INTEGRATED FORWARD-REVERSE LOGISTICS SYSTEM DESIGN:

AN EMPIRICAL INVESTIGATION

By

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To the faculty of Washington State University:

The members of the Committee appointed to examine the dissertation of YONG JOO LEE find it satisfactory and recommend that it be accepted.

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Abstract

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This dissertation is concerned with taking an empirical approach to designing logistics systems that integrate both forward and reverse flows. Currently the literature has abundant reports separately addressing forward and reverse flow logistics systems. However, it is rare in academic journals to find studies of the synergy effects of integrating the two flows, even though many logistics companies practice both flows in their supply chain business. This dissertation fills a gap through considering both flows.

This dissertation models the UPS (United Parcel Services) logistics business, proposing a reduced model developed by synthesizing all relevant literature pertaining to the topic, and a full model by incorporating other important components on the reduced model: price, transportation modes, and outsourcing costs. Due to the complexity of the mathematical models we applied a Monte Carlo simulation to solve them. In the analysis section, we proved the superiority of the full model in profit generation for UPS, in confirmatory analysis, and also discussed many important findings by contrasting the two models from exploratory analysis.

The highlight of the dissertation is the identification of the role played by incorporating pricing into the model for UPS business. Traditional economics defines transaction volume and price by price elasticity. However, the price elasticity for logistics firms has not been studied yet and hence we applied price elasticity in our analysis, assuming values ranged from 0.25 to 2 with a step value of 0.25. Since no literature has paid attention to the pricing effect in logistics firms the major contribution of this dissertation is a thorough analysis of the contribution of the pricing component in an integrated forward and reverse business and the synergy effects of combining the three components.

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CHAPTER ONE

INTRODUCTION

Research overview and research question

Globalizations, the advancement of technology, and fierce competition have been playing pivotal roles in reshaping business theory and practice for the last few decades. Due particularly to the advancement of technology, business processes have been expedited, marketing channels have become more diverse, and product life cycles have been shortened. In line with technological changes, firms are developing supply chain strategies placing more emphasis on customer satisfaction in their business transaction. As a consequence of favorable customer policies adopted by many business entities, customers, more than ever, enjoy increased purchasing power, a wider variety of product choices, and the free return of products.

In the context of operations management, consumers returning products has not caught much attention until recently when OEMs (Original Equipment Manufacturers) realized that they had to proactively react to the reverse process of products flows. In contrast to forward logistics – denoting the product flow from sources to customers – the management of process in a reverse way, i.e, the process of handling returned items from the end customer to the original manufacturer, is referred to as reverse logistics (Louren & Soto, 2002). Since reverse logistics is a relatively new concept we overview the features of the concept in the following sections.

Lately, as more firms pursue opportunities to enhance their competitiveness through outsourcing logistics activities to 3 PLs (Third Party Logistics), the systematic study of 3

PLs engaged in forward and reverse flow operations has been highly important. Nevertheless, the study of 3 PLs' operational function is rarely found within the academic boundary.

Observing a scarcity of research on 3PLs, this dissertation was motivated to fill this wide gap existing in both academic circles and real industry. This dissertation models the business environment of UPS (United Parcel Service), whose supply chain division is devoted to product transportation in both flows as a 3 PL. Even though UPS is a well established company providing a package delivery service, the efficiency of logistics operations in the firm was under-investigated until recently. Having observed the increasing volume of transactions in the firm, UPS is currently considering capacity expansion; either by building new warehouses or by expanding facilities in its five current operations. Given this situation, this dissertation primarily pursues an answer to the following research question for the purpose of aiding UPS managers to react promptly to a rapidly changing business environment.

> "How can UPS extract the most value when it is making decisions on capacity expansion?"

We consider the importance of this question, both academically and practically.

First, the question carries a meaningful connotation in an academic perspective. Even though there are a few papers modeling forward and reverse flow in a firm's logistics operation (Fleischmann et al, 2001, Lu & Bostel, 2007), their ultimate interests are in establishing new logistics systems instead of expanding current operations. Among the plethora of studies in logistics we observe only one paper, conducted by Ko & Evans (2007), whose proposed model imitates the integration of forward and return flow in the logistics operation particularly suited for the UPS business environment. However, in this author's opinion, Ko & Evans (2007) study is off from the research question of this dissertation since they were more concerned with contributing technical enhancements to academic study by developing heuristics to solve their nonlinear model. Hence, raising the research question will bridge the gap existing in the literature between capacity expansion and logistics operations for 3PLs by considering both forward and reverse product flows simultaneously.

Second, the question also denotes a practical significance. Once a firm has a logistics system in place the firm will occasionally face a capacity expansion at different stages of its business development. When making decisions about capacity expansion, a manager might seek a strategic devise surpassing his or her routine decision tools in order to obtain optimal benefit for the firm. Realizing that UPS managers have not assessed the issue of capacity expansion systematically in the past, pursuing and answering this question will provide managers with different approaches to evaluate their alternatives for their business operations.

Research description

Model building

To answer the research question suggested in the previous section, two major models were proposed mimicking closely the current logistics operation in UPS, in which both forward and reverse flows are considered simultaneously; a reduced model and a full model.

The primary activity of this dissertation is to compare the performance of the two models on the same ground. To perform this comparison test, this study attempts to evaluate each model; applying confirmatory analysis and exploratory analysis with real UPS data drawn from database of UPS through Mr. Vowels, a project leader at the firm, via personal communication.

The reduced model was formulated from theories in the current literature on reverse logistics. Since Ko & Evans (2007) is a unique study of UPS logistics operations, and the model in their study was built upon previous theories about firms engaged in reverse activities, their paper became a building block for the development of the reduced model in our study.

Also in the background of the reduced model formulation, it is noteworthy that most of the previous studies discussing reverse activities, including Ko & Evans (2007), are concerned with minimizing the fixed and variable costs associated with building new construction and its operation (Barros et al, 1998, Louwers, 1999). Consequently, the reduced model proposed in our work is designed to seek minimizing costs in its objective function.

However, the application of cost minimization in model development was challenged by Guide et al (2006) who argued that the ultimate interest of a firm is to maximize the profit instead of minimizing the total cost. They observed that research aimed at minimizing the maximum loss from a reverse supply chain operation is less appealing and less likely capture top management attention. Accordingly, our full model, a newly developed one created by incorporating additional components into the reduced model, was designed to reflect the observation made by Guide et al (2006), i.e. the objective function of the full model is concerned with maximizing profit rather than minimizing costs. The additional components considered in the full model include price, transportation mode, and outsourcing costs for remanufacturing.

Hypotheses development

Profit maximization in the objective function for the full model described in the previous section implies building processes that include a revenue component, namely price, within the model. The effects of the price feature received the most attention in our analysis. Accepted price elasticity theory in Economics indicates that increasing the price does not blindly generate the desired revenue enhancement since higher prices result in lower demand. The current price of UPS paid from its clients was used as a basis for the price in the reduced model; we then derived an optimal price for the full model through a Monte Carlo simulation. The model performance of profit realization was conducted by varying the price and demand according to the theory of price elasticity.

Besides the effect of the price component added in the full model, this dissertation also deals with the significance of the optimal selection of transportation modes and outsourcing costs in the full model. Currently UPS relies mainly on ground and air transportation to move products for its customers. However, the current combination of the two transportation modes in UPS is not optimally decided. Hence, similar to the comparison test for price between the two models the performance test for transportation modes was also conducted using the current combinations of transportation modes and optimal combinations of transportation modes.

Due to a growing awareness of environmental concerns and increasingly favorable customer policies, product returning has become a common practice, which has caused

OEMs to accumulate an increasing volume of returned products. When items are collected by UPS from end-customers UPS outsources a portion of returned item for remanufacturing, which interested the firm in knowing how to choose optimal outsourcing costs when the firm currently makes those decisions in a non-optimal manner. Similar to the price effects and transportation effects, the effect of outsourcing costs was also scrutinized by comparing the two models.

The two models are fundamentally concerned with the capacity expansion of facilities run by UPS. Hence, reflecting current operational environments at UPS, the models behavior are described as follows:

- Based on information about the current four facilities used for both forward and reverse flows and the one hub in charge of final distribution and repair services, the model decides whether to expand current locations and repair centers.
- UPS is currently considering opening new warehouses in three candidate locations for forward and reverse flow, and a hub acting in the same role played by the current hub in Louisville, KY. Therefore, their interest lies in whether they open the new facilities and expand them later instead of expanding current buildings, or whether they do an expansion of current facilities and open new ones simultaneously.

In summary, the core frame of the comparison test in deciding optimal facility expansion for UPS is to evaluate the profit difference between the reduced and full models contrasting current price vs. optimal price, the current combination of transportation mode vs. optimal combination of transportation mode, and current outsourcing costs vs. optimal outsourcing costs, in which all optimal values are drawn from Monte Carlo simulation.

Hypotheses statement

In deciding the significance of profit differences between the model comparison tests, confirmatory analysis needed to be applied and that analysis was followed by exploratory analysis to enrich the interpretation of the test outcomes. To conduct a confirmatory analysis, hypotheses statements were prepared in such a way that a single component effect and combined component effects would be manifest. In more detail, the three components of price, transportation modes, and outsourcing costs are designed to be tested individually, which are stated in hypotheses 1 through 3 below. Hypotheses statements 4 through 6 denote a paired factorial combination of the three components to illustrate the effects when two factors are considered simultaneously. Finally, hypothesis 7 tests the existence of the significance of all three components considered together.

The hypotheses statements for the analysis in this dissertation are as follows.

H1: The profit of the full model, incorporating optimal price of items that UPS carries, will be significantly larger than that of the reduced model.

H2: The profit of the full model, incorporating optimal transportation modes of moving items that UPS carries, will be significantly larger than that of the reduced model.

H3: The profit of the full model, incorporating optimal outsourcing costs of items that UPS carries for remanufacturing, will be significantly larger than that of the reduced model.

H4: The profit of the full model, incorporating optimal transportation modes of moving items that UPS carries and outsourcing costs of items that UPS carries for remanufacturing, will be significantly larger than that of the reduced model.

H5: The profit of the full model, incorporating optimal price of items that UPS carries and optimal transportation modes of moving items that UPS carries, will be significantly larger than that of the reduced model.

H6: The profit of the full model, incorporating optimal price of items that UPS carries and outsourcing costs of items that UPS carries for remanufacturing, will be significantly larger than that of the reduced model.

H7: The profit of the full model, incorporating optimal pricing of items that UPS carries, the optimal transportation modes of moving items that UPS carries, and outsourcing costs of items that UPS carries for remanufacturing, will be significantly larger than that of the reduced model.

Research contribution

By attempting to answer the research question and striving to extract new strategic competency valuable to UPS, we believe that this dissertation will contribute to academicians as well as practitioners in a few different aspects. The expected contributions are as follows.

i) Generalization

Since the proposed model in this study comprises critical features common to logistics operations it is applicable to 3PLs in general. Even though the dissertation investigates the business environment particular to UPS, any 3PL can draw insights by inserting its own parameters into the model due to the similarities among 3PLs in warehousing, transportation, and product handling in both flows.

ii) Comparison study using real data

A comparison study is a research tool to evaluate the performance of different models. The benefits of the comparison study can be highlighted as the study identifies the effects of different components or structures applied in the models of the same situations. In a comparison study obtaining data describing company activity accurately is a critical and laborious procedure for both the obtainer and the providers. This author expresses gratitude to all involved in data extraction for this study. In our study the data are very descriptive and extensive, enabling the investigation of the work to be thorough. Indeed, it is rare to find a comparison study in the literature discussing reverse logistics with extensive data, and hence this dissertation can provide links between unexplored method of academic research and business decision-makers who will benefit from their increased access to academic knowledge.

iii) Profit rather than cost emphasis

In this author's observation no systematic attempt has been made to decide prices optimally in the context of facility expansion along with cost components in the field of reverse logistics. That is, both academicians and practitioners treated pricing decision separately from cost behaviors in their strategic decision. However, insights observed by Guide et al (2006) were distinguished and applied in our capacity expansion model. Guide et al (2006), argued that top managers are primarily concerned with maximization of profit in their firm rather than minimization of cost in their strategic decision. This dissertation provides an exhaustive analysis on pricing for UPS aiming to maximize the profit based on price elasticity theory as well adopted in the discipline of Economics.

Overview of reverse logistics

As the power of consumers is growing the product return for customer service and customer retention has become a common practice in the competitive market, which propels the recent practice of reverse logistics in companies. Many firms in the U.S., attracted by the value available in the flow, have proactively participated in handling returned products at the end of their usefulness or from other parts of the product life cycle. These profit-oriented firms see the subdivision of markets, for example, copiers (Krikke et al 1999) and collect, upgrade, and resell the product. Nonetheless, as indicated by Srivastava & Srivastava (2006), reverse logistics have been mainly regulatory-driven in Europe. For example, Germany has stipulated the German Packaging Order and the German Recycling and Waste Control Act, which force the original manufacturers to handle all the waste (Jayaraman et al 1999).

Table 1
Definition of reverse logistics: adapted from Louren and Soto (2002)

Author(s)	Definition
Stock (1992)	“ the role of logistics in recycling, waste disposal and management of hazardous material; a broad perspective includes all issues relating to logistics activities carried out in source reduction, recycling, substitution, reuse of materials and disposal”
Fleischmann et al (1997)	“ a process which encompass the logistics activities all the way from used products no longer required by the user to products again usable in a market”
Krikke (1998)	“the collection, transportation, storage and processing of discarded products”
Dowlatshahi (2000)	“a process in which a manufacturer systematically accepts previously shipped products or parts from the point for consumption for possible recycling, remanufacturing or disposal”
Rogers & Tibben-Lembke (1998)	“the process of planning, implementing, and controlling the efficient, cost effective low of raw materials, in-process inventory, finished good and related information form the point of consumption to the point of origin for the purpose of recapturing value or proper disposal”
Fleischmann et al (2001)	“a process of planning, implementing and controlling the efficient, effective inbound flow and storage of secondary goods and related information opposite to the traditional supply chain directions for the purpose of recovering value and proper disposal”

Electrical and electronic equipment, used cars, and spent batteries are also strictly regulated in the European Union (Schultmann et al 2006). Under the pressure of these environmental restrictions companies are naturally concerned with the sources of cost reductions from returned products. Strategically, some companies enact product recovery program to highlight the environmental image of their brand since investments in philanthropy, local community, and environmental causes are important marketing tools.

As the reverse supply system is driven by these two orientations of profit and legal regulation, it becomes more complex than the forward supply system in managing, controlling, and processing. Guide et al (2001) listed seven characteristics that complicate reverse supply systems and differentiate them from the features of forward logistics:

1) Uncertain timing in the returning and quantity of returns, which adds a degree of uneasiness to demand management and inventory control.
2) A need to balance returns. Too many returned items will cause a firm to penalize the unnecessary carrying cost of inventory.
3) The need to disassemble the returned items. Disassembly is a required process in remanufacturing, but the recovery rate is uncertain, which brings a difficulty in controlling sequential operations.
4) The uncertainty in materials recovered from returned items, which raise the issue of inventory coordination.
5) The requirement for a reverse logistics networks. Companies have to establish collection centers and remanufacturing centers to coordinate the return and remanufacturing process.
6) The complication of material matching restriction. Frequently customers require some components of the product and it will cause a customer satisfaction issue when the part is not obtained.
7) The problems of stochastic routing for materials in repairing and remanufacturing operations. This feature will bring in variability in the operation causing the coordination and controlling problem in reverse operation.

Besides these operational differences between forward and reverse supply systems, conceptually a forward system is a pull system, whereas the reverse system is both a pull and push system (Krikke, 1998). In the forward system the eventual goal is to serve the end customers, while in a reverse system the targets are secondary customer groups, and firms have to implement obligatory returning process from the end-use customers. Therefore much coordination and adjustment are necessary in implementing the push and pull systems in reverse logistics.

Components of reverse logistics

Return type

Products, parts, and materials are frequently in the reverse logistics cycle for varied reasons at different point of the product life cycle of each item. There are four major returns in practice (Krikke et al 2004). Based on the literature and adopting Krikke et al (2004)'s method we delineate the return type as follows.

