster variate was changed for Analysis B (10 action categories), the cluster profile in the three-group solution was distinctly different, as shown in figure 6. Groups B1 and B2 were similar with a dominant focus: Group B1 emphasized mainly supply chain actions, while group B2 emphasized market-based actions. The third group, however, in analysis B was no longer a balanced group. Rather, group B3 was also heavily invested in supply chain activities.

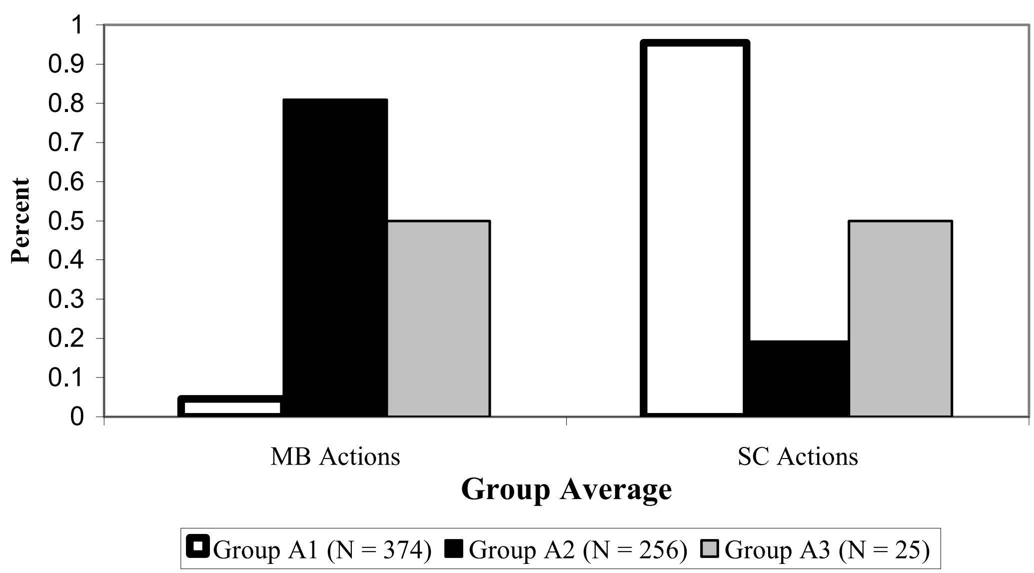


Figure 5. Analysis A: 3-Group Solution – Cluster Variate = MB and SC Actions

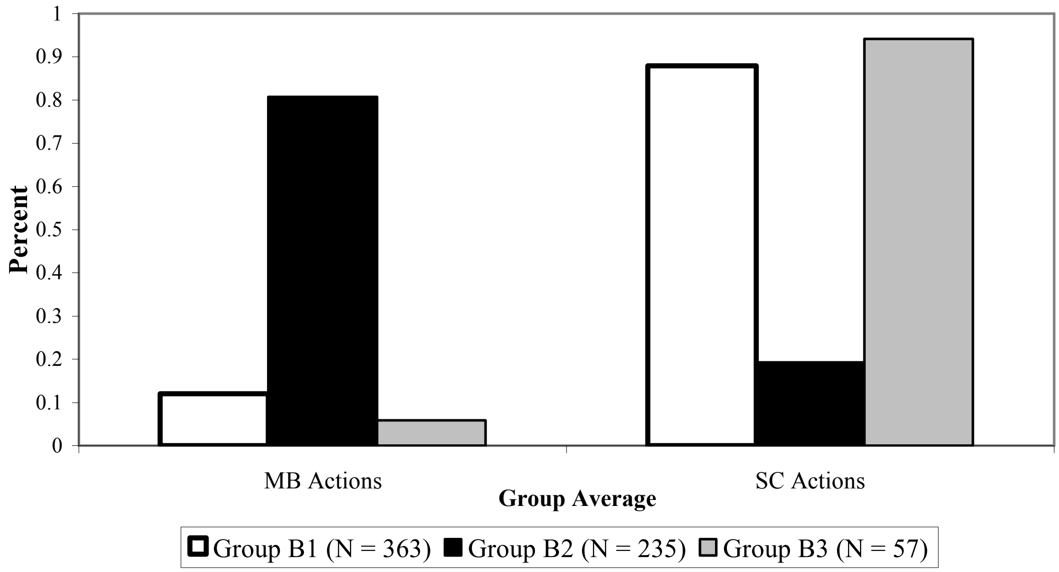


Figure 6. Analysis B: 3-Group Solution – Actions Profile

A closer examination of the 10 action categories in figure 7 shows that the two supply chain groups (B1 and B3) differ in terms of their supply chain focus. Group B1 emphasized materiel flow actions (e.g., distribution, transportation, and warehousing) while group B3 emphasized supply chain integration activities related to information flow and supply chain relationships. In analysis A, the supply chain integration group was replace with Group A3 which balanced marketing and organizational change actions with materiel flow actions (see figure 8).

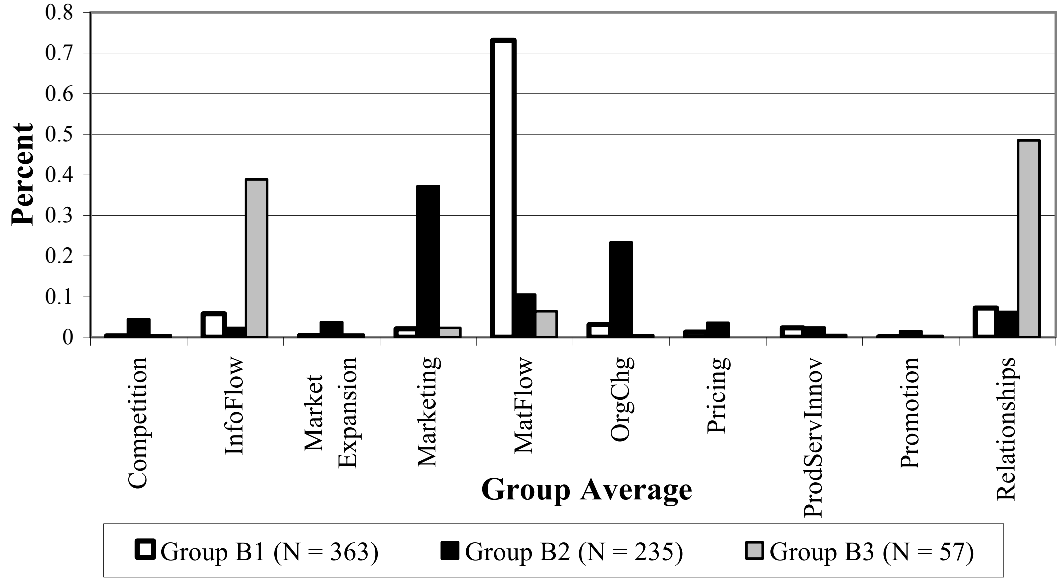


Figure 7. Analysis B: 3-Group Solution – Cluster Variate = 10 Action Categories

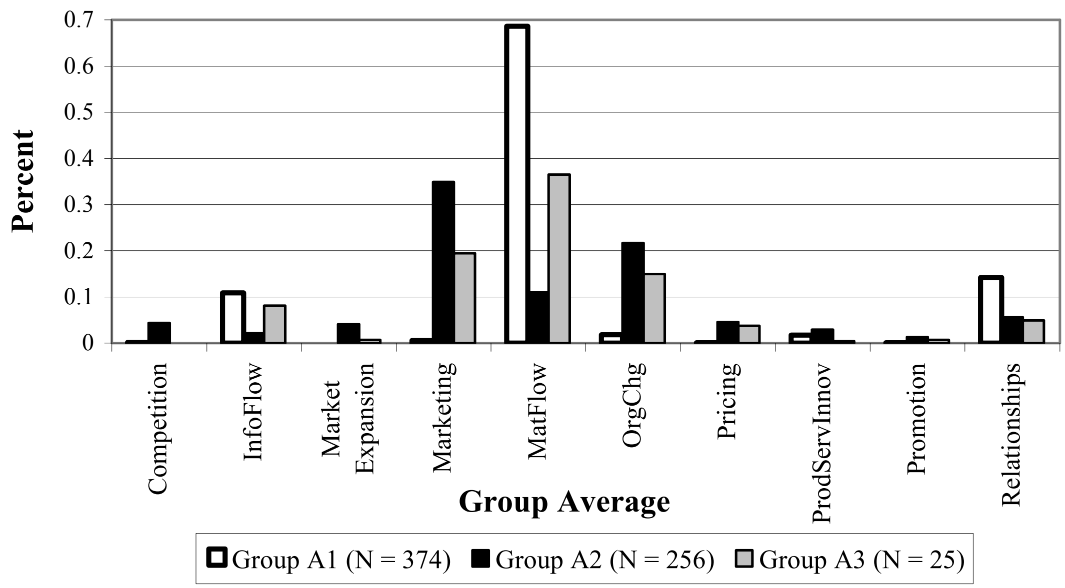


Figure 8. Analysis A: 3-Group Solution – Actions Profile

Firms that engaged in mainly market-based activities (groups A2 and B2) tended to be larger firms, in terms the number of supermarkets and market areas served and realized higher than average sales growth (see table 30). There was no evidence of higher performance for firms engaged in supply chain activities (groups A1, B1, and B3) or those with a balanced approach (group A3).

Table 30. Analysis A&B 3-Group Solution – Characteristics and Performance

		Percent		Standardized Values			
Analysis (Group Size)	**Description**	**MB Actions**	**SC Actions**	**Total Sales**	**Number Supers**	**Markets Served**	**Growth**
A1 (N = 374)	SC 1	0.05	0.95	0.10	0.20	0.29	0.00
A2 (N = 256)	MB	0.81	0.19	1.57	1.63	1.69	0.59
A3 (N = 25)	Balanced	0.50	0.50	-0.03	0.04	0.04	-0.03
B1 (N = 363)	SC 1	0.12	0.88	0.11	0.24	0.34	0.00
B2 (N = 235)	MB	0.81	0.19	1.70	1.72	1.77	0.63
B3 (N = 57)	SC 2	0.06	0.94	-0.02	0.04	0.05	0.03

Number of Clusters: Because cluster analysis is exploratory, there are no objective guidelines or statistical criterion to determine the number of clusters to form. There are ad hoc procedures, but these are generally applied when distance measures are used to define cluster membership. Even with these ad hoc procedures, the number of clusters to form is highly subjective. In this study, a range of three to six cluster solutions was calculated for each analysis (A through C). From a practical point, fewer clusters are easier to communication the distinguishing characteristics. As a minimum, three clusters seemed reasonable, with one group emphasizing market-based actions, one group emphasizing supply chain actions, and at least a third group with some other action repertoire. Each n-cluster solution was examined to see if the cluster variables resulted in distinguishable groups. Firm attributes, such as the total sales, total number of supermarkets, and the number of markets served, along with firm performance measures were also examined to understand how the clusters varied on these measures. The best alternative was selected when the addition of a cluster resulted in a new group of firms with a distinctly different action profile.

N-group solutions: A 4-group, 5-group, and 6-group solution did not emerge in analysis A, with only one observation was assigned to the fourth, fifth, or sixth group, respectively. Therefore, when the percent of market-based actions and percent to supply chain actions were used as the clustering variables, three primary groups emerge, a supply chain group, a market-based group, and a balanced group (figure 5).

This was not the case in Analysis B, where the cluster variate was comprised of the ten action categories in table 26. In the 4-group solution, two supply chain groups and two market-based groups emerged, each emphasizing different types of actions, as shown in figure 10. The two supply chain groups were unchanged in the 4-group solution compared with the 3-group solution, as shown in figure 9. The firms emphasizing market-based activities, however, now formed two distinct groups. Group B2 activities were dominated by organizational change actions (40%), followed by marketing actions (20%). Group B4, on the other hand, emphasized mostly marketing actions (55%).

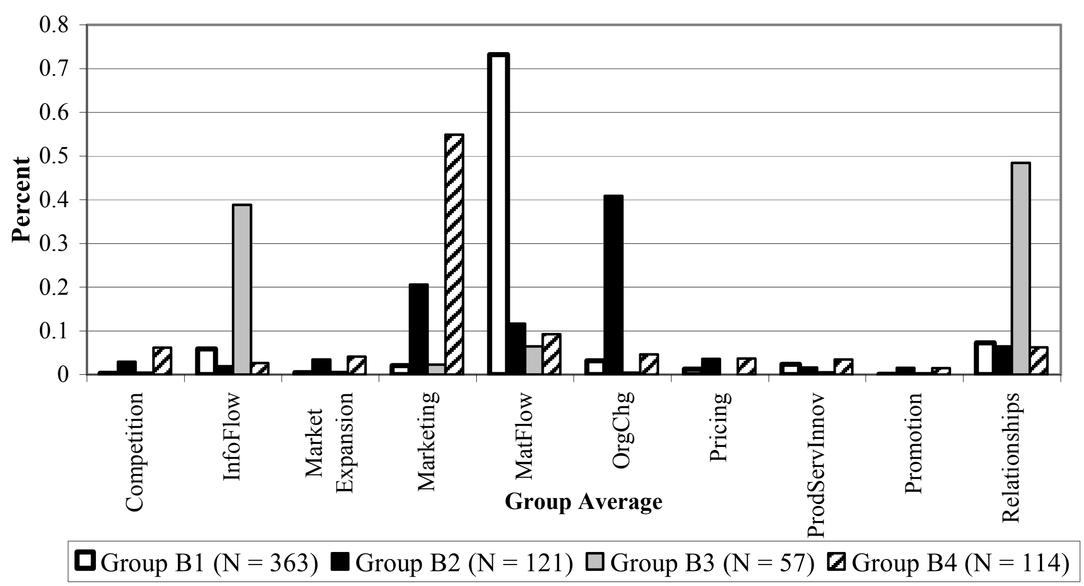


Figure 9. Analysis B: 4-Group Solution – Cluster Variate = 10 Action Categories

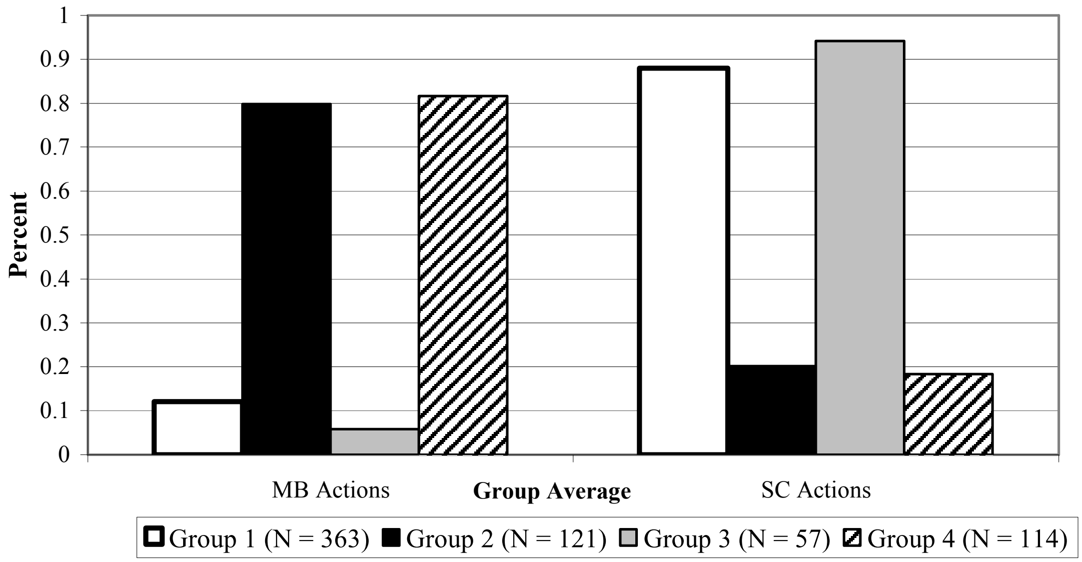


Figure 10. Analysis B: 4-Group Solution – Actions Profile

With this result greater consideration was given to the treatment of organization change as an action category. Previous research has included activities such as acquisition, mergers, and reorganization as market-based actions (Chen and Hambrick, 1995). This is consistent with the organizational theory of adaptation where firms make organizational structure changes to adapt to changing or uncertain environmental factors (Hannan and Freeman, 1984). While mergers or divestment may signal to competitors a firm's intent to expand to new markets or close less profitable ones, organizational change actions also capture internal managerial actions, such as organizational learning and decision-making (Hansen and Wernerfelt, 1989). It is reasonable, then to redefine the top-level action categories in this exploratory phase, with organizational change as a distinct category from all other market-based actions. In cluster analysis C, organizational change actions were considered as a separate category. The cluster variate was defined as the percent of the total firm actions in three main categories: supply chain actions, market-based actions, and organizational change actions. The market-based actions were re-specified to exclude all organizational change activities.