- End of life (EOL) return:

This return takes place when the product life cycle of the item comes to an end. Stricter environmental regulations are being implemented in Europe and municipalities in the U.S. and Asia like Japan. Take-back policies enacted in Europe mandate a company to collect all the end-of-use items. These regulations are triggered by a growing concern about the increasing volume of harmful components and chemicals that should not be land-filled. In responding to the negative environmental effect many firms are attempting to reduce the cost of handling EOL returns or monitor the waste process and develop different techniques for better control (Gungor & Gupta 1999). For example, Ford and GM (General Motors) try to design the disassembly process to be as easily deconstructed as it was easily constructed (Gungor & Gupta 1999).

- Commercial return:

It is estimated that more than $35 billion is consumed annually by U.S. firms to handle, transport, and process returned products (Meyer 1999). A product return made within 90 days is called a commercial return, and its annual estimated value exceeds $100 billion out of the total return volume (Stock et al 2002). The reasons that these returns are made include wrong orders, customer dissatisfaction, defects, problems with installation, and so on. Catalog and internet sales especially record returns are as high as 36 % of items sold (De Brito et al 2002). Companies like Office Depot are making efforts to reduce the volume of these returns by establishing better communication channels between customers and order processors, ensuring that no misplaced orders are shipped out (Meyer 1999). Since the value of the returns is high and the market for these products is frequently immediate, the time value for short life cycle products, such as electronics items, has caught much attention among researchers (Guide et al 2006 and Blackburn 2003). According to Krikke et al's(2003) definition, overstocks of non-sold items due to seasonal effects fit into this category.

- End of Use return:

This category encompasses returned items after some period of operation due to end of lease, trade-in, or product replacement. The products may be refurbished or repaired to be sold in an alternative market like eBay or in a geographically different market.

- Re-usable items:

The products in this classification are the separate parts from the main products such as reusable containers and pallets, refillable cartridges, bottles, and disposable cameras. The values of items in this category are generally low (Krikket 2004).

Recovery options

The first step in reverse logistics with respect to recovery program is to collect the items. Firms have different collection systems and strategies contingent on the product type. With the products collected, firms sort the items based on the condition of the product (Jayaraman 2006). Then companies seek to extract value out of the products or components as much as possible by assigning the returned items into an appropriate recovery method. Based on the literature and practice in the industry we proposed a classification scheme on recovery options as follows:

- Reuse:

As observed earlier, this portion of returned products has no flaw or was never used. These items can be reused with minimal maintenance efforts or without any maintenance efforts. For example, items overstocked in the retailer's warehouse preserves the identity of the product as new. Sometimes these items are restocked as is, or after repackaging.

- Remanufacturing:

Remanufacturing preserves the identity of the product and brings the condition back to new after some operations such as dismantling of the product, restoration and replacement of components. Remanufacturing provides benefits the manufacturer/remanufacturer, in addition to reusing materials, since the energy consumption required for remanufacture is as low as 20-25 % of the new product (Lund 1985). Remanufacturing activity also has a great opportunity and impact on the economy. The table below exhibits some surprising outcomes as of 1996 (Lund 1996). For example, the number of people employed in the remanufacturing industry is no less than that of steel mills, computer manufactures, and pharmaceutical firms. Plus the total annual sales amount is surprisingly high.

Table 2
Size and scope of remanufacturing activity in the U.S., Source: Giuntini and Gaudette (2003)

Content	Statistics
Total number of firms	73,000
Total annual industry sales	$53 billion
Total direct employment	480,000
Average annual company sales	$2.9 million
Average company employment	24
Number of product areas	Over 46 major categories

Table 3
Relative size of remanufacturing activity in the U.S., Source: Giuntini and Gaudette (2003)

Industry	Employment	Shipment value
Remanufacturing	480,000	$53 billion
House hold consumer durables	495,000	$51 billion
Still mill products	241,000	$56 billion
Computers & Peripherals	200,000	$56 billion
Pharmaceuticals	194,000	$68 billion

- <u>Recycling:</u>

Even though remanufacturing is a very desirable option in product recovery programs due to its minimization of environmental effects and the cost reductions, not all products returned are value added through remanufacturing in the reverse supply chain. For example, some EOL return items are more expensive to remanufacture than the selling price of the new products. Then remanufacturing is not a viable option (Ferrer & Whybark 2000). Recycling is a good alternative to disposals, lowering landfills, soil, and ground water pollutions.

Secondary market

New products are generally transacted in the primary market. The channel process of the primary market, as described by the forward supply chain system, is that flows are from factory to manufacturer's distribution center, to retailer distribution center, to the store, and then to the end customer. However, some retailers or remanufacturers face how they have to sell remanufactured products since the markets for used products are sub divisions of the primary market and are intertwined.

A secondary market is defined as a selling channel outside of the primary market, mainly to salvage or overstock brokers (Tibben-Lembke 2004). Even though secondary markets are important transaction places, the structure or sales channels in the secondary markets have not been well documented in comparison to the operational aspects of the reverse supply chains system. Since Tibben-Lembke (2004) and Rogers and Tibben-Lembke (1998) give a good overview of secondary markets this section mainly summarizes the two papers to indicate the relevance of remanufactured products and market channels for the used products.

- Secondary market firms

Close-out liquidators: these people deal with products which have passed their shelf life and can no longer be sold. Mainly they work with manufacturers to sell the products. They mainly sell to different liquidator the products they bought from the manufacturers.

1. Job-out liquidators: They are similar to close-out liquidators. The difference is that they deal in seasonal items and not the past shelf life items
2. Brokers: Brokers handles all types of products that reach their end of

life. They generally do not touch the product, but instead provide services that enable sales in other secondary markets worldwide.

3. Insurance claim liquidators: They specialize in products that have been declared a loss for insurance purposes.

4. Barter companies: They dispose of excess stock from other companies and receive some product in return for the disposal. They are hence generally traders.

5. Gray markets: They are sellers who sell new products outside of the regular market channel.

- <u>Secondary market decisions</u>

The players in the secondary market need to decide how to dispose of their items.

1. Consumer vs. wholesalers:

   One decision that marketers should make is whether to sell it to consumers or wholesalers. Selling directly generates numerous customers. However, the risk is a possible non-payment from the bid winners when items are disposed of via an auction. On the other hand, selling directly to wholesalers is promising, but it causes much transportation operating and handling costs since wholesales occur frequently in the consumer markets for used products being sent out of country, such as to Africa or Asia (Rogers and Tibben- Lembke,1998).

2. Using Auction vs. fixed price sales:

Table 4 illustrates the advantages and disadvantages of different auction formats practiced in secondary market sales.

Table 4
Secondary markets sales mechanism, source: Tibben-Lembke (2003)

Sales mechanism	Advantage	Disadvantage
Fixed price sales	Simple, low, staff requirements	Lower prices received
Informal auction	Higher revenues than fixed price	Requires more staff time
Formal auction	Higher revenues than fixed price Short windows may drive up bids	Buyers not willing to travel to site requires accommodation Buyers many not want to do all bidding at one fixed time
Internet auctions	Higher revenues Does not require ongoing staff attention	Cost to auction host Greater IS needed for sellers Some buyers may not be prepared to bid online

3. Single item vs. Pallet, vs. truckload bulk sales.

   Firms should decide the quantity of sales approaches, this decision might be based on the item value, total volume to be sold, how quickly items must be sold, and the seller's tolerance for dealing with small buyers.

Network

Even though network formulation in the context of forward flow systems has been widely studied, the system performing forward activities in a traditional supply chain is not directly applicable to the network structure of reverse logistics since the forward flow system is not originally designed to handle returned products. Due to on-equipment of handling return products in the forward system and different cost structures, such as the costs of collecting, classifying, testing, and disassembling returned goods that occur only in the reverse channel but not in the forward system (Jayaraman 1999). Fleischmann et al (1997) also indicated that the reverse channel is not necessarily a symmetric picture of forward distribution.

Spurred by the differences and unique features of the reverse logistics channel, much attention was paid to research on the establishment of infra structure, facilities, and locations that generate value out of returned items.

Based on a thorough literature review, we can characterize the research stream as follows.

1) Deterministic formulation in nature

Up to this point the majority of reverse networks assume the return of customers to be deterministic. Many papers highlight the uncertainty residing within the reverse system as was discussed above. Nonetheless the models proposed in the literature do not take the uncertainty factors into consideration. Attempts at incorporating stochastic feature are found only in recent papers in the literature. See, for example, Lieckens & Vandaele (2007), Listes & Dekker (2005), and Biehl et al (2007). The stochastic approach in the papers was mainly assessed via scenario analysis or stochastic programming method. The stochastic programming approach is considered a more systematic approach, but it generates a burden of severe computational time. Scenarios are commonly used to assess the uncertainty. In the analysis in this dissertation parameters are incorporated in diverse scenarios.

2) Cost minimization

Major costs considered in the models include the fixed cost of building and equipment, operational costs, and transportation costs. The majority of the papers seeking optimization generally attempted to minimize these three costs. The reason researchers optimized the model with cost minimization is that the price factor does not play a role in the decision about facilities. However, we wish to reconsider this issue and in reality this issue is interconnected with topics in this dissertation.

3) Case study centered lacking general model

The types of industries practicing reverse logistics vary. This fact brought many different case studies into the formulation of reverse networks. Examples include the carpet industry (Biehl et al 2007, Louwers et al, 1999, Realff et al 2004), sand recycling (Barros et al 1998), and empty gas tanks (Le Blanc 2004). Major exceptions that presented a general model are Fleischmann et al (2002) and Beamon & Fernandes (2004).

4) Heuristics development

The facility location problem is generally classified as a NP-hard problem. NP stands for Nondeterministic Polynomial-time. A problem is assigned to the NP class if it is solvable in polynomial time by a nondeterministic Turing machine. An NP-hard problem is "at least as hard as any NP-problem," (http://mathworld.wolfram.com/NP-HardProblem.html).

We observe a significant research trend in this topic that many authors have attempted to develop heuristics to overcome computational time arising from the nature of NP-hard classification. Some authors applied a Lagrangean multiplier (Marin &

Pelegrin 1998, Lu & Bostel 2007) and others used meta heuristics (Min et al 2006, Ko & Evans 2007).

The gamut of reverse supply system observations and insights developed by the author are condensed in the figure below describing an overview of a general reverse supply chain.

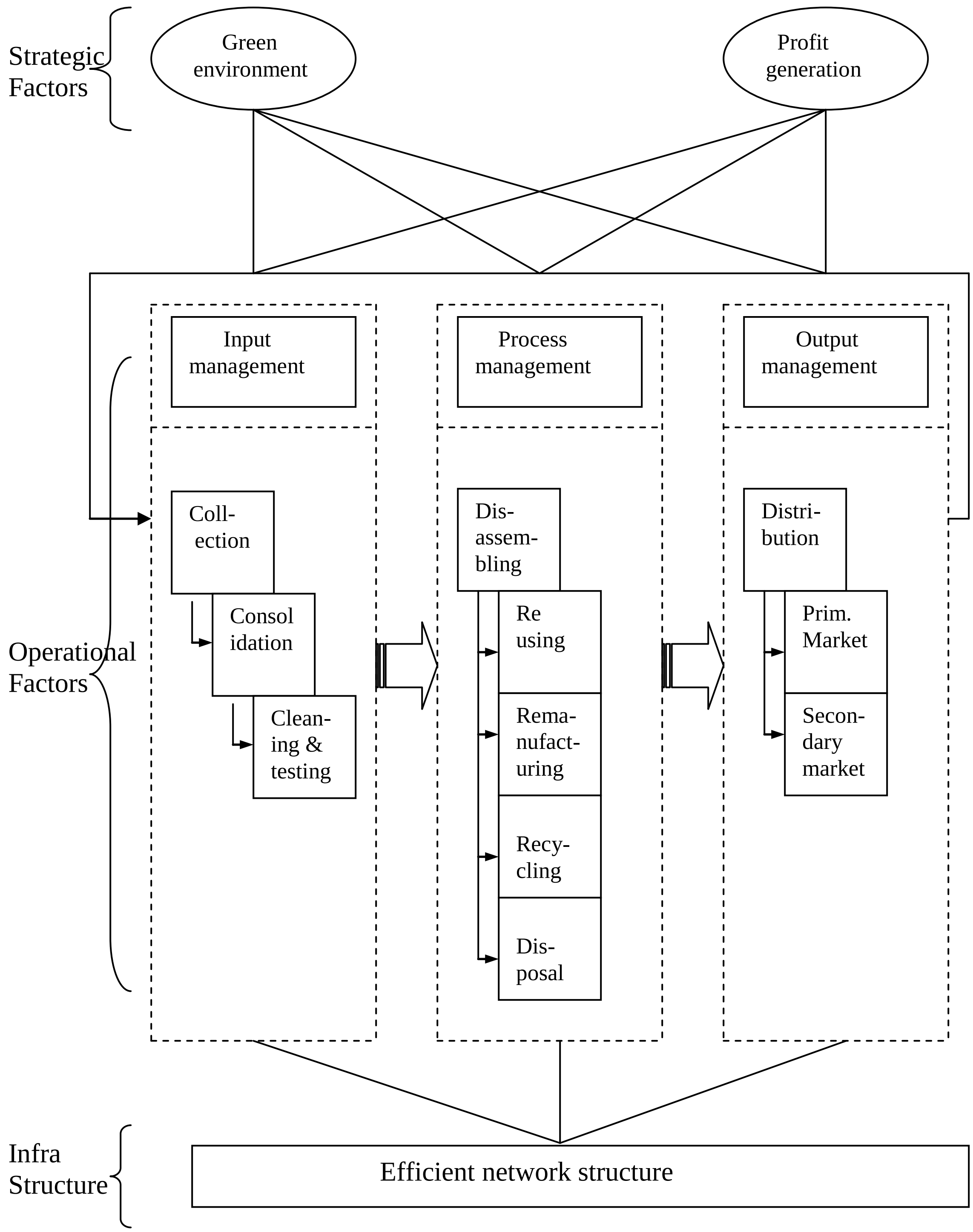


Figure1. Overview of reverse supply chain system

CHAPTER TWO

LITERATURE REVIEW

Introduction

Literature on supply chain management is comprised of two disciplines: forward supply chain and reverse supply chain. Since this dissertation intends to present theories and practices in remanufacturing and recycling we restrict the scope of our literature review to that of the reverse supply chain only.

Previous research on reverse supply chains discusses various topics, which can be delineated into two major categories: strategic issues and tactical issues. Literature addressing strategic issues discusses the relatively long term decisions of firms. They include the formulation of reverse logistic networks, pricing and competition, and the designing of the whole reverse supply chain system. Facility location problems for network construction have been well investigated previously. For the last decade facility location problems received much attention in the context of reverse logistics and hence reports on the issue are abundant.

We also observe some pricing and competition literature in the reverse supply system since pricing for remanufactured items is not as straight forward as the pricing of virgin products due to complexities arising from uncertainties in the system, which will be discussed shortly. Recently research addressing the restructuring of whole supply systems and the strategic aspects of product returns has gradually been evolving.

However, a large portion of the work in reverse supply chain systems so far investigates the tactical aspect of the system. Those papers discuss largely midterm and short term issues that firms face in their operation. Efforts in the articles studying the tactical-side include inventory management and production planning. Not only do the two thrusts of the strategic and tactical side of the papers shed light on enhancing our understanding of previous works, but also some survey papers present a good fathoming of the evolvement of the research on reverse supply chains. Hence we will include important survey papers, although not exhaustively, in addition to papers associated with the two streams of strategy and tactics, in our overview of the literature.

Survey Papers

One of the early papers by Zhang et al (1997) addressing the issue of designing environmentally conscious manufacturing systems classified the design into two areas, namely, product design and process design.

There are a few review papers on location models in the reverse supply system. Min & associates (1998) provides an overview of a location-routing model with comprehensive taxonomy and classification schemes. They classified eleven subcategories under their location-routing model with regard to perspective, and two subcategories under the model with respect to solution methods.