7.2.2. Cluster Analysis C

The 3-, 4-, and 5-group solution for cluster analysis C are depicted in figure 11 through figure 13. Three distinct groups, each emphasizing a different action category emerged in the 3-group solution shown in figure 11. The three groups were characterized as a supply chain group, a market-based group, and an organizational change (or internal action) group. These groups, however, were characteristically different from the three groups formed in analysis A which did not include organizational change as a clustering variable. Specifically, the balanced market-based and supply chain group in analysis A (group A3) did not emerge in the 3-group solution for analysis C.

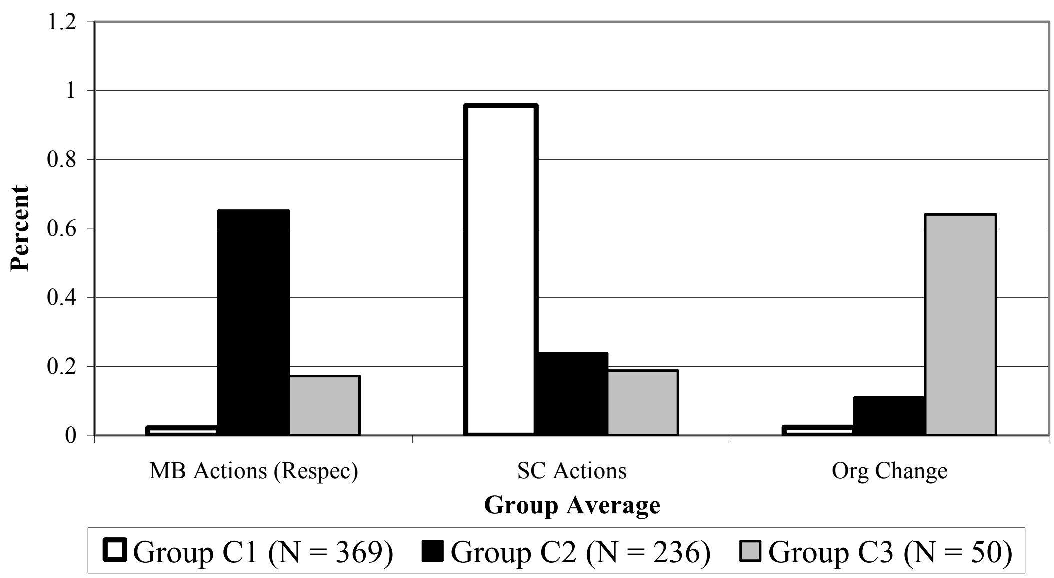


Figure 11. Analysis C: 3-Group Solution – Cluster Variate = MB, SC, and Org Change Actions

This balanced group, however, did emerge in the 4-group solution for Analysis C, shown in figure 12. In the 4-group solution, the supply chain (C1) and organizational change (C3) groups were unchanged. The market-based action group, which accounted for 236 firms in the 3-group solution, however, was reduced in size to 197 firms in the 4-group solution. The remaining 39 firms formed a fourth group (C4) with a balanced 50/50 approach to market-based and supply chain actions. Viable 5- and 6-group solutions also formed, each eroding the market-based action group (C2), and forming relatively small new groups. In the 5-group solution, a group (N = 25) formed emphasizing 40% of their effort in market-based actions and 40% in organizational change actions. To complement this, a sixth group emerged in the 6-group solution (N = 15) emphasizing 40% of their effort in supply chain actions and 40% in organizational change actions (not depicted).

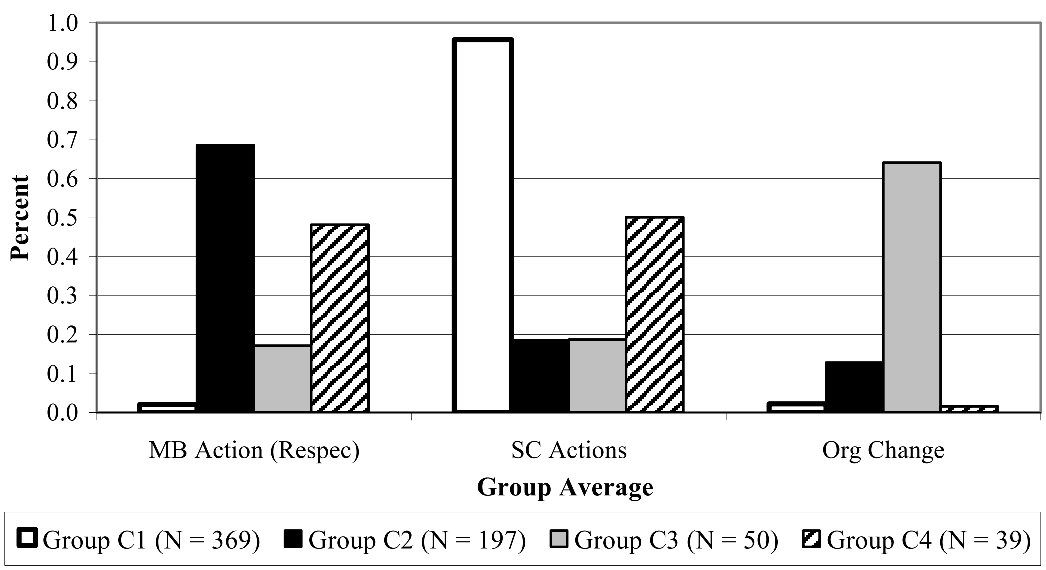


Figure 12. Analysis C: 4-Group Solution – Cluster Variate = MB, SC, and Org Change Actions

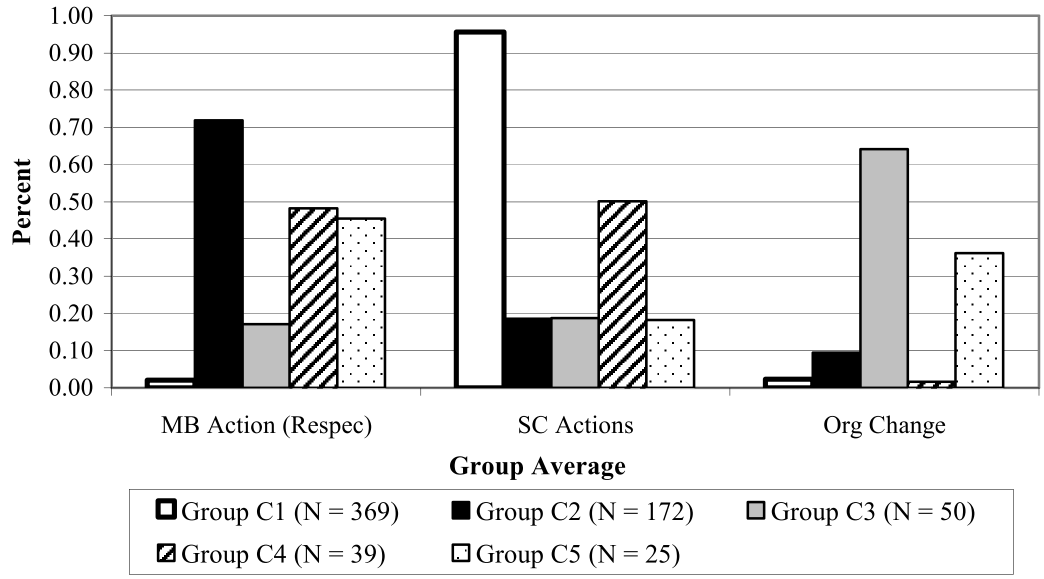


Figure 13. Analysis C: 5-Group Solution – Cluster Variate = MB, SC, and Org Change Actions

7.2.3. Performance and Descriptive Attributes

The group characteristics and performance averages are summarized in table 31 and table 32. A consistent result in all cluster analyses performed (A, B and C), was the higher than average performance for market-focused firms, as shown in previous research (Ferrier et al., 1999). These performance benefits vanished, however, when firms split their action profile between market and supply chain actions, as with group C4. There also appeared to be no performance advantage to firms with a supply chain-only focus (C1) or firms with a high degree of organizational change (C3). The exception was a slight performance advantage for group C5, which emphasized market-based (40%) and organizational change (40%) actions. While firms with a supply chain strategy (C1), organizational change strategy (C3), or balanced strategy (C4) did not realize larger than average performance benefits, these firms were not at a competitive disadvantage either.

These firms tended to converge to the middle with average sales growth during the period of the study.

An interesting result of the exploratory study was with respect to firm size. Organizational change often involves considerable cost in terms of the redistribution of assets and personnel. Larger firms would be better equipped to absorb such costs. While the organizational change-only firms (C3) were larger than average, the largest firms in the study were those that coupled organizational change with market-based actions (C5). These firms were significantly larger in terms of the number of supermarkets and the markets served. The next largest group of firms was the group focusing mainly on market-based actions. This is consistent with prior competitive dynamics research finding larger firms with greater access to resources are able to enact more competitive actions. On the other hand, small firms have been shown to employ different strategies in order to compete effectively (Chen and Hambrick, 1995). In this study the strategy of mid-sized firms was distinctly different. Firms with a strictly supply chain focus tended to be smaller and operate in fewer markets.

Table 31. Analysis C – Group Action Profile

Cluster Solution (Group Size)	**Description**	**Percent of Total Actions**		
		MB[1]	**SC**	**Org Change**
C1 (N = 369)	SC	0.02	0.96	0.02
C2 (N = 236)	MB[1]	0.65	0.24	0.11
C3 (N = 50)	Org Change	0.17	0.19	0.64
C1 (N = 369)	SC	0.02	0.96	0.02
C2 (N = 197)	MB[1]	0.69	0.19	0.13
C3 (N = 50)	Org Change	0.17	0.19	0.64
C4 (N = 39)	Balanced MB[1] & SC	0.48	0.50	0.02
C1 (N = 369)	SC	0.02	0.96	0.02
C2 (N = 172)	MB[1]	0.72	0.19	0.09
C3 (N = 50)	Org Change	0.17	0.19	0.64
C4 (N = 39)	Balanced MB[1] & SC	0.48	0.50	0.02
C5 (N = 25)	MB[1] & Org	0.46	0.18	0.36

1. Market-based action respecified to exclude organizational change actions.

Table 32. Analysis C – Group Attributes and Performance Summary

Cluster Solution (Group Size)	Description	Rank Size	Standardized Values Total Sales	Number Supers	Markets Served	Growth
C1 (N = 369)	SC	3	0.105	0.213	0.337	0.00
C2 (N = 236)	MB[1]	1	1.557	1.598	1.592	0.66
C3 (N = 50)	Org	2	0.630	0.735	0.859	-0.05
C1 (N = 369)	SC	3	0.105	0.213	0.337	0.00
C2 (N = 197)	MB[1]	1	1.848	1.873	1.813	0.79
C3 (N = 50)	Org	2	0.630	0.735	0.859	-0.05
C4 (N = 39)	Balanced MB[1] & SC	4	0.087	0.211	0.479	0.00
C1 (N = 369)	SC	4	0.105	0.213	0.337	0.00
C2 (N = 172)	MB[1]	2	1.782	1.747	1.604	0.87
C3 (N = 50)	Org	3	0.630	0.735	0.859	-0.05
C4 (N = 39)	Balanced MB[1] & SC	5	0.087	0.211	0.479	0.00
C5 (N = 25)	MB[1] & Org	1	2.297	2.735	3.250	0.24

1. Market-based action respecified to exclude organizational change actions.

7.2.4. Changes in Firm Strategies

Focusing on the 3-group solution in Analysis C, there was little change in the group profiles when examined over each year of the study. Figure 14 through figure 16 show the three primary clusters: supply chain, market-based, and organizational change. In the aggregate these groups remained relatively stable in terms of their focus on a particular type of action. Examining the individual firms, the majority of firms made no change in their strategy during the five year period. However, some firms did change group membership. Thirty firms made one change in their action repertoire. Most often these firms changed their strategic focus for one year and then returned to their previous strategy. For other firms, the change was permanent through the remainder of the study period. A very small number of firms switched focus several times – nine firms changed their strategy twice and four firms changed group membership three or more times.

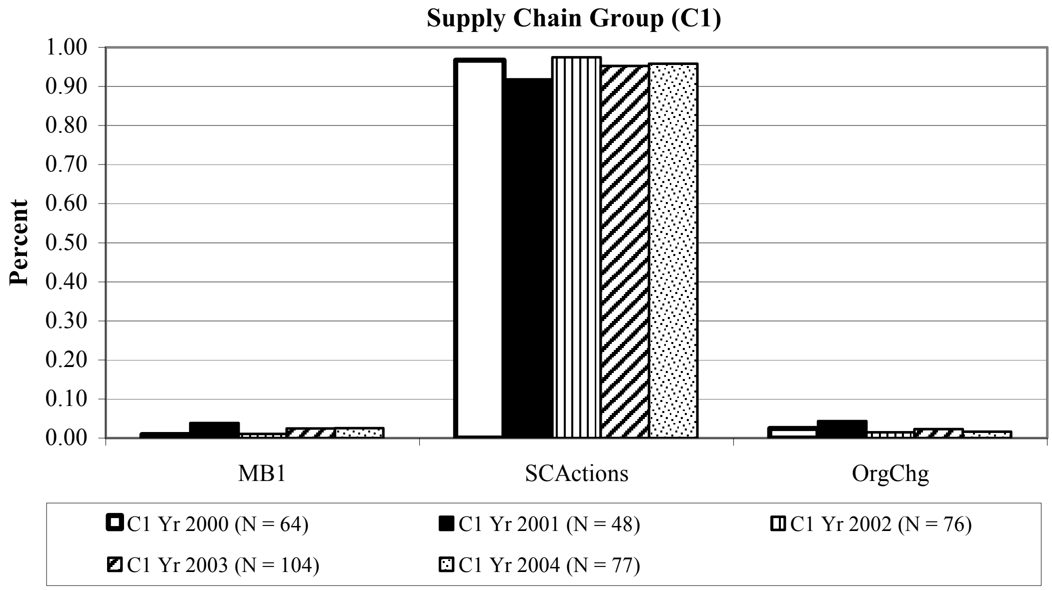


Figure 14. Analysis C: Supply Chain Group

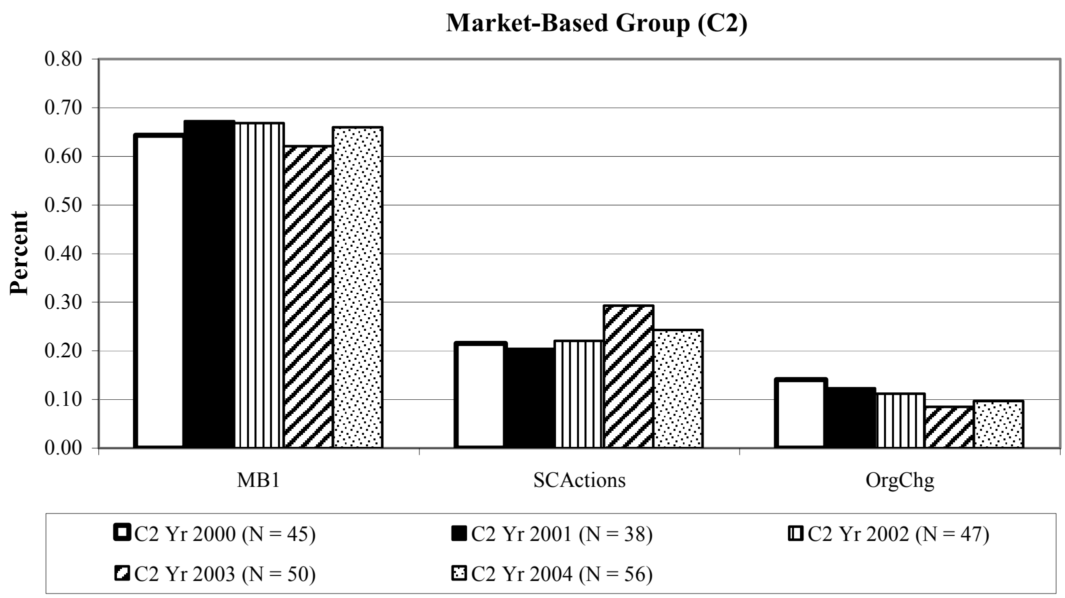


Figure 15. Analysis C: Market-based Group

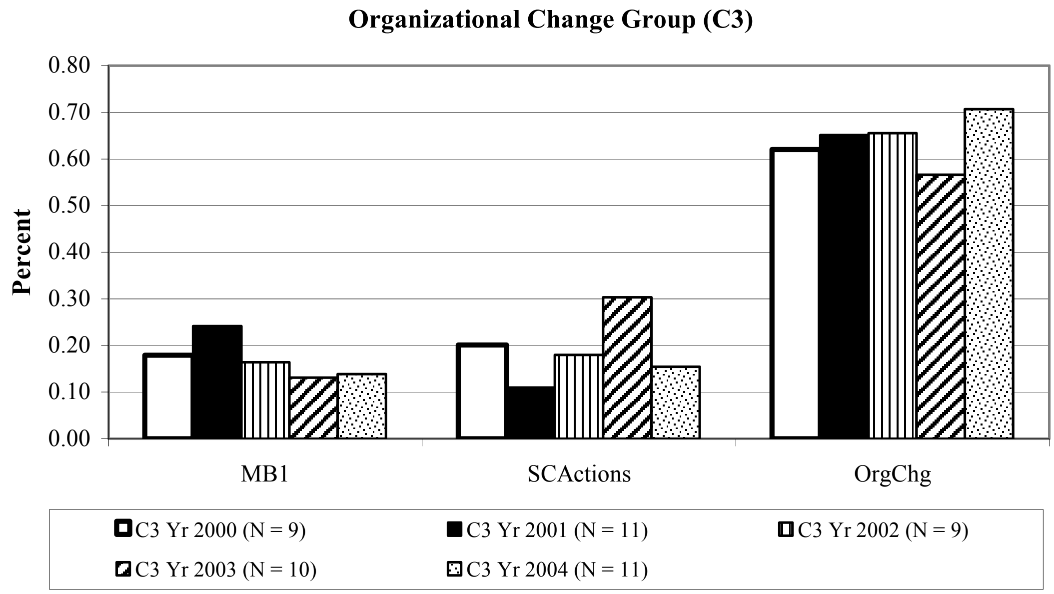


Figure 16. Analysis C: Organizational Change Group

7.3. Discussion

This study examined the relationship between firm performance and the competitive and non-competitive activities of the firm using the Schumpeterian perspective that firm action creates a rivalrous environment. The study examined 170,295 market-based and supply chain actions for 1,163 firms (parent corporations or wholly-owned firms) documented in 33,000 articles over a five year period. The results of the hypotheses testing are summarized in table 33.

Table 33. Summary of Results

	GROWTH	ROE
Total SC Actions	H1a: Supported	H1b: Not Supported
Total MB Actions	H1c: Supported	H1d: Not Supported
SC Diversity	H2a: Opposite of Hypothesized Direction	H2b: Not Supported
MB x SC	H3a: Not Supported	H3b: Not Supported

With respect to competitive actions, the results were largely consistent with the previous research; grocery firms realized a higher growth in sales when engaged in a larger number of market-based actions such as pricing, promotional, and marketing activities. These benefits accrued even when factors such as firm size and market concentration were taken into account. Additionally, a new category of action was introduced in this study as a determinant of firm performance—supply chain actions. The impact of supply chain activities on operational performance objectives has been studied in the extant literature. Studies investigating the impact on financial performance, however, are often limited to survey-based data and do not consider other factors, such as market-based activities, that may account for performance gains. These limitations were addressed in this study using secondary data and market-related performance factors, finding that firms in the grocery industry did realize a higher growth in sales when engaged in a higher number of supply chain actions. The results suggest that supply chain activities provide financial performance benefits in addition to the operational benefits often associated with supply chain management.

Supply chain diversity was shown to be a liability in the grocery industry with higher levels of diversity resulting in negative sales growth. Because some supply chain activities require considerable capital investment, a few well chosen supply chain activities might be the best way to expend limited resources in the grocery industry.

The exploratory study provided insight to the different strategies firms employed in the grocery industry. With respect to market-based actions, the results of the exploratory study were consistent with the regression analysis. Firms employing a competitive strategy focused on market-related activities realized higher than average sales growth. When market-based actions were coupled with supply chain actions in a balanced strategy, however, the higher-than-average performance benefit vanished. While there was no clear competitive advantage to supply chain-only or balanced strategies as a group, these firms did realize average levels of sales growth compared to all firms in the dataset. This was not necessarily inconsistent with the regression analysis. The positive relationship between supply chain actions and sales growth found in the regression analysis captured the marginal contribution of the total number of actions. This is not to say that those same firms did not also engage in market-based activities. On the other hand, the cluster analysis considered only the portfolio of actions, not the magnitude of actions.

The exploratory study found that large and mid-sized firms employed different strategies in order to compete effectively in the marketplace. Large firms, with greater access to resources, focused on market-related strategies and were engaged in more organizational change actions. Mid-sized firms tended to compete effectively by focusing on supply chain-only or balanced strategies.

7.4. Future Research

Considering the 10 disaggregated action categories were useful in the exploratory study, a natural extension to the research is a more rigorous analysis of the 10 action categories using the panel data statistical techniques. This might help to understand whether the relationship between supply chain actions and performance differs depending on the type of action, specifically internal and external actions. It might also help explain the negative relationship between supply chain diversity and sales growth. Furthermore, the exploratory study might provide the foundation to examine specific interactions among the disaggregated actions. For example, organizational change and marketing actions describe the firms in group B2 (see figure 9). It would be interesting to examine how the interaction of organizational change and marketing actions compares with marketing-dominated strategies (e.g., group B4, figure 9). Furthermore, firms that emphasized marketing actions also committed some of their resources to material flow activities.

Another consideration not examined in this study was the lagged relationship between supply chain actions and performance or sales growth. In this study both types of actions, market-based and supply chain, were considered to affect performance in the next time period. Specifically, actions in year t were hypothesized to impact performance in year $t + 1$. However, many supply chain actions require significant capital expenditures which might lengthen the payback period. Thus, efficiency gains accrued through supply chain management programs may not translate into immediate performance benefits. Future research should then consider longer time lags between supply chain actions and performance, particularly profitability.

7.5. Limitations

There were several limitations in this study which should be noted. This study used a structured content method which relied heavily on electronic search and did not independently code each article. Thus, while it is possible that a documented action was mis-represented in this process, the consistency of the coding was considered very high due to the expert indexing practices of Thomson Gale. Furthermore, reliance on an external coding schema helped to reduce researcher bias.

Variable measurement might also limit the results of this study. The percent change in sales as the dependent variable is a viable growth measure, but in this sample it had much less variability than the absolute change in sales. To mitigate the affect of firm size on the absolute change in sales, control variables were added. An alternate approach, not investigated, might be to standardize all variables with respect to firm size, thereby eliminating the need for size-related control variables. Finally, some variables were highly correlated, such as market-based and supply chain actions. While multi-collinearity did not appear to be a problem when examining the variance inflation factors, the high correlation might imply the measurement of some common firm characteristic. However, theoretical distinctions between market-based and supply chain activities remain with the former aimed at capturing customers and the latter geared toward cost-saving and efficiency goals, at least in the short term.

The small sample of firms with financial performance data severely limited this study in terms of the impact of market-based and supply chain actions on profitability. While profitability is also a function of cost, the inclusion of cost-related factors, such as the cost of goods sold, did not change the results of the analysis. Nevertheless, greater effort is needed to increase the number of firms with financial performance data and to perhaps respecify the model in terms of inclusive variables or variable measurement.

Appendices

Appendix 1. Derivation of Full (R, T) Policy

The total cost equation for the Full (R, T) policy is given in equation (5) and rewritten in this appendix for clarity as equation (25).

$$\begin{aligned} TC(T) &= \sum P_i D_i + G_k \sum D_i + \frac{C+nc}{T} + \frac{TF}{2}\sum\left(P_i + G_k\right)D_i \\ &\quad + F\sum\left(P_i + G_k\right)S_i + \frac{\sum K_i E\left[X_i > R_i\right]}{T} \end{aligned} \tag{25}$$

The order interval, T_{Full}, in equation (26) is found by setting equal to zero the first derivative of the total cost function with respect to T, as shown below, and solving for T, where safety stock, $S_i = R_i - \hat{X}_{(i)T+L}$.

$$\frac{\partial}{\partial T} TC(T) = \frac{\partial}{\partial T}\begin{bmatrix} \sum P_i D_i + G_k \sum D_i + \frac{C+nc}{T} + \frac{TF}{2}\sum\left(P_i + G_k\right)D_i \\ +F\sum\left(P_i + G_k\right)S_i + \frac{\sum K_i E\left[X_i > R_i\right]}{T} \end{bmatrix}$$

$$\begin{aligned} \frac{\partial}{\partial T} TC(T) &= \frac{\partial}{\partial T}\frac{1}{T}\left(C + nc + \sum K_i E\left[X_i > R_i\right]\right) + \frac{\partial}{\partial T}\frac{TF}{2}\sum\left(P_i + G_k\right)D_i \\ &\quad + \frac{\partial}{\partial T} F\sum\left(P_i + G_k\right)\left(R_i - \overline{LX}_i - T\overline{X}_i\right) \end{aligned}$$

$$\frac{\partial}{\partial T} TC(T) = -\frac{1}{T^2}\left(C + nc + \sum K_i E\left[X_i > R_i\right]\right) + \frac{F}{2}\sum\left(P_i + G_k\right)D_i - F\sum\left(P_i + G_k\right)\overline{X}_i$$

$$0 = -\frac{1}{T^2}\left(C + nc + \sum K_i E\left[X_i > R_i\right]\right) + \frac{F}{2}\sum\left(P_i + G_k\right)D_i - F\sum\left(P_i + G_k\right)\overline{X}_i$$

$$\frac{2}{T^2}\left(C + nc + \sum K_i E\left[X_i > R_i\right]\right) = F\sum\left(P_i + G_k\right)D_i - 2F\sum\left(P_i + G_k\right)\overline{X}_i$$

$$T_{Full}^2 = \frac{2\left(C + nc + \sum K_i E\left[X_i > R_i\right]\right)}{F\sum\left(P_i + G_k\right)D_i - 2F\sum\left(P_i + G_k\right)\overline{X}_i}$$

$$T_{FULL} = \sqrt{\frac{2\left(C + nc + \sum K_i E\left[X_i > R_i\right]\right)}{F\sum\left(P_i + G_k\right)D_i - 2F\sum\left(P_i + G_k\right)\bar{X}_i}} \tag{26}$$

The probability of a stockout for each item, *i*, is found by taking the first derivative of the cost function for safety stock in equation (25) with respect to the base stock level, R_i, as shown below.

$$P\left(X_i > R_i\right) = \tfrac{\partial}{\partial R_i} TC\left(S_i\right)$$

$$\tfrac{\partial}{\partial R_i} TC\left(S_i\right) = \tfrac{\partial}{\partial R_i}\left[F\left(P_i + G_k\right)S_i + \frac{K_i E\left[X_i > R_i\right]}{T}\right]$$

$$\tfrac{\partial}{\partial R_i} TC\left(S_i\right) = \tfrac{\partial}{\partial R_i} F\left(P_i + G_k\right)\left(R_i - \hat{X}_{(i)T+L}\right) + \tfrac{\partial}{\partial R_i}\tfrac{K_i E\left[X_i > R_i\right]}{T}$$

$$0 = F\left(P_i + G_k\right) - \tfrac{K_i}{T} P\left(X_i > R_i\right)$$

$$\tfrac{K_i}{T} P\left(X_i > R_i\right) = F\left(P_i + G_k\right)$$

$$P\left(X_i > R_i\right) = \frac{TF\left(P_i + G_k\right)}{K_i} \tag{27}$$

Appendix 2. Comparing Models: Full (R, T) and Truck (R, T) Policies

The total cost functions for the Full (R, T) policy, equation (5), and the Truck (R, T) heuristic, equation (10), differ only in their transportation rates. The Full policy uses the unit shipping rate, G_k, from equation (4), corresponding to the shipping quantity, $Q_k = T_{Full} \sum D_i$. In the Truck heuristic, the truckload unit shipping rate, G_0, is used, corresponding to a shipment size equal to the truck capacity, Q_t. By redefining the transportation function, G_k, it can be shown that the Truck (R, T) heuristic is simply a special case of the Full (R, T) policy.

The transportation function for G_k can be redefined by first noting that the unit transportation rate varies from the minimum TL rate, G_0, to the maximum LTL rate, G_1, such that $G_0 \le G_k \le G_1$. Let, J_k be the additional cost in transportation (per shipment) associated with shipping quantity Q_k at a rate other than the TL rate, G_0. This can be written as, $J_k = Q_k \left(G_k - G_0 \right)$. For example, if the shipping quantity is 850 units, the appropriate shipping rate from table 3 is $G_2 = \left(\frac{Q_t}{Q} \right) G_0 = \left(\frac{1000}{850} \right) 3.00$, where $G_2 = \$3.529 / unit$. The actual shipment cost for 850 units is $\left(850\right) G_2 =$ $\$3,000$. However, if the 850 units could have been shipped at the lower TL rate, the total shipment would have cost $\left(850\right) G_0 = \$2,550$. The added cost for not shipping all 850 units at the TL rate is $J_k = Q_k \left(G_k - G_0 \right) = 850\left(3.527 - 3.00\right) = \$450$, or the difference between the actual shipping cost ($3,000) and the cost had all units shipped at the TL rate ($2,550).

The transportation function, G_k, can then be rewritten in equation (28) as a function of the TL rate and an added cost per unit associated with shipping any quantity other than truck capacity.

$$G_k = G_0 + \tfrac{J_k}{Q_k} \qquad (28)$$

J_k is a maximum value at the less-than-truckload weight break and a minimum value $(J_k = 0)$ when the shipping quantity equals the full truck capacity, Q_t (or a positive integer multiple of Q_t). It is now possible to replace the transportation function, G_k, in the total cost equation of the Full (R, T) policy with equation (28), as shown below.

$$TC(T_{Full}) = \sum P_i D_i + \left(G_0 + \tfrac{J_k}{Q_k}\right)\sum D_i + \frac{C + nc}{T_{Full}} + \frac{T_{Full}F}{2}\sum\left(P_i + G_0 + \tfrac{J_k}{Q_k}\right)D_i$$
$$+ F\sum\left(P_i + G_0 + \tfrac{J_k}{Q_k}\right)S_i + \frac{\sum K_i E[X_i > R_i]}{T_{Full}}$$

Thus, when the shipping quantity, Q_k, equals truck capacity, the added shipment cost, J_k, equals zero and the total cost function for the Full (R, T) policy equals the total cost function for the Truck (R, T) heuristic.