Fleischmann et al (2000) is another one reviewing largely case studies on logistics network design for product recovery. The paper reports that the distinguishing feature between a traditional distribution network and a reverse logistics network is a supply uncertainty with respect to the quantity, timing, and condition of returned items, which is not well represented in the previous mathematical model and hence urges the incorporation of the uncertainty aspect in future reverse logistics designs.

We also observe survey papers discussing such issues as distribution, inventory control, and production planning occurring in the operations of remanufacturing. The inventory model in remanufacturing is concerned with the quantity of returned products, partially and fully disassembled parts, as well as new items. Due to this complexity of inventory control in the reverse supply system the theory of traditional inventory systems is hardly applicable to the inventory system of remanufacturing firms.

Guide & Srivastava (1997) overviews previous works on inventory control contrasting the two different inventory management systems. Gungor & Gupta (1999) presented a very comprehensive literature review on environmentally conscious manufacturing systems, illustrating topics of designing manufacturing systems, production plans, product recovery, remanufacturing, and scheduling. In the conclusion of the paper they urge that environmental regulation should be globalized since our environment is a global issue rather than a regional problem.

Guide (2000) provides good insight on the previous studies as to production planning and control for remanufacturing. As Fleischmann did, he also addresses the uncertainty factor within the reverse supply system and identifies seven characteristics that complicate the system. The seven characteristics are 1) the uncertain timing and quantity of returns, 2) a need to balance returns with demands, 3) the disassembly process, 4) a varied material recovery rate, 5) the necessity of a reverse logistics network, 6) material matching complications. i.e. complexity of production planning and materials management caused by customer requests for repair or remanufacturing, demanding to match identical parts to the product. Since the requested parts by customers are frequently a mixture of different new and old components, which may or may not be ready yet, the customer request compels the firm to coordinate their management information system and physical arrival in a timely manner, and 7) stochastic routing in the operation.

Bras et al (1999) is another overview of the literature discussing the remanufacturing process. A good survey paper particularly committed to an overview of quantitative models for production planning and inventory management is provided by Fleischmann et al (1997). They survey the emerging field of reverse logistics and divide the field into three areas, namely: distribution planning, inventory control, and production planning.

Whereas previous studies on facility location problems are deterministic in their models Snyder (2006) comprehensively reviews the facility location problem under uncertainty. He illustrates stochastic models in varied facility locations and robust location problems whose probability information or parameters is unknown. Although this survey does not commit to present facility location problems in the context of the reverse supply chain the models surveyed appear to be precursors to models in the reverse logistics network in the future.

Guide & van Wassenhove (2006) propose the direction of future research. They suggest that transition in future research on closed loop supply chains needs to be made from the focus on environmental issues to business perspective on product returns, striving to increase the profit rather than reducing the cost. Our observations above suggests that such topics as reverse logistics network design and tactical issues in remanufacturing systems received much attention from academicians for the past two decades. Table 5 provides a summary of survey papers ordered chronologically.

Table 5
Summary of survey papers in the literature

Authors	Issues	Application
Zhang et al (1997)	Remanufacturing	Design of environmentally conscious remanufacturing
Guide & Srivastava (1997)	Inventory	Contrast between traditional and reverse supply inventory model
Fleishman et al (1997)	Inventory, production	Review mathematical model and distribution planning
Min et al (1998)	Facility location	Taxonomy and classification scheme for reverse network
Bras et al (1999)	Process control	Necessity of making decision based on both economic and environmental consideration
Gungor & Gupta(1999)	Inventory and planning	Urges the globalization of environmental regulation
Fleischmann et al (2000)	Facility location	Supply uncertainty as a distinguishing factor in the reverse logistics system
Guide (2000)	Production planning	Identification of seven complicating factor in the remanufacturing system
Snyder (2006)	Facility location	Illustration of varied models under uncertainty
Guide & Van Wassenhove(2006)	Future research	Future research needs to target to achieve business goals

Strategic Papers

<u>Logistics network design</u>

With a growing awareness of environmental degradation, as well as every firms intention of profit increase through customer satisfaction, the increase in allowing product returns has been observed over the last decade, and consequently reverse logistics issues have been well-explored in the literature. One area that academicians paid attention to is how to design a reverse supply chain network structure that achieves effectiveness and efficiency for returns flows from the end customers. This facility location or network design problem is not a new issue and it has been dealt with intensively in the context of the forward supply setting for a few decades. Even though reverse logistics systems inherit similar features to forward system, in its operation it is in nature different from forward systems (Jayaraman et al 1999).

Reverse supply chain network design literature handles design issues broadly in two ways: general design and specific functional design. Research to provide a perspective on general design concerns focused on design efficiencies and the selection of overall functional locations. On the other hand many studies report on issues of selecting specific functional points such as pre-processing, which include the collection and classification, processing (implying functions of remanufacturing), recycling, and post-processing - like disposal and vehicle routing problems.

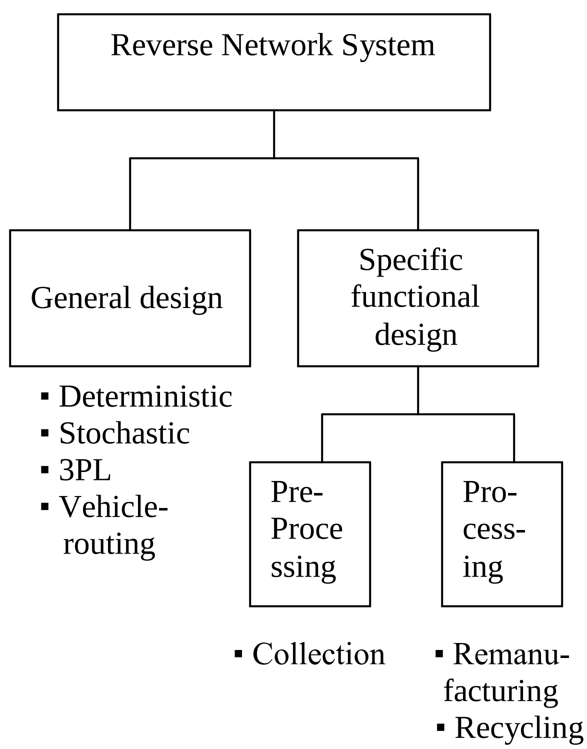


Figure 2: Hierarchy of Literature in reverse network system

General design

Recovery of product flowing from the end customer requires some changes in the traditional network. One approach is to add a recovery network to an already existing forward network (sequential design). Another way is to design forward and reverse networks simultaneously (integral design). This topological issue in network design was examined by Fleischmann et al (2001) indicating that integral design is more cost efficient. The superiority of integral design proposed by Fleischmann (2001) was supported in an e-business setting by Yao (2005). Jayaraman et al (1999) have formulated mixed integer programming to decide the number and location of facilities for an electronic equipment remanufacturing firm in the USA. They suggest that demand is a crucial factor for deciding location problem in a reverse supply network and obtaining enough cores (returned products) is also a key factor for solving the problem, which is differentiated from traditional forward facility location problems. Their work was extended by Jayaraman et al (2003). Other articles handling general design issues in the reverse network includes Beamon & Fernandes (2004), Marin & Pelegrin (1998), and Sheu (2007); they discuss the determination of facilities based on investment and operational costs, return plant location, and the coordination of reverse logistics management to handle hazardous wastes, respectively.

Deterministic models for reverse network design lack the ability to incorporate such uncertainty factors as variances of return amount, timing, and lead time through the network. Based on a recovery network model (RNM) proposed by Fleischmann et al(2001), Salema et al (2007) analyzed the impact of uncertainty in designing multi-product reverse logistics networks with limited capacity via analysis of simulation scenario. Listes (2007) formulated a two-stage mixed integer stochastic model of which the first stage is intended to be solved using a branch-and-bound algorithm. Due to the large problem size and computational difficulty at the second stage he applied a special cutting planes procedure known as integer L-shaped based algorithm, solving the reformulated problem as follows.

$$\text{Min } \sum_{i=1}^{I} a_i k_i + \sum_{k=1}^{K} f_k \varepsilon_k + \sum_{i=1}^{I}\sum_{j=1}^{J} c_{ij} x_{ij} + \sum_{j=1}^{J}\sum_{k=1}^{K} e_{ij} y_{jk} + \sum_{k=1}^{K}\sum_{i=1}^{I} g_{ki} z_{ki} + \theta$$

S.t.

$$x_{ij} \le k_i \quad \forall i, \forall j,$$
$$y_{jk} \le \varepsilon_k \quad \forall j, \forall k,$$
$$z_{ki} \le k_i \quad \forall k, \forall i,$$
$$\sum_{i=1}^{I} x_{ij} \le 1 \quad \forall j,$$
$$\sum_{k=1}^{K} y_{jk} \le 1 \quad \forall j,$$
$$\sum_{i=1}^{I} z_{ki} \le 1 \quad \forall k,$$

$$D_n x + E_n y + F_n z + \theta \ge \delta_n, \quad n = 1, \dots, m,$$
$$\sum_{i=1}^{I} \bar{\rho} P_i k_i + \sum_{j=1}^{J} \tilde{\mu}_k R_k \varepsilon_k + \theta \ge -\sum_{i=1}^{I} \bar{\lambda}_i P_i$$
$$\theta \ge \theta_0,$$
$$\kappa_i, \varepsilon_k, x_{ij}, y_{jk}, z_{ki} \in [0,1] \quad \forall i, \forall j, \forall k$$

Paying attention to the fact that lead time is a crucial component of strategic decision making within firms Lieckens & Vandaele (2007) developed a mixed linear integer programming model adding queuing characteristic with a G/G/m model. The complexity of solving the model was circumvented through differential evolution, a variant genetic algorithm.

Ko & Evans (2007) and Krumwiede & Sheu (2002) discuss the role in logistics played by third-party logistics (3PL). 3PL is “a relation between a shipper and third party which, compared with basic services, has more customized offering, encompasses a broader number of service function and is characterized by a longer-term, more mutually beneficial relationship” (Yeung 2006). 3PLs include UPS, FedEx, ASTRA, and GENCO, whose activities include aiding the return process of goods by scheduling the pickup and transportation, collecting customer information, and tracking the status of returned products (Krumwiede & Sheu 2002). Ko & Evans (2007) present a mixed integer nonlinear model for 3PL companies that consider forward and reverse networks simultaneously, solved by a genetic algorithm approach. Krumwiede & Sheu (2002) summarized the current reverse logistics network in three stages, namely, retrieval, transportation, and disposition. They also developed a logistics decision-making model, based on interviews with mangers in reverse logistics companies, to help potential third-party entering firms to decide whether entering third party business is strategically profitable.

Planning for vehicle routing is also important, but it is complex in reverse logistics systems due to the variability of returning flow in quantity, quality, and timing. Schultmann et al (2006) and Blanc et al (2006) used scenario analysis to represent uncertainty in their model for handling end of life vehicle (ELV) situations in Germany and Netherland, respectively. Crainic et al (1993) also used scenarios for their stochastic model to optimally allocate empty containers in a transportation system. Not only did they consider uncertain demand and supply but they also incorporated such factors as the space and time dependency of events, container substitution, relations with partner companies, and import and export. In contrast to the papers above who handle uncertainty by scenario analysis, there is also a report examining blood distribution by the American Red Cross whose model is solved by a heuristics method of stochastic programming (Alshamrani et al 2007). The objective of their model is to minimize two costs incurred by route travel and the penalty associated with not picking up returned materials by an appropriate time. Since the dynamic stochastic programming they proposed is very prohibitive in computation they proposed a decomposition heuristic.

Specific function design

- <u>Preprocessing (Collection)</u>

Initial collection points can create a bottleneck incurring significant costs and hence collection points play an important role in the performance of the network system. Min et al (2006) proposed a mixed integer programming model for collection points taking the length of holding time for consolidation and transshipment into account.

Their mathematical formulation is as follows:

$$Min \sum_t [\sum_j a_j Z_{jt} + \sum_j s_j Z_{jt}(1 - Z_{jt-1}) + b \cdot w \sum_j \{\sum_i r_{it} Y_{ijt} \cdot \frac{(T_{jt}+1)}{2}\}$$
$$+ h \cdot w \sum_i r_{it} + \sum_j X_{jt} \frac{w}{T_{jt}} \cdot f(X_{jt}, d_j)]$$

$s.t.$

$$\sum_j Y_{ijt} = 1 \quad \forall i \in I, \forall t \in T$$
$$\sum_i Y_{ijt} \le M \cdot Z_{jt} \quad \forall j \in J, \forall t \in T$$
$$\sum_i r_{it} Y_{ijt} T_{jt} = X_{jt} \quad \forall j \in J, \forall t \in T$$

$$
\begin{aligned}
& s.t. \\
& d_{ij} Y_{ijt} \le l \quad \forall i \in I, \forall j \in J, \forall t \in T \\
& z \le \sum_j Z_{jt} \quad \forall t \in T \\
& X_{jt} \ge 0 \quad \forall j \in J, \forall t \in T \\
& T_{jt} \in (0,1,2,3,4,5,6,7) \quad \forall j \in J, \forall t \in T \\
& Y_{ijt,} Z_{jt} \in (0,1) \quad \forall i \in I, \forall j \in J, \forall t \in T
\end{aligned}
$$

They solved the initial problem by applying a genetic algorithm since the class of this mathematical formulation belongs to NP-hard problem. Louwers et al (1999) explored the impact of collecting followed by preprocessing for carpet waste, both under the supply-driven reuse system in Europe, where all supplies are collected and processed, and the demand-driven reuse system in the USA, where only a demanded amount is collected and preprocessed. A major difference between their consideration and other location problems is that the carpet processing locations are condensed and hence are not influenced by other facility locations.

Besides numerical models, a simulation approach was observed in designing a reverse network for collecting End of Life (EOL) appliances in the Sydney, Australia, metropolitan area (Kara et al 2007). Castillo et al (1996) and Kroon & Vrijens (1995) discuss the control and management of reusable container in a reverse logistics network. It is noteworthy that almost all the carpet sold in Western Europe is disposed of in landfills (Louwers et al 1999). Biehl et al (2007) attempted to assess the target of 40% recycling from landfills enforced on the carpet industry through simulation. Since carpet is a bulky product collecting the carpet from the customers is an essential step for reaching the goal. Applying different simulation scenarios for parameter estimation they projected, pessimistically, to reach the aim of a 40% recycle rate from landfills by 2012 in the USA. They suggested that increasing the number of collection centers within the network for a risk pooling effect would result in mitigation of the variation in return flow while facilitating customer returns.

- <u>Processing (Remanufacturing and Recycling)</u>

Spengler et al (1997) presents two strategic and tactical planning tools applicable to dismantling and recycling of buildings in the French-German region. To achieve maximum marginal income they formulated a mixed integer model as follows:

$$Max \sum_{i=1}^{m} \sum_{\mu \in T_i} c_{i\mu}^{v} z_{i\mu} - \sum_{j=1}^{n} c_j^z x_j$$

$$s.t.$$

$$y_i = y_i^a + \sum_{j=1}^{n} x_j v_{ij} \qquad i = 1, \ldots, m$$

$$\sum_{\mu \in T_i} z_{i\mu} - \gamma_i y_i = 0 \qquad i = 1, \ldots, m$$

$$\sum_{i \in I_\mu} z_{i\mu} - Q_\mu \leq 0 \qquad \mu = 1, \ldots, r$$

$$x_j \in N_0 \qquad j = 1, \ldots, n$$

$$z_{i\mu} \geq 0 \qquad i = 1, \ldots, m, \mu \in T_i$$

$$y_i \geq 0 \qquad i = 1, \ldots, m$$

Due to exponential growth of the problem size a commercial solver like LINDO will not efficiently solve this NP-complete problem and thus it was solved by a decomposition method developed by Benders (Benders 1962). Spengler et al (1997) also looked at location and allocation planning of recycling installations for byproducts of the steel industry in Germany and studied an exact solution executed by commercial software. Schultmann et al (2003) also provide a model to improve the current battery recycling structure in Germany and solved using an exact formulation varying by scenarios.