Appendix 3. Visual Basic Module in Excel 2003

```
Option Base 1
Dim item_demand(10, 5) As Double          '[item i][1] = annual demand
                                          '[item i][2] = average daily demand (mean)
                                          '[item i][3] = stdev of daily demand (stdev)
                                          '[item i][4] = expected demand during L+T
                                          '[item i][5] = stdev of expected dmd during L+T
Dim num_items As Integer                  'Number of stock-keeping units
Dim num_factors As Integer                'Number of factors
Dim item_costs(10, 2) As Double           '[item i][1] = purchase p, item i
                                          '[item i][2] = shortage cost, item i
Dim item_levels(10, 5) As Double          '[item i][1] = Base stock level, item i
                                          '[item i][2] = safety stock level, item i
                                          '[item i][3] = probability of stockout, item i
                                          '[item i][4] = z-value, item i
                                          '[item i][5] = expected stockout quantity, item i
Dim shortage_cost(10) As Double           'array for shortage cost per unit, factor levels
Dim shortage As Double                    'assign from array for each iteration
Dim major_order_cost(3) As Double         'array for major order cost, factor levels
Dim major_order As Double                 'assign from array for each iteration
Dim minor_order_cost(3) As Double         'array for minor order cost, line item cost, factor
                                          levels
Dim minor_order As Double                 'assign from array for each iteration
Dim holding_fraction(3) As Double         'array for holding fraction, factor levels
Dim holding As Double                     'assign from array for each iteration
Dim mean_lead_time As Double              'average lead time
Dim stdev_lead_time As Double             'standard deviation of lead time
Dim truck_unit_capacity As Double         'in units (Qt)
Dim TL_unit_rate As Double                'truckload transportation rate per unit
Dim LTL_unit_rate As Double               'less-than-truckload transportation rate per unit
Dim unit_shipment_rate As Double          'unit shipping rate associated with order quantity Qk
Dim order_quantity_Qk As Double           'Total order quantity, Qk
Dim annual_purchase_cost As Currency      'total annual purchase cost
Dim annual_trans_cost As Currency         'total annual cost of transportation
Dim annual_order_cost As Currency         'total annual cost of ordering
Dim annual_holding_cost_cycle As Currency 'total annual holding cost of cycle stock
Dim annual_holding_cost_safety As Currency 'total annual holding cost of safety stock
Dim annual_holding_cost_total As Currency ‘total annual holding cost:  cycle + safety stock
Dim annual_shortage_cost As Currency      'total annual shortage costs
Dim total_annual_inventory_cost As Currency 'total annual cost of inventory
Dim break1_lower, break1_upper, break2_lower, break2_upper As Double
Dim break3_lower, break3_upper, break4_lower, break4_upper As Double
Dim break5_lower, break5_upper, break6_lower, break6_upper As Double
Dim break7_lower, break7_upper, break8_lower, break8_upper As Double
Dim break9_lower, break9_upper As Double
Dim A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T As Integer    'columns
```

```
Dim factor, indexrows_a, indexrows_b, indexrows_c, indexrows_d As Integer
Dim index_i, index_j, index_k, index_p, index_l As Integer
Dim Graph_Qk As Long

Sub MainBaseModel()  'Main Program Routine                    'Sets Input Parameters and Calls
                                                              'subroutines
indexrows_a = 2                                               'initialize to 2nd row for output
indexrows_b = 2
indexrows_c = 2
indexrows_d = 2
A = 1                                                         'Set columns
B = 2
C = 3
D = 4
E = 5
F = 6
G = 7
H = 8
I = 9
J = 10
K = 11
L = 12
M = 13
N = 14
O = 15
P = 16
Q = 17
R = 18
S = 19
T = 20
num_items = Worksheets("Input Parameters").Cells(2, F).Value      'Set Number of Items
num_factors = Worksheets("Input Parameters").Cells(2, A).Value    'Set Number of Factors
rateschedule                                                  'call sub-routine to set rate
                                                              'schedule
factor = 0

For index_i = 1 To num_factors                                'set Major Order Cost
    major_order_cost(index_i) = Worksheets("Input Parameters").Cells(index_i + 1, B).Value
    major_order = major_order_cost(index_i)
    For index_j = 1 To num_factors                            'set Minor Order Cost
        minor_order_cost(index_j) = Worksheets("Input Parameters").Cells(index_j + 1, C).Value
        minor_order = minor_order_cost(index_j)
        For index_k = 1 To num_factors                        'Set Holding Fraction
            holding_fraction(index_k) = Worksheets("Input Parameters").Cells(index_k + 1,D).Value
            holding = holding_fraction(index_k)
            For index_p = 1 To num_factors                    'Set shortage unit Cost
                shortage_cost(index_p) = Worksheets("Input Parameters").Cells(index_p + 1, E).Value
                shortage = shortage_cost(index_p)
                initialize                                    'Initialize variables
```

```
            baseline                                         'Calculate BaseLine
          Next index_p                                       'Select Next Shortage Unit Cost
        Next index_k                                         'Select Next Holding Fraction
    Next index_j                                             'Select Next Minor Order Cost
Next index_i                                                 'Select Next Major Order Cost

Graph_Qk = 10                                                'graph transportation rates

For index_l = 1 To 10000
    Worksheets("Graph_Rates").Cells(index_l + 1, A).Value = Graph_Qk
    order_quantity_Qk = Graph_Qk
    unitshipmentrate 'Get unit shipping rate
    Worksheets("Graph_Rates").Cells(index_l + 1, B).Value = unit_shipment_rate
    Worksheets("Graph_Rates").Cells(index_l + 1, C).Value = Graph_Qk * unit_shipment_rate
    Graph_Qk = Graph_Qk + 10
Next index_l

End Sub

Sub initialize()                                                  'Initialize variables

Dim item As Integer

factor = factor + 1                                               'full factorial design
    Worksheets("Out_Base").Cells(factor + 1, A).Value = factor
    Worksheets("Out_Base").Cells(factor + 1, B).Value = major_order
    Worksheets("Out_Base").Cells(factor + 1, C).Value = minor_order
    Worksheets("Out_Base").Cells(factor + 1, D).Value = holding
    Worksheets("Out_Base").Cells(factor + 1, E).Value = shortage

For item = 1 To num_items                                              'fill array - attributes
    item_demand(item, 1) = Worksheets("Item Input").Cells(item + 1, B).Value   'annual demand, i
    item_demand(item, 2) = Worksheets("Item Input").Cells(item + 1, C).Value   'avg daily demand, i
    item_demand(item, 3) = Worksheets("Item Input").Cells(item + 1, D).Value   'SD daily demand, i
    item_costs(item, 1) = Worksheets("Item Input").Cells(item + 1, E).Value    'purchase price, i
    item_costs(item, 2) = shortage                                             'shortage cost, i
    'Print Current Values to Output File
        Worksheets("Out_Base_Item").Cells(indexrows_a, A).Value = factor
        Worksheets("Out_Base_Item").Cells(indexrows_a, B).Value = item
        Worksheets("Out_Base_Item").Cells(indexrows_a, C).Value = item_demand(item, 1)
        Worksheets("Out_Base_Item").Cells(indexrows_a, D).Value = item_demand(item, 2)
        Worksheets("Out_Base_Item").Cells(indexrows_a, E).Value = item_demand(item, 3)
        Worksheets("Out_Base_Item").Cells(indexrows_a, F).Value = item_costs(item, 1)
        Worksheets("Out_Base_Item").Cells(indexrows_a, G).Value = item_costs(item, 2)
    indexrows_a = indexrows_a + 1
Next item
```

```
mean_lead_time = Worksheets("Input Parameters").Cells(2, G).Value
stdev_lead_time = Worksheets("Input Parameters").Cells(2, H).Value
annual_purchase_cost = 0                                  'initialize
annual_trans_cost = 0                                     'initialize
annual_order_cost = 0                                     'initialize
annual_holding_cost_cycle = 0                             'initialize
annual_holding_cost_safety = 0                            'initialize
annual_shortage_cost = 0                                  'initialize
total_annual_inventory_cost = 0                           'initialize

End Sub

Sub baseline()                          'Calculate Order Interval for Baseline Model

Dim index_r, index_s As Integer
Dim PtimesD As Double
Dim SumPtimesD As Double
Dim PplusG As Double
Dim PplusGtimesD As Double
Dim numerator As Double
Dim denominator As Double
Dim order_interval As Double
Dim t_days As Double
Dim order_cycles As Double
Dim total_annual_demand As Double
Dim holding_safetystock As Double
Dim total_shortage_cost As Double
Dim safetystock As Double
Dim term_a, term_b, term_c, term_d, term_e As Double
holding_safetystock = 0                 'initialize
total_annual_demand = 0                 'initialize
total_shortage_cost = 0                 'initialize

For index_r = 1 To num_items
    total_annual_demand = total_annual_demand + item_demand(index_r, 1)
    PtimesD = item_costs(index_r, 1) * item_demand(index_r, 1)
    Worksheets("Out_Base_Item").Cells(indexrows_b, H).Value = PtimesD
    SumPtimesD = SumPtimesD + PtimesD
    indexrows_b = indexrows_b + 1
Next index_r

numerator = 2 * (major_order + num_items * minor_order)
denominator = holding * SumPtimesD
order_interval = Sqr(numerator / denominator)
t_days = order_interval * 365
order_cycles = 1 / order_interval
```

```
Worksheets("Out_Base").Cells(indexrows_d, F).Value = numerator
Worksheets("Out_Base").Cells(indexrows_d, G).Value = denominator
Worksheets("Out_Base").Cells(indexrows_d, H).Value = order_interval
Worksheets("Out_Base").Cells(indexrows_d, I).Value = t_days
Worksheets("Out_Base").Cells(indexrows_d, J).Value = order_cycles

'Calculate Order Qty, Safety Stock, and Expected Stockout
   order_quantity_Qk = order_interval * total_annual_demand
   order_quantity_Qk = Round(order_quantity_Qk, 0)
   Worksheets("Out_Base").Cells(indexrows_d, K).Value = order_quantity_Qk
   unitshipmentrate                                    'Determine unit shipping rate
   Worksheets("Out_Base").Cells(indexrows_d, L).Value = unit_shipment_rate

For index_s = 1 To num_items
   ' Calculate expected and Stdev of demand during L+T
      term_a = mean_lead_time * item_demand(index_s, 2)               ' L × X̄_i
      term_b = order_interval * 365 * item_demand(index_s, 2)         ' T × X̄_i
      item_demand(index_s, 4) = term_a + term_b                       ' X̂_(i)T+L
      Worksheets("Out_Base_Item").Cells(indexrows_c, I).Value =_
                        item_demand(index_s, 4)
      term_c = mean_lead_time * item_demand(index_s, 3) ^ 2           ' L × σ²_Xi
      term_d = order_interval * 365 * item_demand(index_s, 3) ^ 2     ' T × σ²_Xi
      term_e = item_demand(index_s, 2) ^ 2 * stdev_lead_time ^ 2      ' X̄_i² × σ_L²
      item_demand(index_s, 5) = Sqr(term_c + term_d + term_e)         ' σ_(i)L+T
      Worksheets("Out_Base_Item").Cells(indexrows_c, J).Value =item_demand(index_s, 5)
   'Calculate Safety Stock, stockout probability and Stockout quantity
      item_levels(index_s, 3) = (order_interval * holding *_          ' P(X_i>R_i)
                        item_costs(index_s, 1)) / item_costs(index_s, 2)
      If item_levels(index_s, 3) >= 1 Then item_levels(index_s, 3) = 0.99999
      Worksheets("Out_Base_Item").Cells(indexrows_c, K).Value = item_levels(index_s, 3)
      Worksheets("Out_Base_Item").Cells(indexrows_c, L).FormulaR1C1 =_
                        "=norminv(1-RC[-1],0,1)"
      item_levels(index_s, 4) = Worksheets("Out_Base_Item")._          ' Z_i
                        Cells(indexrows_c, L).Value
      item_levels(index_s, 2) = item_levels(index_s, 4) *_            ' Safety Stock = Z_i σ_(i)L+T
                        item_demand(index_s, 5)
      safetystock = item_levels(index_s, 2)
      If item_levels(index_s, 2) < 0 Then item_levels(index_s, 2) = 0
      Worksheets("Out_Base_Item").Cells(indexrows_c, M).Value = item_levels(index_s, 2)
      holding_safetystock = holding_safetystock + holding *_
                        item_costs(index_s, 1) * item_levels(index_s, 2)
      item_levels(index_s, 1) = item_demand(index_s, 4) + safetystock   'Base stock level, R_i
```

```
        Worksheets("Out_Base_Item").Cells(indexrows_c, N).Value = item_levels(index_s, 1)
        Worksheets("Out_Base_Item").Cells(indexrows_c, O).FormulaR1C1 = _
                    "=RC[-5]*(NORMDIST(RC[-3],0,1,0)-RC[-3]*_
                    (1-NORMDIST(RC[-3],0,1,1)))"
        item_levels(index_s, 5) = Worksheets("Out_Base_Item")._        'E[X_i>R_i]
                    Cells(indexrows_c, O).Value
        total_shortage_cost = total_shortage_cost + item_costs(index_s, 2) *_
                    item_levels(index_s, 5)
    indexrows_c = indexrows_c + 1
Next index_s

'Calculate Costs
    annual_purchase_cost = SumPtimesD
    annual_trans_cost = unit_shipment_rate * total_annual_demand
    annual_order_cost = (major_order + num_items * minor_order) / order_interval
    annual_holding_cost_cycle = 0.5 * order_interval * holding * SumPtimesD
    annual_holding_cost_safety = holding_safetystock
    annual_shortage_cost = total_shortage_cost / order_interval
    total_annual_inventory_cost = annual_purchase_cost + annual_trans_cost + annual_order_cost _
                    + annual_holding_cost_cycle + annual_holding_cost_safety _
                    + annual_shortage_cost

    Worksheets("Out_Base").Cells(indexrows_d, M).Value = annual_purchase_cost
    Worksheets("Out_Base").Cells(indexrows_d, N).Value = annual_trans_cost
    Worksheets("Out_Base").Cells(indexrows_d, O).Value = annual_order_cost
    Worksheets("Out_Base").Cells(indexrows_d, P).Value = annual_holding_cost_cycle
    Worksheets("Out_Base").Cells(indexrows_d, Q).Value = annual_holding_cost_safety
    Worksheets("Out_Base").Cells(indexrows_d, R).Value = annual_holding_cost_cycle_
                    + annual_holding_cost_safety
    Worksheets("Out_Base").Cells(indexrows_d, S).Value = annual_shortage_cost
    Worksheets("Out_Base").Cells(indexrows_d, T).Value = total_annual_inventory_cost
    indexrows_d = indexrows_d + 1
End Sub

Sub MainBaseActualModel()                    'Main Program Routine

indexrows_a = 2                    'initialize rows to row 2 for output
indexrows_b = 2
indexrows_c = 2
indexrows_d = 2
A = 1                    'Set columns
B = 2
C = 3
D = 4
E = 5
F = 6
G = 7
H = 8
I = 9
```

```
J = 10
K = 11
L = 12
M = 13
N = 14
O = 15
P = 16
Q = 17
R = 18
S = 19
T = 20
U = 21
V = 22
W = 23
X = 24
num_items = Worksheets("Input Parameters").Cells(2, F).Value        'Set Number of Items
num_factors = Worksheets("Input Parameters").Cells(2, A).Value      'Set Number of Factors
rateschedule                                                        'set Rate Schedule
factor = 0

 For index_i = 1 To num_factors                                     'set Major Order Cost
    major_order_cost(index_i) = Worksheets("Input Parameters").Cells(index_i + 1, B).Value
    major_order = major_order_cost(index_i)
    For index_j = 1 To num_factors                                  'set Minor Order Cost
        minor_order_cost(index_j) = Worksheets("Input Parameters").Cells(index_j + 1, C).Value
        minor_order = minor_order_cost(index_j)
        For index_k = 1 To num_factors                              'Set Holding Fraction
            holding_fraction(index_k) = Worksheets("Input Parameters").Cells(index_k + 1, D).Value
            holding = holding_fraction(index_k)
            For index_p = 1 To num_factors                          'Set shortage unit Cost
                shortage_cost(index_p) = Worksheets("Input Parameters").Cells(index_p + 1, E).Value
                shortage = shortage_cost(index_p)
                initialize                                          'Initialize variables
                baselineactual                                      'adj holding costs (P+Gk)
            Next index_p                                            'Select Next Shortage Unit Cost
        Next index_k                                                'Select Next Holding Fraction
    Next index_j                                                    'Select Next Minor Order Cost
Next index_i                                                        'Select Next Major Order Cost
End Sub

Sub initialize()                                                    'Initialize variables

Dim item As Integer

factor = factor + 1                                                 'full factorial design
Worksheets("Out_BaseActual").Cells(factor + 1, A).Value = factor
Worksheets("Out_BaseActual").Cells(factor + 1, B).Value = major_order
Worksheets("Out_BaseActual").Cells(factor + 1, C).Value = minor_order
Worksheets("Out_BaseActual").Cells(factor + 1, D).Value = holding
Worksheets("Out_BaseActual").Cells(factor + 1, E).Value = shortage
```

```
For item = 1 To num_items                                                   'fill array attributes
    item_demand(item, 1) = Worksheets("Item Input").Cells(item + 1, B).Value  'annual demand, i
    item_demand(item, 2) = Worksheets("Item Input").Cells(item + 1, C).Value  'avg daily demand,  i
    item_demand(item, 3) = Worksheets("Item Input").Cells(item + 1, D).Value  'sd daily demand, i
    item_costs(item, 1) = Worksheets("Item Input").Cells(item + 1, E).Value   'purchase price, i
    item_costs(item, 2) = shortage                                            'shortage cost, i
    'Print Current Values to Output File
        Worksheets("Out_BaseActual_Item").Cells(indexrows_a, A).Value = factor
        Worksheets("Out_BaseActual_Item").Cells(indexrows_a, B).Value = item
        Worksheets("Out_BaseActual_Item").Cells(indexrows_a, C).Value = item_demand(item, 1)
        Worksheets("Out_BaseActual_Item").Cells(indexrows_a, D).Value = item_demand(item, 2)
        Worksheets("Out_BaseActual_Item").Cells(indexrows_a, E).Value = item_demand(item, 3)
        Worksheets("Out_BaseActual_Item").Cells(indexrows_a, F).Value = item_costs(item, 1)
        Worksheets("Out_BaseActual_Item").Cells(indexrows_a, G).Value = item_costs(item, 2)
    indexrows_a = indexrows_a + 1
Next item

mean_lead_time = Worksheets("Input Parameters").Cells(2, G).Value
stdev_lead_time = Worksheets("Input Parameters").Cells(2, H).Value
annual_purchase_cost = 0                    'total annual purchase cost
annual_trans_cost = 0                       'total annual cost of transportation
annual_order_cost = 0                       'total annual cost of ordering
annual_holding_cost_cycle = 0               'total annual holding cost cycle stock
annual_holding_cost_safety = 0              'total annual holding cost safety stock
annual_shortage_cost = 0                    'total annual shortage costs
total_annual_inventory_cost = 0             'total annual cost of inventory

End Sub

Sub baselineactual()          'Calculate Order Interval for Baseline Model with true holding costs

Dim index_r, index_s As Integer
Dim PtimesD As Double
Dim SumPtimesD As Double
Dim PplusG As Double
Dim PplusGtimesD As Double
Dim SumPplusGtimesD As Double
Dim numerator As Double
Dim denominator As Double
Dim order_interval As Double
Dim t_days As Double
Dim order_cycles As Double
Dim total_annual_demand As Double
Dim holding_safetystock As Double
Dim total_shortage_cost As Double
Dim safetystock As Double
Dim term_a, term_b, term_c, term_d, term_e As Double
```

```
holding_safetystock = 0                          'initialize
total_annual_demand = 0                          'initialize
total_shortage_cost = 0                          'initialize
PplusGtimesD = 0                                 'initialize