Different from the previous works mentioned above, Realff et al (2004) takes the uncertainty factor into consideration for the designing of recycling networks, which are modeled in Robust Optimization (RO) for carpet recycling in U.S. companies. RO is a solution method to find a best configuration by minimizing the maximum deviation of optimal objective values obtained from each scenario. Through scenario analysis they solved issues of the type of recycling task, the location of the task, and the transportation mode. Baros et al (1998) proposes a heuristic procedure for mixed integer programming within the two-level network with capacity constraints to determine the locations of regional depots in the Netherlands that receive sieved sand, and treatment facilities for cleaning and storing polluted sand. Demand uncertainty of sand was explored through scenarios analysis.

Another article that considers uncertainty in system behavior explicitly for a network design model is reported by le Blanc et al (2004). Their concern is determining an optimal number of depots and their geographic location for degassing the LPG-tanks before recycling them. Constructing mixed integer programming they used scenario analysis to resolve uncertainty with respect to the number of collected LPG-tanks.

In contrast to using scenario analysis exclusively to cope with uncertainty Lists and Dekker (2005) in reinvestigating the sand recycling design proposed by Baros et al (1998) applied stochastic programming techniques, claiming them to be more flexible for handling uncertainty and more dynamic than scenario analysis (Kall & Wallace 1994). Their finding is that the number of new openings depends on the amount and quality of incoming flows, whereas the location of a new facility is associated with where the demands are generated. However the drawback of using stochastic programming for the case was reported to be a severe computational time to reach the solution. Lu and Bostel (2007) exhibit a solution method of lagrangean relaxation in great detail for their Remanufacturing model (RMN), describing a mutual interaction between forward and reverse supply chains. They formulated their model as an uncapacitated location problem in mixed integer programming. Their lagrangean heuristic comprises five steps.

1) Initialization: set initial lagrangean multipliers.
2) Solve lagrangean problem based on algorithm and calculate best lower bound.
3) Using location variables obtained from the previous step solve the transportation problem and obtain the best upper bound.
4) Update lagrangean multiplier using sub gradient method
5) Check termination condition. If not met, return to step two.

Table 6 provides the summary of literatures on logistics network design based on network components ordered chronically.

Table 6
Summary of literature on logistics network design

Authors	Network application	Model type	Model solution	Applied business
Kroon and Vrijens(1995)	General	General	Exact	General
Castillo et al (1996)	General	LP & Exact	Simulation	Soft drink container
Marin and Pelegrin (1998)	General	MILP	Lagrangean and Heuristic	General decomposition
Jayaraman et al (1999)	General	MILP	Exact	Electronics
Fleischmann et al (2001)	General	MILP	Exact	Copier & paper
Krumwiede and Sheu (2002)	General	CM	Exact	3PL
Jayaraman et al (2003)	General	MILP	Heuristic	Hazardous product
Beaman & Fernandez(2004)	General	MILP	Exact	General
Listes (2005)	General	MILP	Branch and cut Integer L-shape	Electronic equipment
Yao (2005)	General	General	Exact	E-commerce
Castillo et al (1996)	Collection	MILP	Exact	General
Louwers et al(1999)	Collection	General	Exact	Carpet
Min et al (2006)	Collection	MILP	Heuristic (genetic algorithm)	General
Kara et al (2007)	Collection	Simulation	Exact	EOL appliances
Biehl et al (2007)	Collection	Simulation	Exact	Carpet
Spengler et al (1997)	Recycling	MILP	Decomposition	Hotel & steel
Baros et al (1998)	Recycling	MILP	Heuristic	Sand
Schultmann et al (2003)	Recycling	CM	Exact	Battery
Realff et al (2004)	Recycling	MILP	Exact	Carpet
Le Blanc et al (2004)	Recycling	MILP	Scenario	LPG-tank
Lists & Dekker(2005)	Recycling	STP	Exact	Sand
Lu & Bostel (2007)	Remanu-facturing	MILP	Heuristic (lagrangean relaxation)	General
Crainic et al (1993)	Vehicle routing	General	Exact	Container
Schultmann et al (2006)	Vehicle routing	MILP	Scenario	Auto vehicle
Blanc et al (2006)	Vehicle routing	General	Heuristic & scenario	Auto vehicle
Alshamrani et al (2007)	Vehicle routing	Dynamic stochastic	Decomposition Heuristic	Blood container
Bloemhof-Ruwaard et al (1996)	Disposal	MILP	Heuristic	General

Annotation:
MILP: Mixed Integer Linear Programming
CM: Conceptual Model, STP: Stochastic programming

Channel design

Coordination, competition, and pricing

Examining product returns as a coordination mechanism has been a very popular topic in supply chain management literature lately. Pasternack (1985) considered perishable commodities for multiple retailers whose demand is stochastic with fixed price. Under the situation of a monopolistic manufacturer, he found that neither a full refund for all unsold items nor a zero return of unsold items is optimal, but a partial refund for all unsold items will achieve channel coordination. Padmanabhan & Png (1995) studied when and how to adopt return policies by considering benefit cost analysis. Hahn et al (2004) investigated the case of retailers who promised not to return unsold items when a price discount up front is offered.

With the assumption that retailers should commit to both price and order quantity before demand is realized Emmons & Gilbert (1998) modeled the relationship between a manufacturer and a retailer in a single period setting with price dependent demand uncertainty. They found that manufacturers profit increases by repurchasing the excess stock of retailers at the end of the season. Wang et al (2007) investigated the relationship between demand uncertainty and buyback price from the supplier's perspective. They found that the higher the variance the higher the optimal buyback price and the larger the profit gain of both parties. However, the returns considered in these studies above are from retailers due to demand uncertainty and the retailer's overstocking of inventory.

We are more interested in another body of literature describing coordination and competition when returns are made from customers during their usage of purchased items or at the end of the season. Savaskan & Van Wassenhove (2004) considered a single manufacturer that produces virgin products and remanufactures used products, and a single retailer. They investigated the coordination issue using game theory between the manufacturer, who plays the role of Stackelberg leader, and the retailer, who is a follower. Their coordination scheme is suggested by providing incentives in the form of two-part tariffs.

Savaskan & Van Wassenhove (2006) is an extension to Savaskan and Van Wassenhove (2004), in a situation of a single manufacturer and two retailers with a multi echelon distribution channel. The difference between the two studies is that the latter studies multiple retailers who are competing with each other, whereas the first one studies the competition taking place vertically. A major finding of the work is the decision mechanism of manufacturers on when to collect the returned items directly from customers and when to collect the returned items via retailers.

Ferguson et al (2006) is differentiated from Savaskn & Van Wassenhove (2004, 2006) in that it studies the return behavior for commercial returns, which occur before the end of the warranty period of the product due to customer dissatisfaction, product defects, and so on. They observed false failure returns, which have no functional or cosmetic defects, with products in the electronics industry like HP’s inkjet printers and Bosch Power tools North America. False failure returns cost unnecessary testing, reprocessing, and deterioration of time value to manufacturers. They proposed a target rebate contract for coordination, which stipulates some amount of a payment for each false failure return below a target level. The above papers are mainly interested in finding the coordination mechanism in the channel.

Now let's turn our attention to competition. There are studies that define the Nash equilibrium using a game theoretic approach when competition among channel members takes place. Majumder & Groenevelt (2001) studied the competition occurring between Original Equipment Manufacturer (OEM) and local remanufacturers in two periods of time where the OEM chooses whether to produce in the second period or not. They modeled the competition when local remanufacturers use the returned item which is prebated from OEM, for their remanufacturing – an example product is Lexmark toner cartridges. They proved the existence of pure strategy Nash equilibrium in two periods and concluded that, compared to a monopoly case, when there are competitors an OEM needs to produce less in the first period, causing retailers to increase the remanufacturing cost, whereas the retailer has an incentive when the OEM manufactures more in the first period. i.e. the less production will cost more for OEMs in the first period. However, less production will deprive the retailer of an opportunity to have access to returned products in the next period, which will cost retailers more in production, forcing the retailer's price higher. By the same token, retailers have an incentive to reduce manufacturing costs for OEM to induce more production in the first period.

Extending Majumder & Groenevelt (2001), Ferror & Swaminathan (2006) obtained a closed-form solution for prices and quantities in the Nash equilibrium and identified the optimal region that Manumder & Groenevelt (2001) showed by numerical examination.

Ferguson and Toktay (2006) is another paper discussing the manufacturing strategy for OEMs which also remanufactures, against the retailers who remanufactures by collecting used items produced by OEM from end customers. Instead of using game theory they approached this competition in a more strategic perspective by analyzing and evaluating entry-deterrent strategy in the competition. Their work is mainly linking the fixed and variable costs of collection with the cost and cannibalization effects of remanufacturing to seek a deterrence strategy against the retailers. They present the condition for OEM that the benefit of remanufacturing exceeds the detrimental effect of cannibalization. They also emphasized the choice of remanufacturing for OEM as a deterrent strategy against retailers. Refer to Guide et al (2003), Ray et al (2005) for collection strategy.

Another extension to Majumder & Groenevelt (2001) is Debo et al (2005). Coping with the same competition, management needs to decide on an optimal remanufacturability level. Assuming that the costs of remanufacturing are constant over time, they addressed the issue of market segmentation and technology choice for production in a manufacturing and remanufacturing environment.

Pricing is also an important decision for manufacturing firms, as well as retailers, in a strategic context. Noble & Gruca (1999) overviewed the pricing, both theoretically and practically, in the capital intensive and durable goods manufacturing industry.

In the industry, parity pricing is the mechanism that is used most frequently. Surprisingly, based on the literature, the pricing for remanufactured products has been under-investigated even though pricing literature is numerous. Vorasayan and Ryan (2006) studied the price of refurbished products in their simulation of whole closed-loop supply chain systems via open queuing theory modeling after the electronics industry. Their major interest was to find an optimal price and proportion of returned product to refurbish.

Table 7
Summary of the pricing strategy and findings based on the survey in the industry.

Pricing situation	pricing strategy	Industry practice
New product pricing	Skim pricing	37/270
	Penetration pricing	25/270
	Experience curve pricing	32/270
Competitive pricing	Leader pricing	31/270
	Parity pricing	82/270
	Low-price supplier	24/270
Product line pricing	Complementary product pricing	24/270
	Price Bundling	N/A
	Customer value pricing	29/270
Cost-based pricing	Cost-plus pricing	N/A

Annotation:
Skim pricing: set initial price high and reduce over the time
Penetration pricing: set initial price low and accelerate
Experience curve pricing: set initial price low increasing volume and reduce costs through experience
Leader pricing: initiate a price change expecting others to follow
Parity pricing: match the price by overall market
Low-price supplier: strive to set the price low in the market
Complementary product pricing: price the core product low when complementary can be priced with a higher premium
Price bundling: price is bundled with others to achieve an overall lower price
Customer value pricing: offering price at very competitive levels.
Cost-plus pricing: price is set to give specified margin from the cost when demand is hard to estimate

While Vorasayan & Ryan (2006) is limited to the pricing issue in a monopolistic setting, Mukhopadhyay & Setaputro (2006) has considered the 4 PL deciding optimal pricing and return policies using Stackelberg game theory. 4PLs like Return.com provide process outsourcing. Their model assumed two players, the e-tailer selling a product via an internet and 4PL offering a refurbished product in the secondary market. Ray et al (2005) studied the decision of optimal pricing under the situation of a trade-in rebate, which is a special discount for repeat purchasers on the condition that they return the existing durable and remanufacturable product. They divided the customer group into two, namely, new customers and replacement customers. They studied the optimal pricing scheme with three classifications.

1) Uniform pricing for both customer segments with no trade-in rebates. This scheme is to charge the same price to both customer segments even though the company recognizes the customer segments and age profile.
2) Age independent price differentiation. This scheme separates the customer segments and charges prices accordingly. When the new customer group is charged the price for new product and the replacement segments are charged a price lower than that of a new customer, then the rebate would be the difference between the two prices regardless of the age profile.
3) Age dependent differentiation. This pricing scheme is similar to the previous one but the rebate is based on the age of the existing products.

Reverse supply chain design

A large body of literature is found on reverse supply chain design. Lee & Tang (1997) evaluated the benefit of redesigning for product and process in the supply chain by delaying product differentiation to save inventory cost with more flexibility and providing better service level of the system. Lee and Hwang (1999) discussed the effects of a decentralized design on a multi-echelon supply chain system in terms of cost conservation, incentive compatibility, and informational decentralizability. Feitzinger & Lee (1997) observed the advantages of postponement for the HP (Hewlett-

Packard) company, where mass customization takes place. Swaminathan & Tayur (2003) focused on the designing issue in an e-commerce setting. Fisher (1997) suggests the supply chain design for a product based on a classification of whether the product is functional or innovative.

Since the above papers handle the designing problem in the forward supply chain we convert our attention more to the reverse system, although there exists some similarities of efficiency or cost savings and contrasts like postponement vs. preponement. Applying Fisher (1997) in a reverse setting, Blackburn et al (2004) classified the supply chain into two, an efficient chain and a responsive chain, and presented the time-based reverse supply chain design strategy shown in Table 8.

Table 8
Time value and supply chain

	Efficient chain	Responsive chain
Low MVT product	Match	No match
High MVT product	No match	Match

Annotation:
MVT: Marginal Value of Time.

Blackburn et al (2004) proposed that centralized evaluation activity is appropriate if cost efficiency is the objective. On the other hand, the decentralized evaluation fits well if responsiveness is the goal of the supply chain. In line with Blackburn et al (2004), Guide et al (2006) and Guide et al (2004) studied the time value of commercial product return for the cases of HP inkjet printers and the Robert Bosch Tool Corporation, representing the reverse network with queuing theory. They proposed the preponement concept, which is the opposite of postponement in the forward supply chain by sorting return items as early as possible in the reverse network, enabling the saving of transportation costs and preventing the loss of time value. They suggested using two factors of time-value, decay level and rate of new returns, in the decision to centralize or decentralize the reverse network. A major finding of theirs is that centralization in a reverse network is no longer efficient when the two factors are low. As a result, when the rates of the two factors are low, high designing of a decentralization network to be responsive is appropriate.

Whereas Blackburn et al (2004) and Guide et al (2006) considered internal factors of a company, like the importance of time value, there are some papers that include external factors in the designing of reverse supply chains. Dowlatshahi (2005) included other strategic factors than time in developing an effective reverse logistics network. He pointed out 5 factors: strategic costs, strategic quality, customer service, environmental concerns, and political/legal concerns.

A strategic cost is a non-recurring cost incurred for the design and implementation of reverse logistics, such as the acquisition of additional costs or the cost of additional skilled employees.

Strategic quality focuses on the quality in a strategic perspective for remanufactured products. Complete customer satisfaction for a remanufactured product is as important as that in the forward supply chain (Mason 2002). Since customers and communities are demanding of manufactures the disposal of used products, designing reverse supply systems with an environmental perspective will bring competitive advantages. Companies in a reverse system are also constrained by legal responsibilities (Nagel & Meyer 1999).

Kumar & Yamaoka (2006) investigated a closed-loop supply chain system in the Japanese auto industry. Examining the relationship between reuse and disposal using their consumption data, they proposed for government to levy a recycle tax to control used car exports. Besides the papers above we observe some papers on designing reverse supply chains based on the process of reverse flow (Krikke et al 2004) and secondary markets (Tibben-Lembke 2001).

Tactical Papers

Production planning

Efficient operation in a reverse network setting requires special treatment due to the uncertainty with respect to quality, quantity, and timing of product returns. The disassembly process is not necessarily a symmetric image of assembly due to the large portion of manual labor usually needed for detaching components.

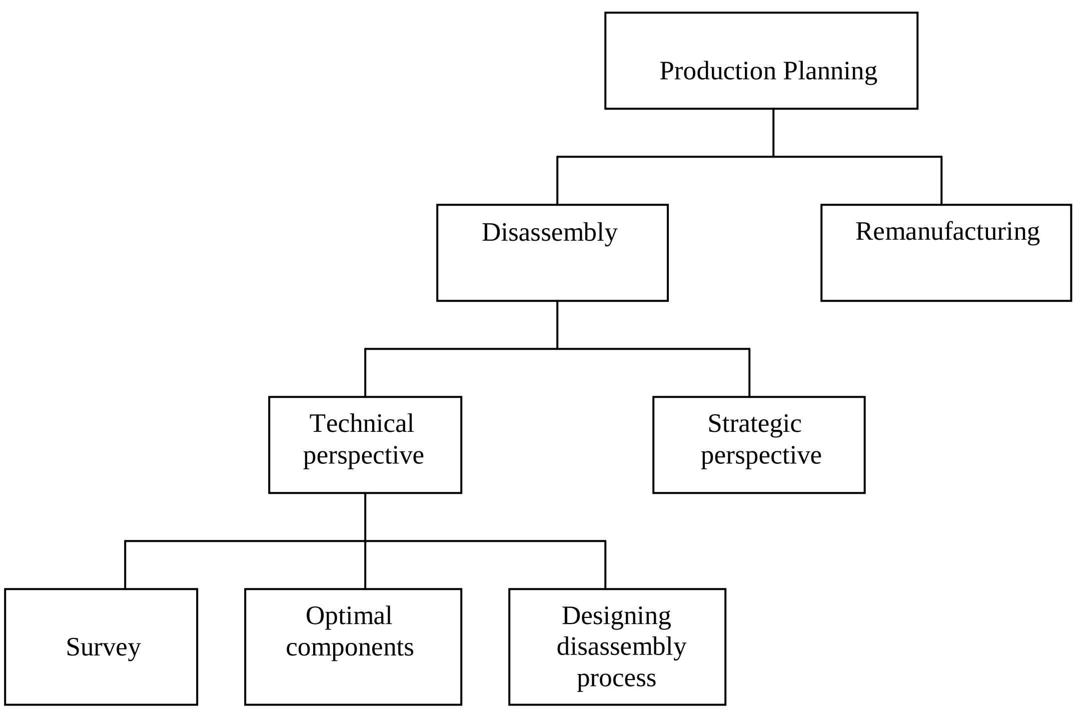


Figure 3. Hierarchy of the literature review in production planning

In addition the recovery rate from disassembled parts is not deterministic and routing processes in the remanufacturing process are also stochastic (Guide et al 2004). In this section papers are collected discussing how to schedule an efficient remanufacturing process taking the stochastic features into consideration.

Disassembly

1) technical perspective

Gungor & Gupta (2001) defines disassembly as a systematic process of separating a product into its constituent parts, components, subassemblies or other groupings. In manufacturing systems frequently disassembly and assembly processes are coupled, but disassembly has different characteristics in seven aspects (Lambert 2003):
a) disassembly is not usually performed to the full extent, which adds a decision variable about the disassembly depth. b) the disassembly process is often not reversible. c) the value added in disassembly is usually modest compared to that obtained in assembly.
d) uncertainty exists due to different quality conditions. e) an uncertainty exists in the supply of the products, f) variety exist in the product, g) and disassembly is mainly carried out by human labor. This asymmetry between disassembly and assembly due mainly to uncertainty has also been discussed by Guide et al (2003).

There is a plethora of literature on disassembly in academic journals, along with some survey papers on the topic. Lambert (2003) thoroughly examined the literature through 2002. He defined the hierarchy of reverse operation and thus the position of disassembly. According to his structure the reverse logistics level, which represents the reuse/recycle chain takes the highest position; the second level is the task planning level, encompassing disassembly line operations; the next level down is the sequence level, associated with product structures; the last level is a detailed level on component geometry. His study reviews papers largely on the third level, the sequence level, of the disassembly sequencing. The paper organized the collection of papers by disassembly theory, a component oriented approach, followed by a product oriented approach dividing the previous papers based on their methodology of mathematical programming and heuristics algorithms. Lambert (2003) also added a hierarchical tree approach and a reverse logistics approach. Recently a survey paper on the topic from the maintenance point of view was released (Kang & Xirouchakis 2006). They discuss the fundamentals of production planning, product representation models, and generating an optimal sequence for disassembly. These two survey papers present an in-depth analysis of the topic from an engineering perspective like artificial intelligence and pure theory perspective, being a lack in the managerial perspective on reverse supply chains, which is called for in the future. A good review on the topic is Gungor & Gupta (1999), the paper provides an overview of manufacturing and product recovery issues in a green environment perspective.

● Study on optimal components retrieval

Since not all of the disassembled parts are used in remanufacturing, one of the relevant questions in the disassembly plant is how many cores should be disassembled to fulfill the specified demand in a cost efficient manner (Langella 2007). Gupta & Taleb (1994) and Taleb & Gupta (1997) addressed the problem of disassembly scheduling allowing commonality among multiple parts. They showed an algorithm which is a reversal of Material Requriments Planning (MRP) (Gupta & Taleb 1994) and two algorithms of core algorithm, which determines the total disassembly requirement for the root items and allocation algorithm generating a disassembly schedule using the solution of the roots (Taleb & Gupta 1997).

Extending Taleb & Gupta (1997), Langella (2007) formulated an integer programming model and also developed heuristics for demand-driven-assembly. His work is a remedy to solutions for possible infeasibilities residing in the heuristics of Taleb & Gupta (1997). He also showed improvement of the model with numerical example by incorporating holding costs and decisions on whether to hold the leaf items or dispose of them in his heuristics. In line with these papers Kim et al (2006) suggested an integer programming model for assembly scheduling under capacity constraints and developed heuristics using Lagrangean relaxation. The above papers are concerned with retrieving optimal product components from returned products in a disassembly operation. Due to uncertainty and complexity within disassembly processes (Guide 1996) and thus an exponential search effort, papers on scheduling for component disassembly mainly focused on developing heuristic algorithms.

There is a research stream investigating recovery strategies based on the quality or time value of the products returned. An initial attempt was made by Krikke et al (1998). They distinguished five product recovery options for returned products or components as shown in table 9.

They proposed a two stage procedure mathematical model incorporating the composition of the product, the quality class, and the recovery and disposal options. The model includes technical criteria, commercial criteria, and ecological criteria for assessing feasibility. Similar mathematical programming for aggregate production planning and control was also developed by Jayaraman (2006).

Table 9
Outline of product recovery options. Source: Krikke et al (1998)

Options	Level of disassembly	Quality requirement	Resulting product
1. Repair	To product level	Restore product to working order	some parts repaired or replaced
2. Refurbishing	To module level	inspect and upgrade critical modules	some modules repaired or replaced
3. Remanufacturing	To part level	Inspect all modules/ parts and upgrade	Used and new modules/parts in new product
4. Cannibalization	Selective	Depends on use in retrieval of parts Others disposed of or recycled	Some parts reused other options
5. Recycling	To material level	Depends on use in remanufacturing	Materials used in new products

He case studied ReCellular, Inc, which trades new, used, and remanufactured handsets. ReCellular sorts the returned items into six categories based on the condition of the handsets. His program decides the optimal quantity of disassembly, disposal, remanufacture, and procurement with a given quality level.

Extending Krikke et al (1998), Tuenter (2006) presented a dynamic programming model for quality dependent recovery strategies in a given tree and associated profits for assembly. Two major parts that Tuenter added to Krikke et al (1998) are that firstly, multiple disassembly processes are allowed, and secondly, partial disassembly is possible in his model. Another difference of his model from Krikke et al (1998) is that he used three recovery options of disposal, recycling, and remanufacturing, taking information of time update into consideration. These three papers seek to find optimal disassembly strategies given quality information about the returned products.

Managers frequently are unaware of opportunities for improving performance of the supply chain by simply focusing on the technical challenger of reproduction (Guide et al 2003). For example, personal computers or electronic products have short life cycles and frequent updates. A bottleneck station in these electronics firms needs to be reinvestigated to improve revenue, not simply attempting to cut costs in the supply chain. The age information of returned items given optimal allocation of reverse activity, was studied by Guide et al (2005). They case studied the Hewlett-Packard Company (HP) in Germany to redesign its marketing procedure. Since HP products, like notebook or personal computers, carry much time value Guide et al (2005)'s linear programming model determined the best reuse option, product dispositioning, reconditioning, and selling, while minimizing time value loss.

● <u>Study on designing disassembly process</u>

a) Certainty

Even though the disassembly process has many uncertainties much of the literature on the topic considers non-destructive disassembly and deterministic sequencing. (Kang & Xirouchakis 2006). This section is devoted to reviewing some papers in this category. In a time constraint environment, firms need to schedule to ensure that all of their products are supplied within a specified time limit, which calls for minimizing setup time in their operation. Haase & Kimms (2000) developed mixed integer programming for lot sizing decisions and scheduling under a general production environment, when setup time for sequential operation is important. Dobson (1992) also presented Lagrangean relaxation heuristics, combined with a minimum spanning tree, for lot scheduling problems with sequence dependent setups. However, these models are not suitable for a disassembly operation since their model is general the disassembly part cannot be isolated in operation (Brander & Forsberg 2005).

Brander & Forsberg (2005) assumed a deterministic and constant disassembly rate with sequential setup times, whose computation of optimal sequence is a traveling salesman problem, and developed a lot-scheduling heuristic for disassembly processes. An interesting thing that they found is that continually running the operation is suboptimal and taking appropriate idle-time will improve the firm's performance in cost saving. An effort to find an optimal makespan where sequential operations of disassembly take place was studied by Veerakamolmal & Gupta (1998). They proposed two steps to minimize the idle time; first, a partial schedule for each subassembly is obtained. Second, they modify the partial schedule in the retrieval process. Lambert (1997, 1999, 2002) contributed by generating an optimal disassembly sequence, and the 1999 and 2002 used a linear programming method. Gungor & Gupta (2007) discussed balancing the disassembly line with an emphasis on the heuristic development of a genetic algorithm.

There have been attempts to study the disassembly procedure by defining the precedence of the disassembly tasks with a Petri-Net (PN) formulation. PN is a graphical and mathematical network structure originally developed to model the computer system (Moore et al 1998). PN defines as a five-tuple of {P,T,A, W, M_0}, where P is a set of locations; T is a set of transitions; $A \subseteq \{P \times T\} \cup \{T \times P\}$ is a set of directed arcs; W is a weight function on arcs; M_0 is an initial marking (Moore et al 1998). Moore et al (2001) indicated that the first work to use PN in disassembly is Zussman et al (1995) followed by Xirouchakis & Kiritsis (1996). However, they did not develop optimal solution methods.

Moore et al (1998) defined all feasible disassembly process in the PN and found the optimal solution that generates the least cost. Since PN is originally an NP-complete type of classification they suggested the near optimal solution by developing heuristics. So the limitation of their work is that the search procedure is exhaustive. Moore et al (2001) extends their previous 1998 work by adding a heuristics approach. Their algorithm is composed of three steps to in order to find near optimal solutions for disassembly procedures. Their first step is to generate a geometrically-based Disassembly Precedence Matrix (DPM). The second step is to generate the Disassembly Petri Net (DPN) for the DPM. Their third step is to apply the heuristics algorithm they developed, a major difference from their previous work. The heuristics algorithm is an alternation of a limited depth-search first for generating partial disassembly sequences, with a branch and bound to select the best set in terms of low cost. These works are mainly for developing algorithms or finding optimal solution dedicated to disassembly procedures. We notice that some authors applied a PN system on the integrated environment of assembly and disassembly (Seeluangsawat & Bohez 2004 and Tsinarakis et al 2005).

b) Uncertainty

The uncertainty pertaining to the whole reverse supply chain associated with product return has been well identified (Guide 2001). Besides that, the following can induce uncertainty in the sequential operation of disassembly (Gungor & Gupta 1998).

1) Defective parts or joints in the upcoming products.
2) Upgrade or downgrade of the product during consumer usage.
3) Disassembly damage.

For example, Brennan et al (1994) discussed the uncertainty arising from severe disparity between the demand for certain parts and yields from disassembly, resulting in a severe inventory control problem.

Some literature discusses the issues related to this uncertainty of disassembly operations. Gungor & Gupta (1998) presented three steps of methodology to efficiently handle defective parts occurring in their example of disassembly operation using a simple flashlight example. They assumed that when the parts are defective they would not be disassembled. Therefore the limitation of their methodology is not applicable for minimizing the amount of discarded bad parts and also is applicable mainly for items that operate with a small number of parts.

Along with this paper, the case of task failure, which has impacts on the sequential operation, was also touched by the same authors (Gungor & Gupta 2001). When task failures happen the remaining sequence of tasks will be disabled, causing early-leaving, skipping, or revisiting the process. Their major concern was how to assign tasks to workstations such that the effects of task failures will be minimized for later operation, using the application of task precedence graphs and matrices, including AND/OR relations. Fuzzy goal programming was implemented for a multi-criteria optimization model of disassembly-to-order systems under uncertainty by Kongar & Gupta (2006). The model considered both profit and environmental goals. The highlighting feature in their model is providing the number of EOL products to be taken back, as well as the number of reused, recycled, restored and disposed items. Therefore, their model captures not only the features of disassembly systems but also revenues, profits, transportation costs, and other costs of the reverse supply system.

One can start a disassembly process; however the plan should be adaptive or reactive to the current situation when uncertainty happens. A group of well organized papers discussing how to adapt to uncertain events in operations is well organized in the survey papers of Kang & Xirouchakis (2006). In summary regarding this issue, Zussman & Zhou (1999) considered product uncertainty. Kanai et al (1999) suggested a method of destructive disassembly such as the shredding of parts to fragments. Chevron et al (1996) proposed a predictive disassembly planning method when data for uncertain situations is inaccurate for coping with disassembly maintenance.

2) <u>Strategic perspective</u>

Previous papers discussed in the technical perspective, assume that the method of assessment in disassembly operations is given. However, this section collects literature examining the strategic viability of disassembly process in the context of economics and reverse supply systems.

Johnson & Wang (1995) presented four levels of disassembly strategy for maximizing recovery activity. The first level is to assess the economic valuation. In this level such factors as percentage of product divertible from disposal, the comparison of cost estimates between recovery versus disposal, trade-off considerations of learning curves, or legislation trends, and feasibility. After this level is assessed, the next interest lies in the designing of an optimal disassembly sequence generation. This level includes deciding sequence and precedence, tooling, clustering, and concurrence to maximize the efficiency. The third level they suggested is the optimization of disassembly, which includes numerous what-if analyses to estimate cost, benefit, and degree of assembly. The last level is a commitment for continuous improvement in disassembly design.

Two papers by the same authors (De Ron & Penev 1994, and Penev & De Ron 1996) discuss the strategic perspective of disassembly feasibility as well. They provided the issue in the disassembly process as follows.

1) Specify the valuable and poisonous materials and components per good
2) Maximize the profit for the execution of the disassembly operations
3) Find the less expensive way to remove the poisonous components and to obtain the valuable ones
4) Send the product to a shredder as soon as no profit or benefit can be realized by executing disassembly operation.

As a first step for determining disassembly they pointed to the product analysis. After identifying product components, all the components need to be represented in a graphical way. The graphical representation will indicate which disassembly operation needs to be performed. Then they recommended assessing the optimal disassembly strategy using mathematical expressions.

An appropriate beneficial treatment of end of life return products for the company is remanufacturing or recycling. However, the cost effects of the remanufacturing process are an important factor in deciding to what extent disassembly operation would be performed. Recently a paper with a more detailed method for feasibility in the car industry, defining the cost structures in disassembly time reduction, was released by Willems et al (2006). They proposed a linear programming model with the objective function of maximizing the total profit through the network. Based on scenarios in the linear program they identified an optimal disassembly strategy.