SumPplusGtimesD = 0                              'initialize

For index_r = 1 To num_items                     'Calculate T based on input parameters
   total_annual_demand = total_annual_demand + item_demand(index_r, 1)
   PtimesD = item_costs(index_r, 1) * item_demand(index_r, 1)
   Worksheets("Out_BaseActual_Item").Cells(indexrows_b, H).Value = PtimesD
   SumPtimesD = SumPtimesD + PtimesD
   indexrows_b = indexrows_b + 1
Next index_r

numerator = 2 * (major_order + num_items * minor_order)
denominator = holding * SumPtimesD
order_interval = Sqr(numerator / denominator)
t_days = order_interval * 365
order_cycles = 1 / order_interval
Worksheets("Out_BaseActual").Cells(indexrows_d, F).Value = numerator
Worksheets("Out_BaseActual").Cells(indexrows_d, G).Value = denominator
Worksheets("Out_BaseActual").Cells(indexrows_d, H).Value = order_interval
Worksheets("Out_BaseActual").Cells(indexrows_d, I).Value = t_days
Worksheets("Out_BaseActual").Cells(indexrows_d, J).Value = order_cycles
'Calculate Order Qty, Safety Stock, and Expected Stockout

  order_quantity_Qk = order_interval * total_annual_demand
  order_quantity_Qk = Round(order_quantity_Qk, 0)
  Worksheets("Out_BaseActual").Cells(indexrows_d, K).Value = order_quantity_Qk
  unitshipmentrate                               'Determine unit shipping rate
  Worksheets("Out_BaseActual").Cells(indexrows_d, L).Value = unit_shipment_rate

For index_s = 1 To num_items
  ' Calculate expected and Stdev of demand during L+T
  term_a = mean_lead_time * item_demand(index_s, 2)                 ' L × X̄_i
  term_b = order_interval * 365 * item_demand(index_s, 2)           ' T × X̄_i
  item_demand(index_s, 4) = term_a + term_b                         ' X̂_(i)T+L
  Worksheets("Out_BaseActual_Item").Cells(indexrows_c, I).Value = item_demand(index_s, 4)
  term_c = mean_lead_time * item_demand(index_s, 3) ^ 2             ' L × σ²_Xi
  term_d = order_interval * 365 * item_demand(index_s, 3) ^ 2       ' T × σ²_Xi
  term_e = item_demand(index_s, 2) ^ 2 * stdev_lead_time ^ 2        ' X̄_i² × σ_L²
  item_demand(index_s, 5) = Sqr(term_c + term_d + term_e)           ' σ_(i)L+T
  Worksheets("Out_BaseActual_Item").Cells(indexrows_c, J).Value = item_demand(index_s, 5)
```

```
    'Calculate Safety Stock, stockout probability and Stockout quantity
    item_levels(index_s, 3) = (order_interval * holding * (item_costs(index_s, 1) +_     ' P(Xi>Ri)
                              unit_shipment_rate)) / item_costs(index_s, 2)
    If item_levels(index_s, 3) >= 1 Then item_levels(index_s, 3) = 0.99999
    Worksheets("Out_BaseActual_Item").Cells(indexrows_c, K).Value = item_levels(index_s, 3)
    Worksheets("Out_BaseActual_Item").Cells(indexrows_c, L).FormulaR1C1 =_
                              "=norminv(1-RC[-1],0,1)"
    item_levels(index_s, 4) = Worksheets("Out_BaseActual_Item")._         ' Zi
                              Cells(indexrows_c, L).Value
    item_levels(index_s, 2) = item_levels(index_s, 4) * _                  ' Safety Stock = Zi σ(i)L+T
    item_demand(index_s, 5)
    safetystock = item_levels(index_s, 2)
    If item_levels(index_s, 2) < 0 Then item_levels(index_s, 2) = 0
    Worksheets("Out_BaseActual_Item").Cells(indexrows_c, M).Value = item_levels(index_s, 2)
    holding_safetystock = holding_safetystock + holding * (item_costs(index_s, 1) +_
                              unit_shipment_rate) * item_levels(index_s, 2)
    item_levels(index_s, 1) = item_demand(index_s, 4) + safetystock         'Base stock level, Ri
    Worksheets("Out_BaseActual_Item").Cells(indexrows_c, N).Value = item_levels(index_s, 1)
    Worksheets("Out_BaseActual_Item").Cells(indexrows_c, O).FormulaR1C1 = _
                              "=RC[-5]*(NORMDIST(RC[-3],0,1,0)-RC[-3]*_
                              (1-NORMDIST(RC[-3],0,1,1)))"
    item_levels(index_s, 5) = Worksheets("Out_BaseActual_Item")._         ' E[Xi>Ri]
                              Cells(indexrows_c, O).Value
    total_shortage_cost = total_shortage_cost + item_costs(index_s, 2) * item_levels(index_s, 5)

    indexrows_c = indexrows_c + 1

    PplusGtimesD = (item_costs(index_s, 1) + unit_shipment_rate) * item_demand(index_s, 1)
    SumPplusGtimesD = SumPplusGtimesD + PplusGtimesD
Next index_s

'Calculate Costs
annual_purchase_cost = SumPtimesD
annual_trans_cost = unit_shipment_rate * total_annual_demand
annual_order_cost = (major_order + num_items * minor_order) / order_interval
annual_holding_cost_cycle = 0.5 * order_interval * holding *
SumPplusGtimesD
annual_holding_cost_safety = holding_safetystock
annual_shortage_cost = total_shortage_cost / order_interval
total_annual_inventory_cost = annual_purchase_cost + annual_trans_cost + annual_order_cost _
                              + annual_holding_cost_cycle + annual_holding_cost_safety _
                              + annual_shortage_cost
Worksheets("Out_BaseActual").Cells(indexrows_d, M).Value = annual_purchase_cost
Worksheets("Out_BaseActual").Cells(indexrows_d, N).Value = annual_trans_cost
Worksheets("Out_BaseActual").Cells(indexrows_d, O).Value = annual_order_cost
Worksheets("Out_BaseActual").Cells(indexrows_d, P).Value = annual_holding_cost_cycle
Worksheets("Out_BaseActual").Cells(indexrows_d, Q).Value = annual_holding_cost_safety
Worksheets("Out_BaseActual").Cells(indexrows_d, R).Value = annual_holding_cost_cycle_
                                                      + annual_holding_cost_safety
Worksheets("Out_BaseActual").Cells(indexrows_d, S).Value = annual_shortage_cost
```

```
Worksheets("Out_BaseActual").Cells(indexrows_d, T).Value = total_annual_inventory_cost
Worksheets("Overview").Cells(indexrows_d, U).Value = t_days
Worksheets("Overview").Cells(indexrows_d, V).Value = order_quantity_Qk
Worksheets("Overview").Cells(indexrows_d, W).Value = unit_shipment_rate
Worksheets("Overview").Cells(indexrows_d, X).Value = total_annual_inventory_cost
indexrows_d = indexrows_d + 1
End Sub

Sub MainFullModel()                                              'Main Program Routine

indexrows_a = 2                                                  'initialize to row 2 for output
indexrows_b = 2
indexrows_c = 2
indexrows_d = 2
indexrows_e = 2
indexrows_f = 2
A = 1                                                            'Set columns
B = 2
C = 3
D = 4
E = 5
F = 6
G = 7
H = 8
I = 9
J = 10
K = 11
L = 12
M = 13
N = 14
O = 15
P = 16
Q = 17
R = 18
S = 19
T = 20
num_items = Worksheets("Input Parameters").Cells(2, F).Value     'Set Number of Items
num_factors = Worksheets("Input Parameters").Cells(2, A).Value   'Set Number of Factors
rateschedule                                                     'set Rate Schedule
factor = 0

 For index_i = 1 To num_factors                                  'set Major Order Cost
    major_order_cost(index_i) = Worksheets("Input Parameters").Cells(index_i + 1, B).Value
    major_order = major_order_cost(index_i)
    For index_j = 1 To num_factors                               'set Minor Order Cost
        minor_order_cost(index_j) = Worksheets("Input Parameters").Cells(index_j + 1, C).Value
        minor_order = minor_order_cost(index_j)
        For index_k = 1 To num_factors                           'Set Holding Fraction
            holding_fraction(index_k) = Worksheets("Input Parameters").Cells(index_k + 1, D).Value
            holding = holding_fraction(index_k)
```

```
            For index_p = 1 To num_factors                          'Set shortage unit Cost
                shortage_cost(index_p) = Worksheets("Input Parameters").Cells(index_p + 1, E).Value
                shortage = shortage_cost(index_p)
                initialize                                          'Initialize variables
                full                                                'Calculate Full Model
            Next index_p                                            'Select Next Shortage Unit Cost
        Next index_k                                                'Select Next Holding Fraction
    Next index_j                                                    'Select Next Minor Order Cost
Next index_i                                                        'Select Next Major Order Cost

End Sub

Sub initialize()                                                    'Initialize variables

Dim item As Integer
total_annual_demand = 0                                             'initialize
factor = factor + 1                                                 'full factorial design
    Worksheets("Out_Full").Cells(factor + 1, A).Value = factor
    Worksheets("Out_Full").Cells(factor + 1, B).Value = major_order
    Worksheets("Out_Full").Cells(factor + 1, C).Value = minor_order
    Worksheets("Out_Full").Cells(factor + 1, D).Value = holding
    Worksheets("Out_Full").Cells(factor + 1, E).Value = shortage

For item = 1 To num_items                                           'fill array with item attributes
    item_demand(item, 1) = Worksheets("Item Input").Cells(item + 1, B).Value    'ann dmd, item i
    item_demand(item, 2) = Worksheets("Item Input").Cells(item + 1, C).Value    'daily dmd, item i
    item_demand(item, 3) = Worksheets("Item Input").Cells(item + 1, D).Value    'sd daily dmd, i
    item_costs(item, 1) = Worksheets("Item Input").Cells(item + 1, E).Value     'purch p, item i
    item_costs(item, 2) = shortage                                              'short cost, i
    total_annual_demand = total_annual_demand + item_demand(item, 1)
    'Print Current Values to Output File
    Worksheets("Out_Full_Item").Cells(indexrows_a, A).Value = factor
    Worksheets("Out_Full_Item").Cells(indexrows_a, B).Value = item
    Worksheets("Out_Full_Item").Cells(indexrows_a, C).Value = item_demand(item, 1)
    Worksheets("Out_Full_Item").Cells(indexrows_a, D).Value = item_demand(item, 2)
    Worksheets("Out_Full_Item").Cells(indexrows_a, E).Value = item_demand(item, 3)
    Worksheets("Out_Full_Item").Cells(indexrows_a, F).Value = item_costs(item, 1)
    Worksheets("Out_Full_Item").Cells(indexrows_a, G).Value = item_costs(item, 2)
    indexrows_a = indexrows_a + 1
Next item

mean_lead_time = Worksheets("Input Parameters").Cells(2, G).Value
stdev_lead_time = Worksheets("Input Parameters").Cells(2, H).Value

annual_purchase_cost = 0                                        'total annual purchase cost
annual_trans_cost = 0                                           'total annual cost of trans
annual_order_cost = 0                                           'total annual cost of ordering
annual_holding_cost_cycle = 0                                   'total annual holding cost of cycle stock
```

```
annual_holding_cost_safety = 0                'total annual holding cost of safety stock
annual_shortage_cost = 0                      'total annual shortage costs
total_annual_inventory_cost = 0               'total annual cost of inventory

End Sub


Sub full()                                    'Calculate Order Interval for Full Model

Dim index_r, index_s, index_t As Integer
Dim t_days As Double
Dim order_cycles As Double

iterativesolution                                   'Call Sub – iterative solution for T
search                                              'Call Sub – T with MIN(Annual Cost)

t_days = optimal_order_interval * 365       'With Optimal T, Calc relevant variables
order_cycles = 1 / optimal_order_interval
unitshipmentrate                                    'Call Sub - Get unit shipping rate

'Output to worksheet
Worksheets("Out_Full").Cells(indexrows_b, F).Value = optimal_order_interval
Worksheets("Out_Full").Cells(indexrows_b, G).Value = t_days
Worksheets("Out_Full").Cells(indexrows_b, H).Value = order_cycles
Worksheets("Out_Full").Cells(indexrows_b, I).Value = order_quantity_Qk
Worksheets("Out_Full").Cells(indexrows_b, J).Value = unit_shipment_rate

calcPplusGvalues                                    'Call Subroutine
calclevels                                          'Call Subroutine
calcannualcosts                                     'Call Subroutine

For index_s = 1 To num_items
    'Output to worksheet
    Worksheets("Out_Full_Item").Cells(indexrows_c, H).Value = PplusG
    Worksheets("Out_Full_Item").Cells(indexrows_c, I).Value = item_demand(index_s, 4)
    Worksheets("Out_Full_Item").Cells(indexrows_c, J).Value = item_demand(index_s, 5)
    Worksheets("Out_Full_Item").Cells(indexrows_c, K).Value = item_levels(index_s, 3)
    Worksheets("Out_Full_Item").Cells(indexrows_c, L).Value = item_levels(index_s, 4)
    Worksheets("Out_Full_Item").Cells(indexrows_c, M).Value = item_levels(index_s, 2)
    Worksheets("Out_Full_Item").Cells(indexrows_c, N).Value = item_levels(index_s, 1)
    Worksheets("Out_Full_Item").Cells(indexrows_c, O).Value = item_levels(index_s, 5)
    indexrows_c = indexrows_c + 1
Next index_s

Worksheets("Out_Full").Cells(indexrows_b, K).Value = annual_purchase_cost
Worksheets("Out_Full").Cells(indexrows_b, L).Value = annual_trans_cost
Worksheets("Out_Full").Cells(indexrows_b, M).Value = annual_order_cost
Worksheets("Out_Full").Cells(indexrows_b, N).Value = annual_holding_cost_cycle
Worksheets("Out_Full").Cells(indexrows_b, O).Value = annual_holding_cost_safety
```

```
Worksheets("Out_Full").Cells(indexrows_b, P).Value = annual_holding_cost_cycle +_
                                                    annual_holding_cost_safety
Worksheets("Out_Full").Cells(indexrows_b, Q).Value = annual_shortage_cost
Worksheets("Out_Full").Cells(indexrows_b, R).Value = total_annual_inventory_cost
Worksheets("Overview").Cells(indexrows_b, M).Value = t_days
Worksheets("Overview").Cells(indexrows_b, N).Value = order_quantity_Qk
Worksheets("Overview").Cells(indexrows_b, O).Value = unit_shipment_rate
Worksheets("Overview").Cells(indexrows_b, P).Value = total_annual_inventory_cost
indexrows_b = indexrows_b + 1

End Sub

Sub iterativesolution()

Dim numerator As Double
Dim denominator As Double
Dim iterations As Long
Dim new_order_interval As Double
Dim T_interval(50000) As Double
total_shortage_cost = 0                              'initialize
iterations = 2
T_interval(1) = 0
T_interval(2) = 0.02                                 'starting point for iterative solution

Do Until Round(T_interval(iterations), 5) = Round(T_interval(iterations - 1), 5)
    'Iterative solution for Order Interval
    order_quantity_Qk = T_interval(iterations) * total_annual_demand
    order_quantity_Qk = Round(order_quantity_Qk, 0)
    unitshipmentrate                                 'Determine unit shipping rate
    calcPplusGvalues                                 'Call sub for calculations
    'Calculate New Order Interval
    numerator = 2 * (major_order + num_items * minor_order + total_shortage_cost)
    denominator = (holding * SumPplusGtimesD) - (2 * holding * SumPplusGtimesdailydemand)
    new_order_interval = Sqr(numerator / denominator)
    'Call sub to calculate item levels
    current_order_interval = new_order_interval      'set order interval for sub routines
    calclevels
    iterations = iterations + 1                      'Next iteration
    T_interval(iterations) = new_order_interval
Loop

current_order_interval = new_order_interval
calcannualcosts                                      'Calculate Costs

End Sub

Sub search()                    'Using current_order_interval return the optimal_order_interval
```

```
Dim index As Integer
Dim total_cost(100000) As Double
Dim T_interval(100000) As Double
Dim Qk(100000) As Integer

index = 1
Qk(index) = Round(order_quantity_Qk, 0)
    'Set for Subroutines
    current_order_interval = Qk(index) / total_annual_demand
    order_quantity_Qk = Qk(index)
    'Call Subroutines
    unitshipmentrate
    calcPplusGvalues
    calclevels
    calcannualcosts
    'Set Total Inv Cost for Comparison
    total_cost(index) = total_annual_inventory_cost
index = index + 1                                   'increment for first comparison
   Qk(index) = Qk(index - 1) + 1
   'Set for Subroutines
   current_order_interval = Qk(index) / total_annual_demand
   order_quantity_Qk = Qk(index)
   'Call Subroutines
   unitshipmentrate
   calcPplusGvalues
   calclevels
   calcannualcosts
   'Set Total Inv Cost for Comparison
   total_cost(index) = total_annual_inventory_cost

   'local search in one direction
   If total_cost(index) < total_cost(index - 1) Then
        Do While total_cost(index) < total_cost(index - 1)
             'Increment Qk and calculate relevant variables
             index = index + 1
             Qk(index) = Qk(index - 1) + 1
             'Set for Subroutines
             current_order_interval = Qk(index) / total_annual_demand
             order_quantity_Qk = Qk(index)
             'Call Subroutines
             unitshipmentrate
             calcPplusGvalues
             calclevels
             calcannualcosts
             'Set Total Inv Cost for Comparison
             total_cost(index) = total_annual_inventory_cost
        Loop
   Else
       If total_cost(index) > total_cost(index - 1) Then
```

```
            'Reset index for search in other direction
            index = 1
            index = index + 1
            Qk(index) = Qk(index - 1) - 1                    'Search in other direction
            'Set for Subroutines
            current_order_interval = Qk(index) / total_annual_demand
            order_quantity_Qk = Qk(index)
            'Call Subroutines
            unitshipmentrate
            calcPplusGvalues
            calclevels
            calcannualcosts
            'Set Total Inv Cost for Comparison
            total_cost(index) = total_annual_inventory_cost
            'local search in other direction
            Do While total_cost(index) < total_cost(index - 1)
                index = index + 1                            'Decrement Qk & calc relevant variables
                Qk(index) = Qk(index - 1) - 1
                current_order_interval = Qk(index) / total_annual_demand
                order_quantity_Qk = Qk(index)
                unitshipmentrate                             'Call Subroutines
                calcPplusGvalues
                calclevels
                calcannualcosts
                total_cost(index) = total_annual_inventory_cost     'Set Total Inv Cost for Comparison
            Loop
        End If
    End If

    Qk_search = Qk(index - 1)
    TCost_search = total_cost(index - 1)
    searchweightbreaks                                       'compare search results w/ wt breaks
    order_quantity_Qk = Qk_search                            'Final Order Quantity & Interval
    current_order_interval = order_quantity_Qk / total_annual_demand
    optimal_order_interval = current_order_interval

End Sub

Sub searchweightbreaks()

Dim Q_break(10) As Long, index_w As Integer, total_cost(10) As Currency

Q_break(1) = break1_upper
Q_break(2) = break2_upper
Q_break(3) = break3_upper
Q_break(4) = break4_upper
Q_break(5) = break5_upper
Q_break(6) = break6_upper
Q_break(7) = break7_upper
Q_break(8) = break8_upper
```

```
Q_break(9) = break9_upper

For index_w = 1 To 9
    current_order_interval = Q_break(index_w) / total_annual_demand
    order_quantity_Qk = Q_break(index_w)
    unitshipmentrate                              'Call Subroutines
    calcPplusGvalues
    calclevels
    calcannualcosts
    total_cost(index_w) =                         'Set Total Inv Cost for Comparison
    total_annual_inventory_cost
    If total_cost(index_w) < TCost_search Then
        Qk_search = Q_break(index_w)
        TCost_search = total_cost(index_w)
    End If
Next index_w

End Sub

Sub calcPplusGvalues()

Dim index_s As Integer
SumPplusGtimesD = 0                                       'initialize
SumPplusGtimesdailydemand = 0
SumPtimesD = 0

For index_s = 1 To num_items
    PtimesD = item_costs(index_s, 1) * item_demand(index_s, 1)
    SumPtimesD = SumPtimesD + PtimesD
    PplusG = item_costs(index_s, 1) + unit_shipment_rate
    PplusGtimesD = PplusG * item_demand(index_s, 1)
    SumPplusGtimesD = SumPplusGtimesD + PplusGtimesD
    PplusGtimesdailydemand = PplusG * item_demand(index_s, 2)
    SumPplusGtimesdailydemand = SumPplusGtimesdailydemand + PplusGtimesdailydemand
Next index_s

End Sub

Sub MainTruckModel()                              'Main Program Routine
                                                  'Sets Input Parameters and Calls subroutines
indexrows_a = 2                                           'initialize to row 2 for output