Remanufacturing

Scheduling production planning in the remanufacturing industry is more complex than that in the forward logistics system due to uncertainty in the disassembly operation, as well as other variants within the system. Much of the literature discussing assembly operations investigates each dispatching rule. Weng & Ren (2006) propose a composite dispatching rule and proved the robustness compared to other factors of rules. Similarly Huang (1984) suggests that the shortest processing time and assembly jobs be considered first, with shortest processing time as the tie-breaker. However, these papers did not consider the features within remanufacturing systems, such as probabilistic routing or other coordination caused by uncertainty. Guide (1996) examined the Drum-Buffer-Rope (DBR) scheduling method combined with other priority dispatching rules. Since DBR mainly focus on the Drum part, which indicates a constraint of the scheduling, other detailed data parts will be much streamlined. Using a simulation with actual data obtained from a remanufacturing industry, he showed the effectiveness of the method in production planning and control in a remanufacturing environment. Another paper by

Guide (1996) induced the same conclusion. The above papers are concerned with job shop floor assembly scheduling.

There is also a stream of research on scheduling the whole remanufacturing operation. Stochastic routing features in the remanufacturing facility and variability in demand were formulated by a Markov decision process in Nakashima et al (2004) under a single period producing a single-item product. In their study they concluded that smooth production in remanufacturing firms will be efficient under stochastic demand. One limitation of their study is that they did not incorporate the life cycle of the product. The whole remanufacturing system can be modeled after queuing theory due to the arrival and departure process in the operation. Souza et al (2002) provided an analytical model to decide the optimal product mix while maintaining an average flow time service level using a GI/G/1 open queuing network model. Contrary to intuition, their finding is that an unbalanced shop may maximize profit while maintaining a desired service level and trying to balance the shop may induce suboptimal effects. They also showed different outcomes when they used different dispatching priority rules in the remanufacturing system, proving the superiority of dynamic dispatching rules. A similar study was performed in the make-to-order remanufacturing system by Souza and Ketzenberg (2002).

Inventory

Due to the tendency towards stricter environmental regulation and the growing power of customers, product take-back policies and returns during and after usage from end customers are becoming more widely recognized among companies and end users.

Inventory management in the reverse supply chain is complicated, among other reasons because of the complexity of return flows and several options to choose for treating returned items (Tang & Grubbstrom 2005). The recovery options that companies can adopt for returned items include repair, refurbishing, remanufactuirng, cannibalization, and recycling, (Thierry et al 1995) and disposal options. Many research papers appeared in the literature on inventory theory of reverse logistics models for returned products.

There could be two large research streams among those papers; repairable inventory management and remanufacturing inventory management.

Repairable inventory management is concerned with returned items in reusable condition, which are common in the military: e.g., aircraft and aircraft components, to be repaired rather than discarded. Researchers on this topic have contributed by providing the optimal stocking of parts at bases (forward location) and a central depot facility where repairing takes place while maintaining predetermined service levels (Guide and Srivastava 1997). It is recommended to refer to Guide & Srivastava (1997) for a detailed review of the topic, and Allen and D'Esopo (1967) for ordering policy, Moinzadeh & Lee (1986) for batch size and stocking level, and Lee (1987) for emergency lateral transshipment.

Even though this research shares the same stream of handling returned products our concentration is more on the second research stream, remanufacturing inventory management, since in the repairable inventory each defective item triggers an immediate demand for a replacement, this property does not hold for every case of the product recovery setting in our study (Mahadevan et al 2003).

One of the criteria for classification of traditional inventory theory, which we will follow in this section, is the assumption of demand randomness, namely, a deterministic or stochastic model. Another common way to sort the type of stochastic model is either a periodic review or a continuous review. As we realize that this classification scheme is well fitted to our study in reverse logistics settings as well, we will apply this method to overview the inventory literature.

1) Deterministic Model

The deterministic model in inventory theory assumes that the demand in the future is known. Even though this is not always true in practice the deterministic model has proven robust and is very widely used to explain inventory phenomenon.

Schrady (1967) is considered the first paper discussing product repairing in a deterministic context (Choi et al 2007). Assuming fixed lead times for external orders and recovery he derived a batch size for outside procurement Q_p and batch size of repaired unit Q_R as follows. $Q_p^* = \sqrt{\dfrac{2A_p d(1-r)}{h_1(1-r)+h_2 r}}$ and $Q_R^* = \sqrt{\dfrac{2A_R d}{h_1 + h_2}}$

,where A_p is the fixed cost for initiating the repair cycle, and A_R is a fixed order cost, h_1 is a holding cost for new or repaired items, and h_2 is a holding cost for items needing to be repaired, *r* is a repair rate, and *d* is a demand. Here we observe that the formula is similar to the traditional EOQ model. An extension was made to the Schrady (1967) approach by Nahmias and Rivera (1979), they considered a finite repair rate, which was assumed infinite in the Schrady. These two papers are about one echelon model.

Richter (1996), Richter (1996), and Richter and Dobos (1999) were studying different situations and developed a two-stage model. They considered two shops: first and second shop. The second shop is for collecting the used product and storing for a specified collection period T until the products are brought to the first shop or disposed of somewhere outside the system. The first shop needs to determine EOQ for new products and repairable products to meet the demand in the second shop. Their major interest is to define the relationship between the disposal rate and setup times. They discussed some cases of existence and nonexistence of the optimal disposal rate. The situation that these three papers assumed is more close to the practice of current reverse logistics due to the consideration of the collection facility within the model. Richter (1997) investigated the optimal inventory holding policy and reported that either 'dispose of all' or 'not disposal at all' was proved to be optimal. Similar results were reported in Dobos & Richter (2004), proving the optimality of the pure strategy in remanufacturing and recycling; i.e. minimization of inventory holding costs can be achieved by either remanufacturing all product or recycling all.

Koh et al (2002) also assumed a situation of collection first and recovery at the second stage, finding the joint EOQ and EPQ for stationary demand satisfied by the new components or remanufactured product. They concluded that lot sizes are easily found analytically, but integer variables of the number of orders and the number of setups are not analytically found. This paper is closely related to Dobos & Richter (2000) in that Dobos & Richter (2000) is a full proof of finding integer values for the number of orders and setups attempted in the previous work of Richter & Dobos (1999).

Despite the similarity in the assumptions, there are a few differences between Koh et al (2002) and Richter's work mentioned earlier; first, repair capacity was limited in Koh et al whereas it was infinite in Richter's, second, Koh et al considered parametric behavior for the case of (1,R) and (R,1) separately, but Richters studied (P,R) combined in two serially connected systems, where P denotes the number of orders for newly purchased items and R the number of recovery setups in a cycle. Oh and Hwang (2006) also studied similar two stage situations, which are mainly applicable for recycling systems.

Extending Koh (2002), Choi et al (2007) studied the optimal sequences of number of orders for serviceable products and the number of setups in the recovery shop by treating them as decision variables.

2) Stochastic model

A stochastic model in inventory theory for product recovery assumes stochastic end product demands and stochastic returns of end used items. One of the popular classification schemes for stochastic models in the traditional inventory is whether fixing the ordering time horizon or fixing the order quantity, namely, the periodic review and continuous review models. In the product recovery setting a stochastic model also can be divided by periodic review and continuous review. Therefore, in the sequel, we apply this classification scheme to examine inventory theory under stochastic environments in the reverse supply system.

- Periodic review

Allowing backlogging, Simpson (1977) studied the situation of returns arriving at each remanufacturing facility, where disposal or remanufacturing decisions are made assuming no lead times in remanufacturing and purchasing. Using a dynamic programming method he provided the optimal solution for the three parameters: scrap down to level, repair up to level, and purchase up to level. Inderfurth (1997) investigated the lead time effects for Simpson's case. He identified that when the lead times for both purchasing and remanufacturing are the same the result for Simpson holds, but the matter is complicated when the two lead times are not identical due to the existence of two-state variables.

Extending Inderfurth (1997), Kiesmuller & Scherer (2003) provided both exact and approximation methods to solve three variables that the previous two studied: how many items to produce, remanufacture, and dispose of in a finite time horizon. The extension is that they examined both models without keeping of returns and with keeping of the returned items, assuming that the lead times between remanufacturing and manufacturing are the same. Considering the complexity indicated by Inderfurth (1997) of obtaining an optimal solution for the tree parameters discussed above, Kiesmuller (2003) attempted to find an optimal solution for the three parameters when the lead times are different by integrating information about inventory position for both remanufacturing and manufacturing systems.

The question of multiple echelons for inventory theory has been well studied since Clark and Scarf (1960). Extending Simpson (1978) and Inderfurth (1997), Decroix (2006) generalized the analysis of a multi-echelon system in a product recovery situation. His fundamental concept for solving a multi-echelon system is to decompose the system into a single-stage system and the optimal policy for the single stage system turned out to be a simple structure.

Finding an optimal (S, M) policy, where S is a produce up to and M is a remanufacture up to, is still a challenging task. Kiesmuller and Minner (2003) sought to find the optimal (S, M) policy by applying a news vendor model approach. In their model optimal S is chosen such that the probability that the demand does not exceed the inventory level is equal to the ratio of the underage cost per unit (c_u) and the sum of underage and overage per unit ($c_u + c_o$), $F(S) = \frac{c_u}{c_u + c_o}$, where *F* denotes the cumulative demand distribution.

Even though they examined both cases of when the two lead times are the same and different, a limitation of their model is a non-consideration of disposal options. All of the papers above are concerned with an optimal solution for finding how many items to manufacture, remanufacture, and optionally dispose of.

There are a few papers that focused on inventory management during an assembly/disassembly operation in the remanufacturing process, handling the recovery of parts of products or the balancing of component inventories. DeCroix & Zipkin (2005) considered an assembly system consisting of N items with precedence relations. Each period *t*, stochastic demand *D* for new items and *R*, return will be realized. As some portion of *J* is recovered from the process they will join in the serviceable inventory. Here, since the demand and return are independent, balancing and sequencing in the assembly operation is an issue. They showed that uncertain returns can cause the unbalancing of the operation and presented two heuristics to mitigate the impact of various factors arising from uncertain returns.

When the decomposition process is focused in relation to inventory theory, issue is a stochastic property of decomposition. Takahashi et al (2007) proposed two policies considering the decomposition process and compared the performance of the two by using a Markov analysis.

E-commerce returns have a slightly different return practice from end of use returns. Legislation requires the manufacturers to accept product returns, purchased via a mail order, with full price, if the condition of the product is good. Consequently, return volumes in an e-commerce setting is as high are 35% of initial purchases (Gentry 1999, and Meyer 1999). Vlachos & Dekker (2003) studied the e-commerce industry using a news vendor model analysis and presented guidelines for decision making on choosing between return options, and some properties of the optimal solutions.

- <u>Continuous review</u>

In a continuous review production system, there are two ways to transfer the inventories, namely, a PUSH strategy and a PULL strategy.

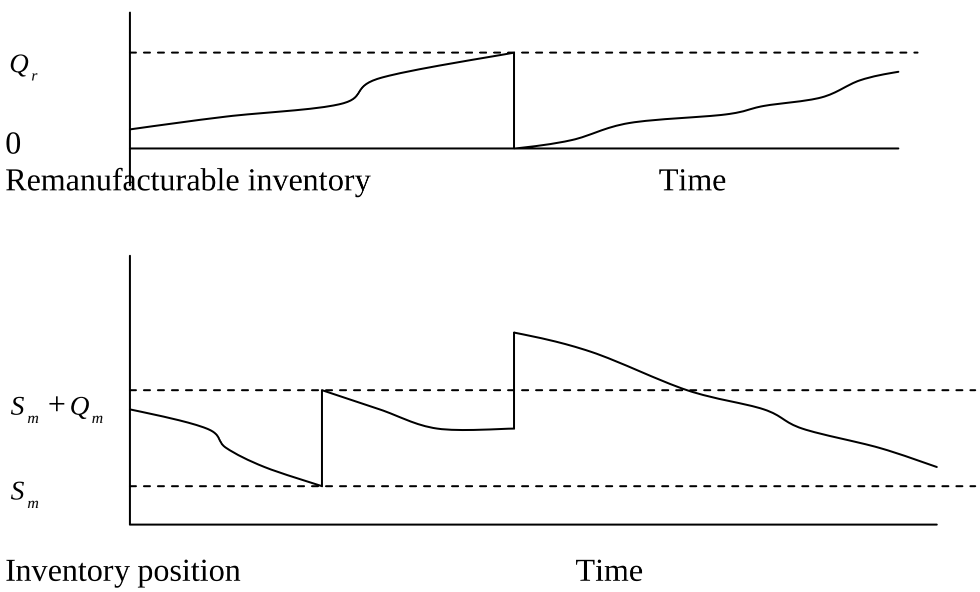


Figure 4. PUSH strategy (Van Der Laan et al, 1999)

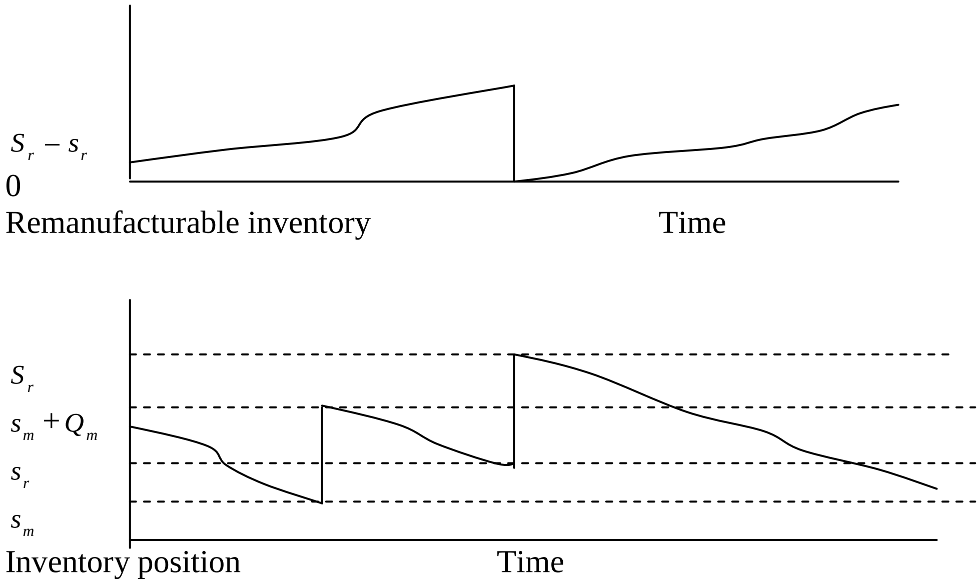


Figure 5. PULL strategy (Van Der Laan et al, 1999)

(s_m, Q_m, Q_r) A PUSH policy can be described as follows: When Q_r of remanufacturable items are collected the batch of Q_r is pushed to the remanufacturing process, which results in an increase by Q_r in the serviceable inventory without considering the situation in the serviceable inventory. Manufacturing starts whenever the serviceable inventory drops to s_m +1.

(s_m, Q_m, s_r, S_r) A PULL policy is to pull the inventory as needed in the serviceable inventory. As soon as the serviceable inventory position $I_s(t)$ drops below the level s_r +1, it is checked whether sufficient remanufacturable inventory is available on-hand to increase the serviceable inventory position to the level S_r. If sufficient remanufacturable inventory is present, a batch of size S_r - $I_s(t)$ enters the remanufacturing process to be remanufactured. However, when the serviceable inventory position drops below s_m +1 and a still insufficient manufacturing order size Q_m is placed to increase the serviceable inventory (Van der Laan et al, 1999).

Including Van der Laan et al (1999), there are several papers discussing the two strategies. Those include Van der Laan and Teunter (2006) that presents heuristics for parameter calculation of (s, Q) policy with a push and pull strategy and Teunter et al (2004) which is a study of the case when the remanufacturing lead time is much slower than that of manufacturing. Van der Laan & Salomon (1997) is a study extending the pure PUSH and PULL strategy by adding disposal options. The authors reported the superiority of PULL-disposal strategy over PUSH-disposal strategy when remanufacturing inventory is valued much lower than serviceable inventory. However, they indicated that two policies considering disposal are not robust to changes in regard to demand and returns.