indexrows_b = 2
indexrows_c = 2
A = 1                                                     'Set columns
B = 2
C = 3
D = 4
E = 5
F = 6
G = 7
```

```
H = 8
I = 9
J = 10
K = 11
L = 12
M = 13
N = 14
O = 15
P = 16
Q = 17
R = 18
S = 19
T = 20
num_items = Worksheets("Input Parameters").Cells(2, F).Value      'Set Number of Items
num_factors = Worksheets("Input Parameters").Cells(2, A).Value    'Set Number of Factors
rateschedule                                                      'Set Rate Schedule
factor = 0

For index_i = 1 To num_factors                                    'set Major Order Cost
   major_order_cost(index_i) = Worksheets("Input Parameters").Cells(index_i + 1, B).Value
   major_order = major_order_cost(index_i)
   For index_j = 1 To num_factors                                 'set Minor Order Cost
      minor_order_cost(index_j) = Worksheets("Input Parameters").Cells(index_j + 1, C).Value
      minor_order = minor_order_cost(index_j)
      For index_k = 1 To num_factors                              'Set Holding Fraction
         holding_fraction(index_k) = Worksheets("Input Parameters").Cells(index_k + 1, D).Value
         holding = holding_fraction(index_k)
         For index_p = 1 To num_factors                           'Set shortage unit Cost
            shortage_cost(index_p) = Worksheets("Input Parameters").Cells(index_p + 1, E).Value
            shortage = shortage_cost(index_p)
            initialize                                            'Initialize variables
            truck                                                 'Calculate Truck Model
         Next index_p                                             'Select Next Shortage Unit Cost
      Next index_k                                                'Select Next Holding Fraction
   Next index_j                                                   'Select Next Minor Order Cost
Next index_i                                                      'Select Next Major Order Cost

End Sub
Public Sub initialize()                                           'Initialize variables
Dim item As Integer
factor = factor + 1                                               'full factorial design
    Worksheets("Out_Truck").Cells(factor + 1, A).Value = factor
    Worksheets("Out_Truck").Cells(factor + 1, B).Value = major_order
    Worksheets("Out_Truck").Cells(factor + 1, C).Value = minor_order
    Worksheets("Out_Truck").Cells(factor + 1, D).Value = holding
    Worksheets("Out_Truck").Cells(factor + 1, E).Value = shortage

For item = 1 To num_items                                         'fill array with item attributes
   item_demand(item, 1) = Worksheets("Item Input")._              'assign annual demand, item i
   Cells(item + 1, B).Value
```

```
    item_demand(item, 2) = Worksheets("Item Input")._              'assign avg daily demand, item i
    Cells(item + 1, C).Value
    item_demand(item, 3) = Worksheets("Item Input")._              'assign sd daily demand, item i
    Cells(item + 1, D).Value
    item_costs(item, 1) = Worksheets("Item Input")._               'assign purchase price for item i
    Cells(item + 1, E).Value
    item_costs(item, 2) = shortage                                 'assign shortage cost for item i
    'Print Current Values to Output File
    Worksheets("Out_Truck_Item").Cells(indexrows_a, A).Value = factor
    Worksheets("Out_Truck_Item").Cells(indexrows_a, B).Value = item
    Worksheets("Out_Truck_Item").Cells(indexrows_a, C).Value = item_demand(item, 1)
    Worksheets("Out_Truck_Item").Cells(indexrows_a, D).Value = item_demand(item, 2)
    Worksheets("Out_Truck_Item").Cells(indexrows_a, E).Value = item_demand(item, 3)
    Worksheets("Out_Truck_Item").Cells(indexrows_a, F).Value = item_costs(item, 1)
    Worksheets("Out_Truck_Item").Cells(indexrows_a, G).Value = item_costs(item, 2)
    indexrows_a = indexrows_a + 1
Next item

mean_lead_time = Worksheets("Input Parameters").Cells(2, G).Value
stdev_lead_time = Worksheets("Input Parameters").Cells(2, H).Value

Worksheets("Overview").Cells(factor + 1, A).Value = factor
Worksheets("Overview").Cells(factor + 1, B).Value = major_order
Worksheets("Overview").Cells(factor + 1, C).Value = minor_order
Worksheets("Overview").Cells(factor + 1, D).Value = holding
Worksheets("Overview").Cells(factor + 1, E).Value = shortage
Worksheets("Overview").Cells(factor + 1, K).Value =
mean_lead_time
Worksheets("Overview").Cells(factor + 1, L).Value =
stdev_lead_time

annual_purchase_cost = 0                        'total annual purchase cost
annual_trans_cost = 0                           'total annual cost of transportation
annual_order_cost = 0                           'total annual cost of ordering
annual_holding_cost_cycle = 0                   'total annual holding cost of cycle stock
annual_holding_cost_safety = 0                  'total annual holding cost of safety stock
annual_shortage_cost = 0                        'total annual shortage costs
total_annual_inventory_cost = 0                 'total annual cost of inventory

End Sub

Sub truck()                                'Calculate Order Interval for Truck Model

Dim order_interval As Double
Dim index_r, index_s As Integer
Dim t_days As Double
Dim order_cycles As Double
Dim PplusG As Double
Dim SumPplusGtimesD As Double
Dim SumPtimesD As Double
Dim term_a, term_b, term_c, term_d, term_e As Double
```

```
Dim total_annual_demand As Double
Dim holding_safetystock As Double
Dim total_shortage_cost As Double
Dim safetystock As Double

holding_safetystock = 0                                   'initialize
total_annual_demand = 0                                   'initialize
total_shortage_cost = 0                                   'initialize

For index_r = 1 To num_items
    total_annual_demand = total_annual_demand + item_demand(index_r, 1)
Next index_r

'Calculate order interval, order quantity, unit shipping rate
order_interval = truck_unit_capacity / total_annual_demand
t_days = order_interval * 365
order_cycles = 1 / order_interval
order_quantity_Qk = Round((order_interval *
total_annual_demand), 0)
unit_shipment_rate = TL_unit_rate

Worksheets("Out_Truck").Cells(indexrows_b, F).Value = order_interval     'Output to worksheet
Worksheets("Out_Truck").Cells(indexrows_b, G).Value = t_days
Worksheets("Out_Truck").Cells(indexrows_b, H).Value = order_cycles
Worksheets("Out_Truck").Cells(indexrows_b, I).Value = order_quantity_Qk
Worksheets("Out_Truck").Cells(indexrows_b, J).Value = unit_shipment_rate

For index_s = 1 To num_items
   'Calculate P+G0 and Sum(P+G0)*D
   PplusG = item_costs(index_s, 1) + unit_shipment_rate
   SumPtimesD = SumPtimesD + item_costs(index_s, 1) * item_demand(index_s, 1)
   SumPplusGtimesD = SumPplusGtimesD + PplusG * item_demand(index_s, 1)
        Worksheets("Out_Truck_Item").Cells(indexrows_c, H).Value = PplusG
   'Calculate expected and Stdev of demand during L+T
   term_a = mean_lead_time * item_demand(index_s, 2)              'L × X̄_i
   term_b = order_interval * 365 * item_demand(index_s, 2)        'T × X̄_i
   item_demand(index_s, 4) = term_a + term_b                      'X̂_(i)T+L
   Worksheets("Out_Truck_Item").Cells(indexrows_c, I).Value = item_demand(index_s, 4)
   term_c = mean_lead_time * item_demand(index_s, 3) ^ 2          'L × σ²_Xi
   term_d = order_interval * 365 * item_demand(index_s, 3) ^ 2    'T × σ²_Xi
   term_e = item_demand(index_s, 2) ^ 2 * stdev_lead_time ^ 2     'X̄²_i × σ²_L
   item_demand(index_s, 5) = Sqr(term_c + term_d + term_e)        'σ_(i)L+T
   Worksheets("Out_Truck_Item").Cells(indexrows_c, J).Value = item_demand(index_s, 5)
   'Calculate stockout probability, Stockout quantity, Safety Stock, and Base Stock Level
   item_levels(index_s, 3) = (order_interval * holding * PplusG)/item_costs(index_s, 2)  'P(X_i>R_i)
```

```
    If item_levels(index_s, 3) >= 1 Then item_levels(index_s, 3) = 0.99999
    Worksheets("Out_Truck_Item").Cells(indexrows_c, K).Value = item_levels(index_s, 3)
    Worksheets("Out_Truck_Item").Cells(indexrows_c, L).FormulaR1C1 _
    = "=norminv(1-RC[-1],0,1)"
    item_levels(index_s, 4) = Worksheets("Out_Truck_Item")._        ' Z_i
    Cells(indexrows_c, L).Value
    item_levels(index_s, 2) = item_levels(index_s, 4) * _           ' Safety Stock = Z_i σ_(i)L+T
    item_demand(index_s, 5)
    safetystock = item_levels(index_s, 2)
    If item_levels(index_s, 2) < 0 Then item_levels(index_s, 2) _   'Set to zero for purpose of holding
    = 0                                                               cost
    Worksheets("Out_Truck_Item").Cells(indexrows_c, M).Value = item_levels(index_s, 2)
    holding_safetystock = holding_safetystock + holding * PplusG * item_levels(index_s, 2)
    item_levels(index_s, 1) = item_demand(index_s, 4) + safetystock          'Base stock level, R_i
    Worksheets("Out_Truck_Item").Cells(indexrows_c, N).Value = item_levels(index_s, 1)
    Worksheets("Out_Truck_Item").Cells(indexrows_c, O).FormulaR1C1 = _
              "=RC[-5]*(NORMDIST(RC[-3],0,1,0)-RC[-3]*(1-NORMDIST(RC[-3],0,1,1)))"
    item_levels(index_s, 5) = Worksheets("Out_Truck_Item")._        ' E[X_i>R_i]
    Cells(indexrows_c, O).Value
    total_shortage_cost = total_shortage_cost + item_costs(index_s, 2) * item_levels(index_s, 5)
    indexrows_c = indexrows_c + 1
Next index_s

annual_purchase_cost = SumPtimesD                              'Calculate Costs
annual_trans_cost = unit_shipment_rate * total_annual_demand
annual_order_cost = (major_order + num_items * minor_order) / order_interval
annual_holding_cost_cycle = 0.5 * order_interval * holding * SumPplusGtimesD
annual_holding_cost_safety = holding_safetystock
annual_shortage_cost = total_shortage_cost / order_interval
total_annual_inventory_cost = annual_purchase_cost + annual_trans_cost + annual_order_cost _
                              + annual_holding_cost_cycle + annual_holding_cost_safety _
                              + annual_shortage_cost
Worksheets("Out_Truck").Cells(indexrows_b, K).Value = annual_purchase_cost
Worksheets("Out_Truck").Cells(indexrows_b, L).Value = annual_trans_cost
Worksheets("Out_Truck").Cells(indexrows_b, M).Value = annual_order_cost
Worksheets("Out_Truck").Cells(indexrows_b, N).Value = annual_holding_cost_cycle
Worksheets("Out_Truck").Cells(indexrows_b, O).Value = annual_holding_cost_safety
Worksheets("Out_Truck").Cells(indexrows_b, P).Value = annual_holding_cost_cycle +_
                                                      annual_holding_cost_safety
Worksheets("Out_Truck").Cells(indexrows_b, Q).Value = annual_shortage_cost
Worksheets("Out_Truck").Cells(indexrows_b, R).Value = total_annual_inventory_cost

'write key parameters to Model Comparison Overview WorkSheet
'get number items
    Worksheets("Overview").Cells(indexrows_b, F).Value = Worksheets("Input_
    Parameters").Cells(2, F).Value
'get avg item weight
     Worksheets("Overview").Cells(indexrows_b, G).Value = Worksheets("Input_
     Parameters").Cells(2, I).Value
```

```
'get TL unit rate
    Worksheets("Overview").Cells(indexrows_b, H).Value = Worksheets("Rates").Cells(2, D).Value
'get LTL unit rate
    Worksheets("Overview").Cells(indexrows_b, I).Value = Worksheets("Rates").Cells(2, E).Value
'get truck capacity
    Worksheets("Overview").Cells(indexrows_b, J).Value = Worksheets("Input _
    Parameters").Cells(2, L).Value
Worksheets("Overview").Cells(indexrows_b, Q).Value = t_days
Worksheets("Overview").Cells(indexrows_b, R).Value = order_quantity_Qk
Worksheets("Overview").Cells(indexrows_b, S).Value = unit_shipment_rate
Worksheets("Overview").Cells(indexrows_b, T).Value = total_annual_inventory_cost
indexrows_b = indexrows_b + 1

End Sub

Sub calclevels()

Dim index_t As Integer, term_a, term_b, term_c, term_d, term_e As Double, safetystock As Double
total_shortage_cost = 0                                                    'initialize
holding_safetystock = 0

For index_t = 1 To num_items
    'Calculate expected and Stdev of demand during L+T
    term_a = mean_lead_time * item_demand(index_t, 2)                      ' L × X̄_i
    term_b = current_order_interval * 365 * item_demand(index_t, 2)        ' T × X̄_i
    item_demand(index_t, 4) = term_a + term_b                              ' X̂_(i)T+L
    term_c = mean_lead_time * item_demand(index_t, 3) ^ 2                  ' L × σ²_Xi
    term_d = current_order_interval * 365 * item_demand(index_t, 3) ^2     ' T × σ²_Xi
    term_e = item_demand(index_t, 2) ^ 2 * stdev_lead_time ^ 2             ' X̄²_i × σ²_L
    item_demand(index_t, 5) = Sqr(term_c + term_d + term_e)                ' σ_(i)L+T

    'Calculate Safety Stock, stockout probability and Stockout quantity
    PplusG = item_costs(index_t, 1) + unit_shipment_rate                         ' P(X_i>R_i)
    item_levels(index_t, 3) = (current_order_interval * holding * PplusG) / item_costs(index_t, 2)
    If item_levels(index_t, 3) >= 1 Then item_levels(index_t, 3) = 0.99999
    'holding cell to calculate Z & E[X>R]
    Worksheets("Out_Full_Item").Cells(3, Q).Value = item_levels(index_t, 3)
    Worksheets("Out_Full_Item").Cells(3, R).FormulaR1C1 = "=norminv(1-RC[-1],0,1)"     ' Z_i
    item_levels(index_t, 4) = Worksheets("Out_Full_Item").Cells(3, R).Value
    item_levels(index_t, 2) = item_levels(index_t, 4) * item_demand(index_t, 5)' Safety Stock = Z_i σ_(i)L+T
    safetystock = item_levels(index_t, 2)
    If item_levels(index_t, 2) < 0 Then item_levels(index_t, 2) = 0
```

```
    holding_safetystock = holding_safetystock + holding * PplusG * item_levels(index_t, 2)
    item_levels(index_t, 1) = item_demand(index_t, 4) + safetystock          'Base stock level,  R_i
    Worksheets("Out_Full_Item").Cells(3, P).Value = item_demand(index_t, 5)      ' E[X_i>R_i]
    Worksheets("Out_Full_Item").Cells(3, S).FormulaR1C1 = _
              "=RC[-3]*(NORMDIST(RC[-1],0,1,0)-RC[-1]*(1-NORMDIST(RC[-1],0,1,1)))"
    item_levels(index_t, 5) = Worksheets("Out_Full_Item").Cells(3, S).Value
    total_shortage_cost = total_shortage_cost + item_costs(index_t, 2) * item_levels(index_t, 5)
Next index_t

End Sub

Sub calcannualcosts()

annual_purchase_cost = SumPtimesD
annual_trans_cost = unit_shipment_rate * total_annual_demand
annual_order_cost = (major_order + num_items * minor_order) / current_order_interval
annual_holding_cost_cycle = 0.5 * current_order_interval * holding * SumPplusGtimesD
annual_holding_cost_safety = holding_safetystock
annual_shortage_cost = total_shortage_cost / current_order_interval
total_annual_inventory_cost = annual_purchase_cost + annual_trans_cost + annual_order_cost _
                              + annual_holding_cost_cycle + annual_holding_cost_safety _
                              + annual_shortage_cost

End Sub

Sub rateschedule()                                 'Determine Freight Rate Schedule

Dim TL_freight_rate As Double                                        '$/cwt
Dim LTL_freight_rate As Double                                       '$/cwt
Dim truck_lbs_capacity As Double                                     'in pounds
Dim truck_cwt_capacity As Double                                     'in cwt
Dim weight_break_cwt As Double                                       'in cwt
Dim weight_break_unit  As Double                                 'in units
Dim item_weight As Double                                        'average weight of all items
                                                                 'assume items are equal
'get input values
     item_weight = Worksheets("Input Parameters").Cells(2, I).Value
     TL_freight_rate = Worksheets("Input Parameters").Cells(2, J).Value
     LTL_freight_rate = Worksheets("Input Parameters").Cells(2, K).Value
     truck_lbs_capacity = Worksheets("Input Parameters").Cells(2, L).Value

'calculate rates per unit
     TL_unit_rate = TL_freight_rate * item_weight / 100
     LTL_unit_rate = LTL_freight_rate * item_weight / 100
     Worksheets("Rates").Cells(2, 2).Value = TL_freight_rate
     Worksheets("Rates").Cells(2, 3).Value = LTL_freight_rate
     Worksheets("Rates").Cells(2, 4).Value = TL_unit_rate
     Worksheets("Rates").Cells(2, 5).Value = LTL_unit_rate
     Worksheets("Rates").Cells(4, 2).Value = truck_lbs_capacity
```

```
'calculate truck capacity and wt breaks
    truck_cwt_capacity = truck_lbs_capacity / 100                    '1cwt = 100 lbs.
    weight_break_cwt = truck_cwt_capacity * (TL_freight_rate / LTL_freight_rate)
    Worksheets("Rates").Cells(5, 2).Value = truck_cwt_capacity
    Worksheets("Rates").Cells(8, 2).Value = weight_break_cwt
    weight_break_unit = Round((weight_break_cwt * 100 / item_weight), 0)
    truck_unit_capacity = Round((truck_lbs_capacity / item_weight), 0)      'Qt
    Worksheets("Rates").Cells(6, 2).Value = truck_unit_capacity
    Worksheets("Rates").Cells(9, 2).Value = weight_break_unit

'Set upper & lower unit break points
    break1_lower = 1
    break1_upper = weight_break_unit
        Worksheets("Rates").Cells(13, 2).Value = break1_lower
        Worksheets("Rates").Cells(13, 3).Value = break1_upper
    break2_lower = break1_upper + 1
    break2_upper = truck_unit_capacity
        Worksheets("Rates").Cells(14, 2).Value = break2_lower
        Worksheets("Rates").Cells(14, 3).Value = break2_upper
    break3_lower = break2_upper + 1
    break3_upper = break2_upper + weight_break_unit
        Worksheets("Rates").Cells(15, 2).Value = break3_lower
        Worksheets("Rates").Cells(15, 3).Value = break3_upper
    break4_lower = break3_upper + 1
    break4_upper = 2 * truck_unit_capacity
        Worksheets("Rates").Cells(16, 2).Value = break4_lower
        Worksheets("Rates").Cells(16, 3).Value = break4_upper
    break5_lower = break4_upper + 1
    break5_upper = break4_upper + weight_break_unit
        Worksheets("Rates").Cells(17, 2).Value = break5_lower
        Worksheets("Rates").Cells(17, 3).Value = break5_upper
    break6_lower = break5_upper + 1
    break6_upper = 3 * truck_unit_capacity
        Worksheets("Rates").Cells(18, 2).Value = break6_lower
        Worksheets("Rates").Cells(18, 3).Value = break6_upper
    break7_lower = break6_upper + 1
    break7_upper = break6_upper + weight_break_unit
        Worksheets("Rates").Cells(19, 2).Value = break7_lower
        Worksheets("Rates").Cells(19, 3).Value = break7_upper
    break8_lower = break7_upper + 1
    break8_upper = 4 * truck_unit_capacity
        Worksheets("Rates").Cells(20, 2).Value = break8_lower
        Worksheets("Rates").Cells(20, 3).Value = break8_upper
    break9_lower = break8_upper + 1
    break9_upper = break8_upper + weight_break_unit
        Worksheets("Rates").Cells(21, 2).Value = break9_lower
        Worksheets("Rates").Cells(21, 3).Value = break9_upper

End Sub
```

```
Sub unitshipmentrate()
unit_shipment_rate = 0                                         'initialize
Select Case order_quantity_Qk                      'Select Case calculate unit shipping rate

    Case break1_lower To break1_upper
        unit_shipment_rate = LTL_unit_rate
    Case break2_lower To break2_upper
        unit_shipment_rate = (truck_unit_capacity / order_quantity_Qk) * TL_unit_rate
    Case break3_lower To break3_upper
        unit_shipment_rate = (truck_unit_capacity / order_quantity_Qk) * _
                             (TL_unit_rate - LTL_unit_rate) + LTL_unit_rate
    Case break4_lower To break4_upper
        unit_shipment_rate = 2 * (truck_unit_capacity / order_quantity_Qk) * TL_unit_rate
    Case break5_lower To break5_upper
        unit_shipment_rate = 2 * (truck_unit_capacity / order_quantity_Qk) * _
                             (TL_unit_rate - LTL_unit_rate) + LTL_unit_rate
    Case break6_lower To break6_upper
        unit_shipment_rate = 3 * (truck_unit_capacity / order_quantity_Qk) * TL_unit_rate
    Case break7_lower To break7_upper
        unit_shipment_rate = 3 * (truck_unit_capacity / order_quantity_Qk) * _
                             (TL_unit_rate - LTL_unit_rate) + LTL_unit_ rate
    Case break8_lower To break8_upper
        unit_shipment_rate = 4 * (truck_unit_capacity / order_quantity_Qk) * TL_unit_rate
    Case break9_lower To break9_upper
        unit_shipment_rate = 4 * (truck_unit_capacity / order_quantity_Qk) * _
                             (TL_unit_rate - LTL_unit_rate) + LTL_unit_rate
    Case Else
        unit_shipment_rate = 0
    End Select
End Sub
```