Some authors investigated the lead time effects in the two strategy system. Van der Lann et al (1999) comprehensively treated the issue in terms of the variability and duration of lead times. They reported that in costs the duration of manufacturing lead time has larger influences than that of remanufacturing. Also it was found that cost increases are more sensitive to a larger variability in remanufacturing lead times than to a larger variability in the counterpart. Inderfurth & Van der Laan (2001) is another paper proving the impacts of lead time on system performance.

Another stream of research in the continuous review model is the application of traditional simple (s, Q) policy into the manufacturing/remanufacturing system. Fleischmann et al (2002), Van der Laan et al (1996), and Fleischmann & Kuik (2003) are classified into this stream. Among those, Van der Laan et al (1996) is an attempt to study the system when disposal options are considered. Teunter & Vlachos (2002) is also an in-depth analysis of disposal options, and reported some cases where the consideration of disposal options is not appropriate or not much ineffective. For example, they concluded that when remanufacturing is not very profitable, including a disposal options is irrelevant to profit generation.

CHAPTER THREE

RESEARCH DESIGN

Overview of problems and objectives

Description of UPS business environments

United Parcel Service Inc, commonly known as UPS, was founded by 19-year-old Jim Casey on August 28th, 1907 as a delivery service provider. Celebrating its 100th anniversary of business in the year 2007, it is headquartered in Sandy Springs, Georgia, USA, and delivers 15 million packages a day in over 200 countries around the world. Its revenue was up to $47.547 billion in 2006 and they had 427,700 employees in 2007 (Weber 2007). As a globally-leading logistics firm, UPS specializes in delivery services and the transportation businesses. They operate UPS stores, a franchise network for retail shipping and postal services. They are also involved in air cargo, consulting, risk management, and other mail services domestically and globally.

In addition to these service offerings, UPS is deeply involved in constructing a green supply chain system in a sustaining environment. Since their business mainly depends on vehicle operations UPS strives to maintain top fleet condition for delivery through Preventative Maintenance Inspections (PMI), ensuring better an engine status, lower fuel consumption, and emissions (ups.com). UPS also has committed to recycling, the proper treatment of hazardous waste, decreased water consumption and increased conservation.

UPS is called a third party logistics (3PL) business since it provides outsourced or third party services of supply chain management function specialized in integrated warehousing and transportation services. These 3PLs, such as UPS, FedEx, ASTRA and

GENCO, deliver not only the products and materials from manufacturing facilities to distribution centers or retail stores (forward flow) but also aid in collecting and managing product returns from customers (reverse flow) tailored into customer's needs, based on market conditions and demand (Krumwiede & Sheu 2002). The advantages of outsourcing logistics for companies are 1) reduction in overall logistics cost, 2) gaining high quality customer services, 3) commitment to the core competencies of their own firm, and 4) faster and more efficient deliveries (Buco 2006).

Providing 3PL functioning, UPS currently runs five major warehouses in Cincinnati, OH, Dallas, TX, Los Angeles, CA, San Jose, CA, and one hub in Louisville, KY. These five warehouses perform both forward and reverse logistics functioning for UPS customers such as Motorola, Hewlett-Packard (HP), Dell, Toshiba, Sprint, and others. Forward logistics for UPS is the traditional activity of moving items for its clients. It provides delivery of the needed items, and amount, directly from the manufacturer's production facilities and then later ships the items to the hub for final distribution to customers. UPS is also involved in reverse logistics activities. Reverse logistics services provided by UPS comprise the movement of returned products and the treatment of those products afterwards in its dedicated warehouse.

Observing the growth of its business in both forward and reverse supply chain systems, UPS is currently pursuing a strategic edge as a 3PL by expanding existing facilities or opening new buildings at new locations in an optimal manner, which is a major focus of this dissertation.

Methodology selection

Fundamentally both the reduced and full models are NP-hard problems and are mixed integer nonlinear programming formulations for the design of facility location problem, achieving maximum benefit by operating forward and reverse flows simultaneously, which implies a greater challenge for solving relative to a linear formulation. In addition to being an NP-hard type and the nonlinearity, complexity was added to the models when the models have to solve 36 decision variables and 1,008 constraints. A commercial software professional was contacted to address this issue and he expressed a deep concern as to solution time and computer system capacity. Literature is abundant on how to circumvent these solution time and computer system capacity problems, and one of them is by developing and applying heuristics to obtain a near optimal solution (Ko & Evans, 2007).

A heuristic algorithm is a strategy that does not examine all possible solutions to a problem. Therefore, a heuristic algorithm seeks a "good enough" solution within a plausible amount of time to execute implying that a solution is close to the optimal, but may or may not be optimal. However, a heuristics approach was not implemented in this study even though we present algorithm at the end of the dissertation, and a few reasons are prominent in deciding on a methodology different from heuristics.

1) Ko & Evans (2007) has proposed a heuristic algorithm applicable to the forward and reverse logistics system in UPS. In this author's opinion, their paper focused on developing a methodology of heuristics. They used a genetic algorithm and proved that their proposed algorithm solved all the test cases in a reasonable amount of computation time and reported that the gap of objective values between the optimal and the heuristic

was narrow enough to be 0.78 % to 8.18%. Therefore, considering the fact that our reduced model is very close to their model, developing and implementing a heuristic was not an extremely value added activity since their heuristics method can be used by those who are interested in it.

2) The primary objective of this study is to conduct a confirmatory analysis allowing further investigation of the problems faced by UPS in their logistics operation. In order to achieve this goal a statistical analysis tool would be a good fit for our study. Clearly, conclusions drawn by statistical method are inferior to that obtained by commercial software for nonlinear solutions, but numerous applied studies have interpreted phenomena of interest based on statistical implications.

Hence, we use statistical methods to examine the hypothesis as an alternative to solving a nonlinear formulation directly. The solution procedure applying the statistical method is as follows:

1) Convert nonlinear decision variables to linear variables by constructing possible ranges for those nonlinear variables aided by a UPS manager to obtain appropriate ranges. This process will result in the transformation of both models from nonlinear to linear formulations in nature.

2) Develop a Monte Carlo simulation devising scenarios and solve the linear formulation using commercial software.

3) Use a statistical approach, such as regression analysis and confidence interval constructions to test the hypothesis and conduct exploratory analysis as needed.

In step 2) the solution procedure mentioned above states a development of a simulation. The purpose of the simulation of the UPS logistics system in this study is to present a variety of possible optimal outcomes for a given UPS operating environment. The UPS logistics system is distinguished in size from small companies committed to logistics, and from companies that only perform either forward or reverse logistics activities, because of the fact that the UPS supply-chain team carries both forward and reverse logistic activities, and from manufacturing firms which also transport items in that UPS is a non-manufacturing firm and is a 3PL.

This complexity, and some uncertainty in data stemming from magnitude, dual logistics operations, and the 3PL characteristics of UPS, can be well represented by simulating UPS operations in order to grasp certain characteristics in deciding facility locations.

Acquiring correct data for the study is an important step in order to draw meaningful insight out of this study. In contrast to the definitive data points, implying constant parameters, offered by the UPS operations manager, some portion of the data was obtained in the form of ranges as the best representatives for those parameters. Throughout this study we call the parameters whose values are given as fixed constants "fixed parameters", and the parameters whose values are given in ranges "ranged parameters". To circumvent the impreciseness of ranged parameters the simulation organized with scenarios could provide a meaningful result for a conclusive approach, getting around the indefiniteness of some parameter points. A more detailed rational for using a Monte Carlo simulation follows in the next section.

Mathematical Model

<u>Full model</u>

Maximize:

$$\left\| \sum_t \sum_w \sum_u \sum_m \sum_p (PFCW_{twump})(XFCW_{twump}) + \sum_t \sum_w \sum_u \sum_m \sum_p (PFNW_{twump})(XFNW_{twump}) \right\|$$

Total service revenue paid by client *l* for forward flow of product *p* from warehouse *w* to customer *u* via mode *m*.

$$-\left(\sum_t \sum_w \sum_p (fonw_{twp})(capNW_{twp})(YNW_{twp})\right)$$

Total fixed cost for opening new warehouse *w* at time *t*

$$-\left(\sum_t \sum_w \sum_p (fecw_{twp})(g_p)(ECPCW_{twp})(YECW_{twp}) + \sum_t \sum_w \sum_p (fenw_{twp})(g_p)(ECPNW_{twp})(YENW_{twp})\right)$$

Total fixed cost for expanding current warehouse and new warehouse *w* at time *t*

$$-\left(\sum_t \sum_w \sum_u \sum_m \sum_p (fhcw_{twup})(XFCW_{twump}) + \sum_t \sum_w \sum_u \sum_m \sum_p (fhnw_{twup})(XFNW_{twump})\right)$$

Total storage or handling cost for product *p* in warehouse *w* at time *t*.

$$-\left\|\left(\sum_t \sum_w \sum_u \sum_m \sum_p \begin{matrix}((tcost_{tmp})(TPORTION_{tmp}) \\ ((distc_{twump})(XFCW_{twump}) + (distn_{twump})(XFNW_{twump}))))\end{matrix}\right\|$$

Total transportation cost for product *p* from warehouse *w* to customer *u* via mode *m* for forward service at time *t*.

$$+\left\|\left(\sum_t \sum_u \sum_w \sum_m \sum_p (CPR_{tuwmp})(XRCW_{tuwmp}) + \sum_t \sum_u \sum_w \sum_m \sum_p (NPR_{tuwmp})(XRNW_{tuwmp})\right)\right\|$$

Total service revenue for reverse flow for product *p* from *u* to warehouse *w* via mode *m* at time *t*. This equation describes that the service revenue paid by clients will be optimally decided in the model. Therefore the UPS will use this price in negotiating with its clients.

$$-\left\|\left(\sum_t \sum_u \sum_w \sum_m \sum_p \begin{matrix}((tcost_{tmp})(TPORTION_{tuwmp}) \\ ((distc_{tuwmp})(XRCW_{tuwmp}) + (distn_{tuwmp})(XRNW_{tuwmp}))))\end{matrix}\right\|$$

Total transportation cost of reverse flow for product p from customer u to warehouse w via mode m at time t.

$$-\left(\sum_t \sum_u \sum_w \sum_m \sum_p (fhcr_{twp})(XRCW_{tuwmp}) + \sum_t \sum_u \sum_w \sum_m \sum_p (fhnr_{twp})(XRNW_{tuwmp})\right)$$

Total storage cost for returned product before they are shipped to repair center via mode m at time t.

$$-\left(\sum_t \sum_w \sum_r (fonr_{twr})(capNR_{twrp})(YNR_{twrp})\right)$$

Total fixed cost for opening new repair center r at time t

$$-\left(\sum_t \sum_w \sum_r \sum_p (fecr_{twrp})(g_p)(ECPCR_{twrp})(YECR_{twrp})\right.$$
$$\left.+\sum_t \sum_w \sum_r \sum_p (fenr_{twrp})(g_p)(ECPNR_{twrp})(YENR_{twrp})\right)$$

Total fixed cost for expanding repair center r at time t

$$-\,||\,\Big(\sum_t \sum_w \sum_w \sum_r \sum_m \sum_p \frac{((tcost_{tmp})(distcc_{twwrmp})(TPORTION_{tmp}))}{(XCWCR_{twwrmp})}$$
$$+\sum_t \sum_w \sum_w \sum_r \sum_m \sum_p \frac{((tcost_{tmp})(distcn_{twwrmp})(TPORTION_{tmp}))}{(XCWNR_{twwrmp})}$$
$$+\sum_t \sum_w \sum_w \sum_r \sum_m \sum_p \frac{((tcost_{tmp})(distnc_{twwrmp})(TPORTION_{tmp}))}{(XNWCR_{twwrmp})}$$
$$+\sum_t \sum_w \sum_w \sum_r \sum_m \sum_p \frac{((tcost_{tmp})(distnn_{twwrmp})(TPORTION_{tmp}))}{(XNWNR_{twwrmp})}\Big)\,||$$

Total transportation cost for returned item p from warehouse w to repair center r via mode m at time t.

$$-\left(\sum_t \sum_w \sum_r \sum_p (rcqp_{twrp})(XQCR_{twrp})\right.$$
$$\left.+\sum_t \sum_w \sum_r \sum_p (rnqp_{twrp})(XQNR_{twrp})\right)$$

Total in-house quality checking cost.

$$-\left(\sum_t \sum_w \sum_r \sum_p (rpcp_{twrp})(XRPCR_{twrp})\right.$$
$$\left.+\sum_t \sum_w \sum_r \sum_p (rpnp_{twrp})(XRPNR_{twrp})\right)$$

Total in-house repairing cost.

$$- \| (\sum_t \sum_w \sum_r \sum_d \sum_p (PMCR_{twrdp})(XMCR_{twrdp}) + \sum_t \sum_w \sum_r \sum_d \sum_p (PMNR_{twrdp})(XMNR_{twrdp})) \|$$

Total outsourcing cost for remanufacturing for product *p* outsourced to *d* from repair center *r* at time *t*. All remanufacturing is done by outsourcing. Therefore UPS needs to decide the contract price for remanufacturing to different manufacturers on outsourcing.

$$- (\sum_t \sum_w \sum_r \sum_e \sum_p (rlcp_{twrep})(XLCR_{twrep}) + \sum_t \sum_w \sum_r \sum_e \sum_p (rlnp_{twrep})(XLNR_{twrep}))$$

Total recycling cost from Louisville and Memphis repair centers to recycling facilities *e* for product *p*.

Subject To:

<u>Constraint 1:</u>

$$\sum_w \sum_m XFCW_{twump} + \sum_w \sum_m XFNW_{twump} \leq CDMD_{tup} + NDMD_{tup}, \ \forall t, u, p$$

$, where$

$$Ln(CDMD_{tup}) = Ln(a_{tup}) + (b_{tup})Ln(((\sum_w \sum_m PFCW_{twump}))))$$

$$Ln(NDMD_{tup}) = Ln(a_{tup}) + (b_{tup})Ln(((\sum_w \sum_m PFNW_{twump}))))$$

$,$

$CDMD_{tup} = demand\ for\ product\ p\ in\ current\ location\ at\ time\ t$

$NDMD_{tup} = demand\ for\ product\ p\ in\ new\ location\ at\ time\ t$

$a_{tup} = primary\ demand\ for\ product\ p\ in\ customer\ u\ at\ time\ t$

$b_{tup} = price\ elasticity of\ UPS\ for\ product\ p\ in\ cusotmer\ u\ at\ time\ t$

$PFCW_{twump} = current\ price\ of\ UPS\ for\ product\ p\ at\ time\ t$

$PFNW_{twump} = new\ price\ of\ UPS\ for\ product\ p\ at\ time\ t$

Amount of all forwarded items from client's location, from the current and new warehouses and will meet the demand of customers.

Constraint 2:

$$\sum_u \sum_m XFCW_{twump} + \sum_u \sum_m XRCW_{tuwmp}$$
$$\leq capCW_{twp} + (\sum_p ECPCW_{twp})(YECW_{twp}), \forall t, w, p$$

Storage in current warehouses cannot exceed the capacity limit unless expanded.

Constraint 3:

$$\sum_u \sum_m XFNW_{twump} + \sum_u \sum_m XRNW_{tuwmp}$$
$$\leq (capNW_{twp})(YNW_{twp}) + (ECPNW_{twp})(YENW_{twp}), \forall t, w, p$$

Storage in new warehouses cannot exceed the capacity limit unless expanded.

Constraint 4:

$$YNW_{twp} + YENW_{twp} \leq 1, \forall t, w, p$$

New opening and expansion cannot be made simultaneously.

Constraint 5:

$$\sum_t YNW_{twp} \leq 1, \forall w, p$$

New opening is made only once

Constraint 6:

$$YENW_{twp} \leq \sum_{\tau=1}^{t} YNW_{\tau wp}, \forall t, w, p$$

Expansion can be made only when opening is done.

Constraint 7:

$$\sum_w \sum_m XRCW_{tuwmp} + \sum_w \sum_m XRNW_{tuwmp}$$
$$= (rtn_{tup})(\sum_w \sum_m XFCW_{t-1wump} + \sum_w \sum_m XFNW_{t-1wump}), \forall t, u, p$$

Number of all returned items to the warehouses will be the return rate of the previous outflow to customers.