Appendix 4. Grocery Item Demand Characteristics

Item	Description	Mean	SD	Annual Demand	Purchase Price	Shortage Cost	Probability Distribution	MSE	χ^2	p-value	K-S	p-value
1	Silk Soy Milk Plain	9.55	3.21	3,486	2.17	0.67	NORM (9.55, 3.18)	0.017	2.600	0.467		
2	Jiffy Corn Muffin Mix	14.30	8.49	5,220	0.32	0.06	2+WEIB (13.3, 1.34)	0.009	2.580	0.284	0.077	>0.15
3	Pills Grands Golden Corn	5.84	3.04	2,132	1.23	0.39	NORM (5.84, 3.01)	0.020	4.530	0.035	0.043	>0.15
4	Hunts Spad Sce Four Cheese	8.39	4.79	3,062	0.85	0.13	NORM (8.39, 4.74)	0.013	5.750	0.059	0.136	>0.15
5	Lnl Cottage Chse Sc 1%	6.27	2.70	2,289	1.52	0.77	TRIA (2, 4.57, 14)	0.034	7.820	0.050	0.102	>0.15
6	Whiskas Temptations Seafood	5.41	2.62	1,975	1.04	0.15	2+11*BETA (0.863, 1.92)	0.013	4.280	0.127	0.155	>0.15
7	Gerber Rice Cereal	3.22	1.84	1,175	1.43	0.17	NORM (3.22, 1.82)	0.035	11.200	0.005	0.116	>0.15
8	Overlake Blueberries	10.00	4.48	3,650	1.40	0.51	2+17*BETA (1.22, 1.37)	0.017	5.960	0.120	0.065	>0.15
9	Whiskas Bits O Beef Dinner	13.50	6.51	4,928	0.51	0.08	NORM (13.5, 6.44)	0.004	0.915	0.367	0.064	>0.15
10	Fancy Feast Flaked Salm Wfish	7.41	4.48	2,705	0.40	0.03	2+EXPO(5.41)	0.014	2.770	0.250	0.133	>0.15
11	Musselman Apple Juice	14.30	11.80	5,220	1.48	0.53	3+GAMM(10.8, 1.05)	0.027	6.810	0.009	0.144	>0.15
12	Ortega Soft Taco Dinner Kit	5.31	3.40	1,938	1.84	0.59	0.999+13*BETA(0.742, 1.49)	0.007	2.250	0.524	0.139	>0.15
13	Shake Bake Chicken	7.27	3.50	2,654	1.48	0.40	NORM(7.27, 3.46)	0.019	6.880	0.009	0.113	>0.15
14	Hunt Tomato Paste	7.59	4.30	2,770	0.96	0.03	NORM(7.59, 4.25)	0.040	12.100	<0.005	0.106	>0.15
15	Combo Cheddar Cheese Pretzel	6.14	4.35	2,241	1.31	0.47	0.999+EXPO(5.14)	0.022	4.280	0.126	0.187	0.049
16	Breakstone Sour Cream	19.20	4.42	7,008	0.78	0.31	6+22*BETA(2.96, 1.99)	0.008	1.100	0.587	0.081	>0.15
17	Shurfine California Blend	10.80	4.83	3,942	0.83	0.65	NORM(10.8, 4.78)	0.011	2.500	0.122	0.119	>0.15
18	Campbell Cream Chicken Soup	15.60	7.45	5,694	0.87	0.11	3+36*BETA(1.52, 2.81)	0.005	1.170	0.565	0.070	>0.15
19	Greens Scooter Crunch	18.00	8.22	6,570	1.15	0.56	4+31*BETA(1.14, 1.38)	0.016	5.760	0.134	0.080	>0.15
20	Pedigree Choice Chkn Rice	8.41	4.21	3,070	0.56	0.09	NORM(8.41, 4.16)	0.023	5.890	0.017	0.139	>0.15
21	Shurfine Yellow Amer Cheese	25.80	18.00	9,417	1.90	0.79	5+WEIB(22.1, 1.2)	0.044	11.000	<0.005	0.178	0.075
22	Int Delite French Vanilla	11.10	4.15	4,052	1.15	0.43	4+23*BETA(1.71, 3.84)	0.009	1.560	0.224	0.152	>0.15
23	Pills Btrmlk Biscuits	7.51	3.73	2,741	1.97	0.94	NORM(7.51, 3.69)	0.011	1.640	0.215	0.088	>0.15
24	Cole Mini Garlic Bread	15.90	5.71	5,804	0.96	0.47	TRIA(7, 11.3, 27)	0.012	7.460	0.061	0.145	>0.15
25	Tetley Tea Bags Decaf	7.24	2.96	2,643	2.03	0.41	TRIA(0.999, 7.5, 14)	0.005	2.180	0.541	0.123	>0.15

Item	Description	Mean	SD	Annual Demand	Purchase Price	Shortage Cost	Probability Distribution	MSE	χ^2	p-value	K-S	p-value
26	Pillsbury Grands Flaky	7.47	3.85	2,727	0.88	0.41	NORM(7.47, 3.81)	0.038	6.850	0.009	0.081	>0.15
27	Shultz Fun Tas Stixs	7.88	3.02	2,876	0.72	0.24	TRIA(2, 6.65, 15)	0.009	2.460	0.487	0.117	>0.15
28	Breakstone Sour Cream Reg	50.10	33.10	18,287	1.31	0.47	15+EXPO(35.1)	0.002	0.314	0.600	0.211	0.019
29	Kraft Shred Mozz Cheese skim	15.80	12.70	5,767	1.83	0.76	3+LOGN(24.3, 78)	0.011	2.510	<0.005	0.194	0.038
30	Fancy Feast Tend Liver & Chkn	9.82	5.79	3,584	0.40	0.03	0.999+30*BETA(1.35, 3.23)	0.019	5.150	0.024	0.091	>0.15
31	Stouf Homestyle Chicken	4.69	2.36	1,712	3.19	1.35	NORM(4.69, 2.34)	0.063	14.600	<0.005	0.069	>0.15
32	Trop Twst Strawbery Kiwi Cycl	4.45	3.10	1,624	1.97	0.27	0.999+16*BETA(0.757, 2.75)	0.004	0.397	0.541	0.189	0.047
33	Bounty Big White Blancos	16.40	5.18	5,986	1.59	0.10	8+20*BETA(1.09, 1.53)	0.026	9.050	0.030	0.086	>0.15
34	Domino Dark Brown Sugar	8.00	6.07	2,920	0.58	0.10	2+EXPO(6)	0.008	2.380	0.322	0.107	>0.15
35	Budget Lt Spec Sel Rigat Broc	7.59	4.03	2,770	0.71	0.33	0.999+17*BETA(1.25, 1.97)	0.022	1.060	0.113	0.082	>0.15
36	Era Liq Reg Cp 16 Use	4.25	1.82	1,551	2.51	0.48	TRIA(0.999, 4.5, 8)	0.020	4.680	0.210	0.111	>0.15
37	Shake Bake Original Pork	10.90	5.03	3,979	1.48	0.41	2+25*BETA(1.66, 3)	0.011	3.350	0.203	0.086	>0.15
38	Heluva Gd French Onion Dip	4.49	2.68	1,639	2.38	0.98	0.999+8*BETA(0.521, 0.674)	0.006	2.780	0.600	0.213	0.018
39	Old El Paso Refried Beans Ff	5.20	2.76	1,898	0.95	0.22	0.999+ERLA (2.1, 2)	0.007	3.850	0.162	0.124	>0.15
40	Alpo Prime Slices W Beef	7.71	5.22	2,814	0.53	0.07	0.999+WEIB(7.13, 1.23)	0.021	5.330	0.074	0.095	>0.15
41	Fancy Feast Ocean Fish	8.75	6.10	3,194	0.40	0.03	0.999+23*BETA(0.732, 1.44)	0.004	1.500	0.688	0.151	>0.15
42	Frenchs Mustard Squeeze	10.00	4.35	3,650	0.74	0.16	2+17*BETA(1.32, 1.48)	0.013	4.470	0.225	0.080	>0.15
43	Cherry Man Maraschino Cherry	6.51	3.46	2,376	1.00	0.25	NORM(6.51, 3.43)	0.035	8.120	<0.005	0.096	>0.15
44	Fancy Feast Cod Sole Shrimp	13.20	5.83	4,818	0.40	0.03	NORM(13.2, 5.77)	0.058	11.100	<0.005	0.168	0.103
45	Black Pearl Ripe Olive Small	6.20	3.04	2,263	1.02	0.58	NORM(6.2, 3.01)	0.017	5.910	0.053	0.067	>0.15
46	Kraft Nat Mild Ched Chunk	11.00	6.03	4,015	1.70	0.75	3+ERLA(4.02, 2)	0.047	7.490	0.007	0.184	0.057
47	York Peppermint Miniatures	4.04	2.00	1,475	2.48	0.79	0.999+9*BETA(1.19, 2.34)	0.033	12.300	<0.005	0.126	>0.15
48	SF Sweet Garden Peas	8.41	4.16	3,070	0.34	0.09	NORM(8.41, 4.12)	0.011	2.940	0.090	0.091	>0.15
49	Morton Iodized Salt	9.31	3.99	3,398	0.38	0.04	3+15*BETA(1.03, 1.41)	0.001	0.306	>0.75	0.093	>0.15
50	SF Double Duos Cookies	4.59	2.60	1,675	1.61	0.57	0.999+12*BETA(1.04, 2.43)	0.031	9.270	0.010	0.126	>0.15
51	Crisco Oil	4.27	2.28	1,559	1.99	0.30	0.999+11*BETA(1.15, 2.71)	0.004	2.640	0.275	0.119	>0.15
52	Shurfine Sour Cream	24.10	7.04	8,797	0.55	0.24	TRIA(12, 19.1, 45)	0.016	4.300	0.237	0.085	>0.15
53	Pills Grands Flky Buttermilk	12.20	6.21	4,453	1.23	0.39	TRIA(0.999, 7.21, 30)	0.007	1.410	0.707	0.081	>0.15

Item	Description	Mean	SD	Annual Demand	Purchase Price	Shortage Cost	Probability Distribution	MSE	χ^2	p-value	K-S	p-value
54	Lol Whip Butter Aa Salt Bowl	7.55	2.56	2,756	1.44	0.65	3+12*BETA(1.58, 2.58)	0.011	3.060	0.227	0.134	>0.15
55	Campbell Hmstyl Chick Noodle	12.00	5.57	4,380	1.09	0.14	0.999+25*BETA(1.74, 2.22)	0.018	4.280	0.126	0.081	>0.15
56	Lipton Onion Soup Mix 2 Pk	13.50	5.09	4,928	1.10	0.26	5+WEIB(9.24, 1.49)	0.018	4.320	0.235	0.161	0.129
57	Friskies Salmon Dinner	14.10	6.54	5,147	0.33	0.04	0.999+33*BETA(2.03, 3.07)	0.004	0.647	0.445	0.088	>0.15
58	Fancy Feast Flaked Trout	13.30	6.19	4,855	0.40	0.03	4+ERLA(4.66, 2)	0.009	2.310	0.334	0.078	>0.15
59	Skippy Snk Bar Pbtr Marsh 6 P	2.80	1.47	1,022	2.21	0.52	NORM(2.8, 1.46)	0.011	3.710	0.173	0.110	>0.15
60	Welchs Strawberry Breeze Cktl	4.39	2.12	1,602	1.67	0.66	NORM(4.39, 2.1)	0.023	6.520	0.040	0.056	>0.15
61	Dannon Lacreme Straw	6.67	2.73	2,435	1.45	0.71	TRIA(0.99, 5.29, 13)	0.030	8.310	0.042	0.142	>0.15
62	Eggo Homestyle Waffles	28.40	8.10	10,366	1.35	0.53	NORM(28.4, 8.02)	0.012	4.380	0.039	0.167	0.107
63	Jello Inst Van Pudding	10.50	5.97	3,833	0.64	0.08	0.999+ERLA(4.73, 2)	0.011	2.170	0.358	0.090	>0.15
64	Clear Choice Cal Fr Peach	9.08	5.09	3,314	0.46	0.06	0.999+22*BETA(1.23, 2.12)	0.034	11.900	<0.005	0.102	>0.15
65	King Syrup Glass	8.45	3.45	3,084	1.16	0.31	TRIA(0.999, 7.35, 17)	0.013	3.150	0.387	0.080	>0.15
66	Shurfine Shredded Cheddar	39.60	22.60	14,454	1.33	0.61	13+117*BETA(0.842, 2.86)	0.017	5.280	0.023	0.126	>0.15
67	Pills H Jack Pancakes	6.00	2.68	2,190	1.46	0.66	0.999+11*BETA(1.44, 1.73)	0.013	4.560	0.218	0.105	>0.15
68	Dart Nat Plas Drink Cup 16oz	10.40	3.45	3,796	0.75	0.25	NORM(10.4, 3.41)	0.006	2.020	0.385	0.068	>0.15
69	Sf Margarine Quarters	12.80	7.55	4,672	0.46	0.22	TRIA(0.999, 8.29, 35)	0.017	3.440	0.346	0.172	0.090
70	Scott 1000 Bath Tissue Wht	6.43	2.47	2,347	3.91	0.25	TRIA(0.999, 6.29, 12)	0.031	11.600	0.009	0.092	>0.15
71	White Paper Plates 150 Ct	10.60	3.79	3,869	1.47	0.48	2+17*BETA(12.04, 1.99)	0.007	1.760	0.433	0.108	>0.15
72	Kid Cuisine Chicken Nugget	21.20	6.17	7,738	1.31	0.47	TRIA(10, 17.5, 36)	0.026	7.850	0.049	0.096	>0.15
73	Shurfine Squeeze Mustard	5.16	2.49	1,883	0.73	0.25	2+10*BETA(0.782, 1.7)	0.005	0.645	0.728	0.147	>0.15
74	Sf Orange Soda 2 Liter	5.02	2.12	1,832	0.62	0.16	UNIF(0.999, 9)	0.014	5.140	0.528	0.132	>0.15
75	Heinz Squeeze Ketchup	9.80	10.60	3,577	1.12	0.35	2+78*BETA(0.389, 3.5)	0.021	11.500	<0.005	0.436	<0.01
76	Bumble Bee Solid White Water	28.60	7.43	10,439	2.56	0.46	NORM(28.6, 7.36)	0.015	4.080	0.045	0.110	>0.15
77	Smart Balance 67% Spread Bowl	13.60	4.37	4,964	1.33	0.47	NORM(13.6, 4.33)	0.009	1.880	0.189	0.068	>0.15
78	Sf Grape Juice	7.25	4.87	2,646	2.00	0.63	2+EXPO(5.26)	0.034	5.920	0.053	0.161	0.133
79	Nestle Chunky Singles	7.39	5.64	2,697	0.34	0.15	0.999+EXPO(6.39)	0.027	5.650	0.063	0.198	0.033
80	Oreida Shoestring Fries	12.50	4.68	4,563	1.69	0.70	TRIA(5, 9.29, 25)	0.016	2.660	0.458	0.102	>0.15

Item	Description	Mean	SD	Annual Demand	Purchase Price	Shortage Cost	Probability Distribution	MSE	χ^2	p-value	K-S	p-value
81	Shurfine Straw Preserves	3.51	1.63	1,281	1.78	0.80	TRIA(0.999, 2.29, 7)	0.004	0.789	>0.75	0.152	>0.15
82	Sf Plastic Wrap 12	4.75	2.28	1,734	0.75	0.36	0.999+8*BETA(0.969, 1.1)	0.014	4.480	0.361	0.108	>0.15
83	Sf Baby Lima Beans	17.70	6.37	6,461	1.00	0.44	6+26*BETA(1.41, 1.71)	0.002	0.540	>0.75	0.083	>0.15
84	Friskies Chicken & Salmon	11.30	5.81	4,125	0.33	0.04	NORM(11.3, 5.76)	0.015	2.690	0.267	0.076	>0.15
85	Campbell Beef Broth	9.24	4.30	3,373	0.76	0.11	NORM(9.24, 4.25)	0.026	7.090	0.030	0.081	>0.15
86	Kraft 3 Cheese Mac & Cheese	11.10	4.37	4,052	0.83	0.08	NORM(11.1, 4.33)	0.015	1.920	0.404	0.108	>0.15
87	Reynolds Wrap Heavy Duty Foil	10.00	5.83	3,650	1.83	0.54	3+35*BETA(0.958, 3.82)	0.017	3.940	0.048	0.156	>0.15
88	Oreida Golden Crinkle Fries	24.30	7.16	8,870	1.69	0.71	NORM(24.3, 7.09)	0.021	4.050	0.046	0.092	>0.15
89	Glad Drawstring Tall Kit	4.35	2.02	1,588	3.29	0.68	NORM(4.35, 2)	0.032	12.200	<0.005	0.081	>0.15
90	Bounty White Towels(C)	13.70	3.95	5,001	0.91	0.25	TRIA(4, 14.9, 21)	0.015	2.310	0.511	0.109	>0.15
91	Frigo Ricotta Cheese P/Skim	8.47	3.55	3,092	1.60	0.97	3+16*BETA(1.22, 2.35)	0.009	4.340	0.122	0.091	>0.15
92	Green Giant White Shoepeg Corn	8.67	4.23	3,165	0.81	0.14	NORM(8.67, 4.19)	0.009	3.260	0.210	0.066	>0.15
93	Starbucks Brkfst Blnd W B Cof	3.16	1.60	1,153	6.03	0.94	NORM(3.16, 1.59)	0.013	4.900	0.089	0.095	>0.15
94	White Paper Plates 9	12.90	4.16	4,709	0.98	0.41	TRIA(4, 11.7, 23)	0.011	1.660	0.654	0.099	>0.15
95	Friskies Prime Filet Ckn Gvy	13.70	6.55	5,001	0.33	0.04	NORM(13.7, 6.49)	0.013	2.170	0.158	0.098	>0.15
96	Heinz Tomato Ketchup	12.30	7.72	4,490	1.86	0.12	2+WEIB(11.1, 1.34)	0.031	7.460	0.007	0.103	>0.15
97	Swanson Pancakes & Sausage	9.35	3.83	3,413	1.04	0.51	NORM(9.35, 3.79)	0.019	4.530	0.036	0.108	>0.15
98	Popsicle Creamsicle Orang Ras	5.27	3.56	1,924	1.54	0.94	0.999+14*BETA(0.699, 1.59)	0.012	4.300	0.125	0.164	0.120
99	Popsicle Fudgesicle Sf	7.31	4.14	2,668	1.78	0.95	0.999+16*BETA(1.01, 1.56)	0.008	2.670	0.457	0.070	>0.15
100	Frigo P Skim Mozzarella Ball	6.57	3.91	2,398	2.65	1.42	0.999+16*BETA(0.978, 1.83)	0.002	0.649	0.727	0.111	>0.15

Appendix 5. Supply Chain Actions Source Publications

Title	Frequency	Description
Advantage	Monthly	Published by the Food Marketing Institute. Provides news and information about issues, programs, business trends and developments.
Progressive Grocer	Monthly	Strategic publication serving upper management in the supermarket industry. Trends in store development, technology, marketing, logistics, international retailing, human resources, and consumer purchasing patterns.
Frozen Food Age	Monthly	Devoted to retail, manufacturing, and logistics decision-makers in the frozen and refrigerated food industry.
Grocery Headquarters	Monthly	Reporting on issues, trends and strategies involved in the operation of food retailers, including developments throughout the distribution chain.
Food Logistics	Monthly	Articles and benchmark research in the areas of warehousing, material handling, transportation and information management.
PROMO Magazine		Serves marketing professionals at consumer product and service companies, retail chains, and Internet businesses.
Supermarket News	Weekly	Nationally circulated weekly trade magazine for the food distribution industry.
Supermarket Business	Monthly	Reporting on issues affecting the supermarket industry
Food & Drug Packaging	Monthly	Reporting on packaging issues

Appendix 6. Supply Chain Actions

Action Type	BCRC Category	Total Number of Actions	2000	2001	2002	2003	2004
SC	Alliance	323	194	85	14	5	25
SC	Buildings and Facilities	8,220	745	1080	1334	2361	2700
SC	Capacity	318	0	39	0	5	274
SC	Contracting	7,303	883	1702	1312	1894	1512
SC	Customer Relations	1,191	5	5	30	74	1077
SC	Distribution	4,433	364	523	916	2129	501
SC	E-Commerce	311	137	67	20	10	77
SC	Equipment and Supplies	2,815	420	625	744	654	372
SC	Information Management	1,193	147	15	221	505	305
SC	Inventory	263	5	47	59	92	60
SC	Labeling	4,318	549	292	1228	1545	704
SC	Logistics	1,010	84	83	282	369	192
SC	Outsourcing	191	1	30	61	48	51
SC	Packaging	1,025	86	108	163	333	335
SC	Partnerships	679	50	40	195	116	278
SC	Product Development	722	32	35	117	295	243
SC	Purchasing	818	205	55	265	140	153
SC	Quality Management	386	0	47	118	109	112
SC	Service Development	70	0	0	0	0	70
SC	Storage	91	19	11	15	20	26
SC	Suppliers	1,700	171	158	506	689	176
SC	Technology	4,217	396	260	1081	1420	1060
SC	Transportation	344	18	72	97	92	65
SC	Warehousing	4,309	612	894	897	1202	704
	Totals:	46,250	7,123	8,274	11,677	16,110	13,076

Appendix 7. Market-Based Actions

Action Type	BCRC Category	Total Number of Articles	2000	2001	2002	2003	2004
MB	Acquisition	13,693	2180	2351	3287	3245	2630
MB	Advertising	2,219	301	604	575	373	366
MB	Competition	6,469	725	640	1538	1737	1829
MB	Design & Construction	483	50	41	86	174	132
MB	Divestment	11,475	1717	1961	2768	2798	2231
MB	Downsize	248	30	0	20	80	118
MB	Endorsements	93	5	25	18	45	0
MB	Environmental Policy	50	10	5	35	0	0
MB	Facility Closure	562	0	0	4	0	558
MB	Franchise	250	73	21	79	27	50
MB	Green Market	30	10	0	0	0	20
MB	Growth	3,085	215	242	1076	649	903
MB	Innovation	777	50	35	371	175	146
MB	Investment	2,489	131	494	612	709	543
MB	Investor Relations	269	15	13	61	80	100
MB	Joint Venture	302	53	75	49	115	10
MB	Labor Relations	3,327	50	135	472	1094	1576
MB	Licensing Agreements	183	30	20	49	54	30
MB	Location	1,259	149	171	234	448	257
MB	Market Research	355	0	5	55	50	245
MB	Market Share	4,017	389	651	711	1094	1172
MB	Market Size	190	0	0	30	20	140
MB	Marketing	42,219	5583	6064	10910	10690	8972
MB	Marketing Agreements	90	0	0	10	10	70
MB	Mediation	709	0	24	55	115	515
MB	Mergers	12,535	2048	2160	2914	2977	2436
MB	Negotiation	918	0	44	112	212	550
MB	Organization Formation	40	0	0	0	5	35
MB	Prices and Rates	7,526	873	769	2101	2283	1500
MB	Product Defects and Recalls	254	45	15	69	70	55
MB	Product Discontinuation	165	0	0	85	70	10
MB	Product Enhancement	321	0	0	122	169	30
MB	Product Introduction	1,846	106	89	358	908	385
MB	Property	435	39	158	88	88	62
MB	Public Relations	461	88	60	168	70	75
MB	Remodeling	619	63	107	142	90	217
MB	Renovation	466	15	100	124	70	157
MB	Reorganization	991	55	63	70	119	684
MB	Restructuring	1,038	112	139	88	86	613
MB	Service Discontinuation	50	0	0	0	20	30
MB	Service Enhancement	251	0	0	0	0	251
MB	Service Introduction	432	0	5	6	55	366
MB	Target Marketing	854	10	205	98	263	278
	Totals:	124,045	17,220	19,492	31,652	33,340	32,351

Disclaimer

The views expressed in this dissertation are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the U.S. Government.

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