Constraint 8:

$$\sum_w \sum_r \sum_m XCWCR_{twwrmp} + \sum_w \sum_r \sum_m XCWNR_{twwrmp} = \sum_u \sum_m XRCW_{tuwmp}, \forall t, w, p$$

Balance equation. The amount transported from current warehouses to repair centers in both current and new warehouses *w* is the same as the amount sent to repair centers at current warehouses from customer points.

Constraint 9:

$$\sum_{w}\sum_{r}\sum_{m} XNWCR_{twwrmp} + \sum_{w}\sum_{r}\sum_{m} XNWNR_{twwrmp} = \sum_{u}\sum_{m} XRNW_{tuwmp}, \forall t, w, p$$

Balance equation. The amount transported from new warehouses to repair centers in both current and new warehouses *w* is same as the amount sent to repair centers at new warehouses from customer points.

Constraint 10:

$$\sum_{w}\sum_{m}\sum_{p} XCWCR_{twwrmp} + \sum_{w}\sum_{m}\sum_{p} XNWCR_{twwrmp}$$
$$\leq capCR_{twrp} + (\sum_{p} ECPCR_{twrp})(YECR_{twrp}), \forall t, w, r$$

Storages for current repair center cannot exceed the capacity limit unless expanded.

Constraint 11:

$$\sum_{w}\sum_{m}\sum_{p} XCWNR_{twwrmp} + \sum_{w}\sum_{m}\sum_{p} XNWNR_{twwrmp}$$
$$\leq (capNR_{twrp})(YNR_{twrp}) + (\sum_{p} ECPNR_{twrp})(YENR_{twrp}), \forall t, w, r$$

Storages for new repair center cannot exceed the capacity limit unless opened and expanded.

Constraint 12:

$$\sum_{t} YNR_{twrp} \leq 1, \forall w, r, p$$

$$YNR_{twrp} \leq YNW_{twp}, \forall t, w, p$$

New opening is made only once
New repair center cannot be open unless new facility is open

Constraint 13:

$$YNR_{twrp} + YENR_{twrp} \leq 1, \forall t, r, p$$

New opening and expansion cannot be made simultaneously.

Constraint 14:

$$YENR_{twrp} \leq \sum_{\tau=1}^{t} YNR_{twrp}, \forall t, w, r, p$$

Expansion can be made only when opening is done.

Constraint 15:

$$XQCR_{twrp} = \sum_{w}\sum_{m} XCWCR_{twwrmp} + \sum_{w}\sum_{m} XNWCR_{twwrmp}, \forall t, r, p$$

Constraint 16:

$$XQNR_{twrp} = \sum_{w}\sum_{m} XCWNR_{twwrmp} + \sum_{w}\sum_{m} XNWNR_{twwrmp}, \forall t, r, p$$

Balance equation. The amount sent for quality check at the current repair center is the same as the amount sent to the repair center. Same for NR.

Constraint 17:

$$XRPCR_{twrp} + \sum_{d} XMCR_{twrdp} + \sum_{e} XLCR_{twrep} = XQCR_{twrp}, \forall t, w, r, p$$

Constraint 18:

$$XRPNR_{twrp} + \sum_{d} XMNR_{twrdp} + \sum_{e} XLNR_{twrep} = XQNR_{twrp}, \forall t, w, r, p$$

Balance equation. The amount of in-house repairing, outsourced items and recycled items for remanufacturing is same as the amount sent to quality checking.

Constraint 19:

$$XRPCR_{twrp} + XRPNR_{twrp} = (rpPortion)(XQCR_{twrp} + XQCR_{twrp}), \forall t, w, r, p$$

Balance equation. The amount of in-house repairing represents 88% of returned product.

Constraint 20:

$$\sum_{d} XMCR_{twrdp} + \sum_{d} XMNR_{twrdp} = (rmPortion)(XQCR_{twrp} + XQNR_{twrp}), \forall t, w, r, p$$

Balance equation. The amount of outsourcing represents 5% of returned product.

Constraint 21:

$$\sum_{e} XLCR_{twrep} + \sum_{e} XLNR_{twrep} = (rlPortion)(XQCR_{twrp} + XQNR_{twrp}), \forall t, w, r, p$$

Balance equation. The amount of recycling represents 7% of returned product.

Constraint 22:

Non negativity constraints for all decision variables.

Reduced model

Ko & Evans (2007) is the best available for a reduced model

This current study is comprised of two research thrusts of 3PLs and forward-reverse logistics. The major function of 3PLs' is to provide logistics services for their customers. We observe many papers discussing business activities performed by the 3PLs. According to Arroyo et al (2006), the literature on 3PLs can be classified into three categories: 1) studies on the main benefits of 3PLs [cost savings, operational efficiency, flexibility, and improved customer services]. 2) Logistics outsourcing processes from the point of view of a single firm. 3) Global 3PL strategies. Since reverse logistics is emerging as an important entity in the supply chain system (Lund 1996, Giuntini & Gaudette 2003, Srivastava 2007, Blumberg 1999), 3PLs get involved in facilitating product returns for their clients' by scheduling the pickup, transportation, and tracking the status of returned goods. Out of many papers on 3PLs a few papers discussing reverse logistics were observed: Krumwiede & Sheu (2002), which reviews the current industry practice of reverse logistics, and Ko & Evans (2007), which we value highly in our analysis.

As environmental concerns and economic motivation from returned products increase, growing attention has been paid to reverse logistics over the last few decades (Wu & Dunn 1995, Yao 2005). One of the interests that firms have is how to design reverse logistics system efficiently so that they can extract as much value as possible out of the product returns (Fleischmann et al 2001, Beamon & Fernandez 2004, Lickens & Vandaele 2007). We have organized the relevant literature on the issue in the previous section of this dissertation. Structural asymmetry between forward and reverse logistics has influenced the research on reverse channel facility location problems and the examination of how to accommodate the product return system separately from the forward logistics system. However, as indicated by Fleischmann et al (2001), most firms that plan to construct reverse logistics systems have already established the infra structure of their own forward logistics systems. This important notion has motivated both the academicians and practitioners to integrate the two systems, seeking combination effects out of each. For example, designing a warehouse for both new products and returned products at the same location will save travel costs for delivering new items from the warehouse and shipping back to the same place to store the old products.

Another illustration could be the combination of manufacturing and remanufacturing centers. The benefit would be to sharing technology, machine tools, and the proficiencies of skilled workers. Ko & Evans (2007) highlights this synergy effect through combining forward and reverse logistics in the UPS Company. To this author's knowledge, Ko & Evans (2007) is the sole paper published in an academic journal discussing facility location problems in a reverse logistics setting for the UPS firm. The paper is a multi-period, two-echelon, multi-commodity, and capacitated location model.

The model includes four entities; client facilities, warehouse, repair center, and customers. Currently, UPS performs both forward and reverse commodity flows. In the forward flow, the clients or a manufacturer will store the items in the warehouse operated by UPS. The stored goods will eventually be transported out to the customers in the market place. For reverse flow, the model explains that items are gathered at the repair center where the manipulation of returned goods is carried out. An outstanding feature of the model is the consideration of a hybrid warehouse with a repair center installed at the same location. The environments of reverse and hybrid facilities in Ko & Evans (2007) model also represents the best practice of reverse flows performed in UPS. For example, the hybrid warehouse-repair center represents the consolidation point, also called hub, in Louisville, Kentucky. Their model contains a nonlinear feature in formulation with the objective function of minimizing total cost.

A major contribution of the paper is to develop the heuristic model using a genetic algorithm motivated by the model classification of NP-hard type. Although Ko & Evans (2007) is the only paper directly related to our topic for UPS systems, the paper describes the core logistics activities accurately overall for UPS. Consequently, the Ko & Evans (2007) model in our study will serve as a the reduced model, which is defined as the best model in the literature to represent the UPS system.

Reduced model formulation

Maximize:

$$\sum_{t}\sum_{w}\sum_{u}\sum_{m}\sum_{p}(ranged\_PFCW_{twump})(XFCW_{twump})$$
$$+\sum_{t}\sum_{w}\sum_{u}\sum_{m}\sum_{p}(ranged\_PFNW_{twump})(XFNW_{twump})$$

Total service revenue for forward flow of product *p* from facility *i* of client *l* and warehouse *w* to customer *u* via mode *m*.

$$-(\sum_{t}\sum_{w}\sum_{p} fonw_{twp})(capNW_{twp})(YNW_{twp}))$$

Total fixed cost for opening new warehouse *w* at time *t*

$$-(\sum_{t}\sum_{w}\sum_{p}(fecw_{twp})(g_{p})(ECPCW_{twp})(YECW_{twp})$$
$$+\sum_{t}\sum_{w}\sum_{p}(fenw_{twp})(g_{p})(ECPNW_{twp})(YENW_{twp}))$$

Total fixed cost for expanding current warehouse and new warehouse *w* at time *t*

$$-(\sum_t \sum_w \sum_u \sum_m \sum_p (fhcw_{twup})(XFCW_{twump}) + \sum_t \sum_w \sum_u \sum_m \sum_p (fhnw_{twup})(XFNW_{twump}))$$

Total storage or handling cost for product *p* in warehouse *w* at time *t*.

$$-(\sum_t \sum_w \sum_u \sum_m \sum_p \begin{matrix} ((tcost_{tmp})(ranged\_TPORTION_{tmp}) \\ ((distc_{twump})(XFCW_{twump}) + (distn_{twump})(XFNW_{twump})))) \end{matrix}$$

Total transportation cost of reverse flow for product *p* from customer *u* to warehouse *w* via mode *m* at time *t.*

$$+(\sum_t \sum_u \sum_w \sum_m \sum_p (ranged\_CPR_{tuwmp})(XRCW_{tuwmp})$$
$$+\sum_t \sum_u \sum_w \sum_m \sum_p (ranged\_NPR_{tuwmp})(XRNW_{tuwmp}))$$

Total service revenue for reverse flow for product *p* from *u* to warehouse *w* via mode *m* at time *t*. This equation describes that the service revenue paid by clients will be optimally decided in the model. Therefore the UPS will use this price in negotiating with its clients.

$$-(\sum_t \sum_u \sum_w \sum_m \sum_p (fhcr_{twp})(XRCW_{tuwmp}) + \sum_t \sum_u \sum_w \sum_m \sum_p (fhnr_{twp})(XRNW_{tuwmp}))$$

Total storage cost for returned product before they are shipped to repair center via mode *m* at time *t*.

$$-(\sum_t \sum_w \sum_r (fonr_{twr})(capNR_{twrp})(YNR_{twrp}))$$

Total fixed cost for opening new repair center *r* at time *t*

$$-(\sum_t \sum_w \sum_r \sum_p (fecr_{twrp})(g_p)(ECPCR_{twrp})(YECR_{twrp})$$
$$+\sum_t \sum_w \sum_r \sum_p (fenr_{twrp})(g_p)(ECPNR_{twrp})(YENR_{twrp}))$$

Total fixed cost for expanding repair center *r* at time *t*

$$-(\sum_t \sum_w \sum_w \sum_r \sum_m \sum_p \begin{matrix}((tcost_{tmp})(distcc_{twwrmp}) \\ (ranged\_TPORTION_{tmp})(XCWCR_{twwrmp}))\end{matrix}$$

$$+\sum_t \sum_w \sum_w \sum_r \sum_m \sum_p \begin{matrix}((tcost_{tmp})(distcn_{twwrmp}) \\ (ranged\_TPORTION_{tmp})(XCWNR_{twwrmp}))\end{matrix}$$

$$+\sum_t \sum_w \sum_w \sum_r \sum_m \sum_p \begin{matrix}((tcost_{tmp})(distnc_{twwrmp}) \\ (ranged\_TPORTION_{tmp})(XNWCR_{twwrmp}))\end{matrix}$$

$$+\sum_t \sum_w \sum_w \sum_r \sum_m \sum_p \begin{matrix}((tcost_{tmp})(distnn_{twwrmp}) \\ (ranged\_TPORTION_{tmp})(XNWNR_{twwrmp})))\end{matrix}$$

Total transportation cost for returned item *p* from warehouse *w* to repair center *r* via mode *m* at time *t*.

$$-(\sum_t \sum_w \sum_r \sum_p (rcqp_{twrp})(XQCR_{twrp})$$

$$+\sum_t \sum_w \sum_r \sum_p (rnqp_{twrp})(XQNR_{twrp}))$$

Total in-house quality checking cost.

$$-(\sum_t \sum_w \sum_r \sum_p (rpcp_{twrp})(XRPCR_{twrp})$$

$$+\sum_t \sum_w \sum_r \sum_p (rpnp_{twrp})(XRPNR_{twrp}))$$

Total in-house repairing cost.

$$-(\sum_t \sum_w \sum_r \sum_d \sum_p (ranged\_PMCR_{twrdp})(XMCR_{twrdp})$$

$$+\sum_t \sum_w \sum_r \sum_d \sum_p (ranged\_PMNR_{twrdp})(XMNR_{twrdp}))$$

Total outsourcing cost for remanufacturing for product *p* outsourced to *d* from repair center *r* at time *t*. All remanufacturing are done by outsourcing. Therefore UPS needs to decide the contract price for remanufacturing to different manufacturers on outsourcing.

$$-(\sum_t \sum_w \sum_r \sum_e \sum_p (rlcp_{twrep})(XLCR_{twrep})$$

$$+\sum_t \sum_w \sum_r \sum_e \sum_p (rlnp_{twrep})(XLNR_{twrep}))$$

Total recycling cost from Louisville and Memphis repair centers to recycling facilities *e* for product *p*.

Subject To:

<u>Constraint 1</u>:

$$\sum_{w}\sum_{m} XFCW_{twump} + \sum_{w}\sum_{m} XFNW_{twump}$$

$$\leq ranged\_CDMD_{tup} + ranged\_NDMD_{tup},\ \forall t,u,p$$

$$,where$$

$$Ln(ranged\_CDMD_{tup}) = Ln(a_{tup}) + (b_{tup})Ln(((\sum_{w}\sum_{m} reduced\_PFCW_{twump})))$$

$$Ln(ranged\_NDMD_{tup}) = Ln(a_{tup}) + (b_{tup})Ln(((\sum_{w}\sum_{m} reduced\_PFNW_{twump})))$$

,

$ranged\_CDMD_{tup} = demand\ for\ product\ p\ in\ current\ location\ at\ time\ t$

$ranged\_NDMD_{tup} = demand\ for\ product\ p\ in\ new\ location\ at\ time\ t$

$a_{tup} = primary\ demand\ for\ product\ p\ in\ customer\ u\ at\ time\ t$

$b_{tup} = price\ elasticity of\ UPS\ for\ product\ p\ in\ cusotmer\ u\ at\ time\ t$

$ranged\_PFCW_{twump} = current\ price\ of\ UPS\ for\ product\ p\ at\ time\ t$

$ranged\_PFNW_{twump} = new\ price\ of\ UPS\ for\ product\ p\ at\ time\ t$

Amount of all forwarded items from client's location, from the current and new warehouses and will meet the demand of customers.

<u>Constraint 2</u>:

$$\sum_{u}\sum_{m}\sum_{p} XFCW_{twump} \leq capCW_{twp} + (\sum_{p} ECPCW_{twp})(YECW_{twp}), \forall t,w,p$$

Storage in current warehouses cannot exceed the capacity limit unless expanded.

<u>Constraint 3</u>:

$$\sum_{u}\sum_{m}\sum_{p} XFNW_{twump} \leq (capNW_{twp})(YNW_{twp}) + (\sum_{p} ECPNW_{twp})(YENW_{twp}), \forall t,w,p$$

Storage in new warehouses cannot exceed the capacity limit unless expanded.

<u>Constraint 4</u>:

$$YNW_{twp} + YENW_{twp} \leq 1, \forall t,w,p$$

New opening and expansion cannot be made simultaneously.

<u>Constraint 5</u>:

$$\sum_{t} YNW_{twp} \leq 1, \forall w,p$$

New opening is made only once

Constraint 6:

$$YENW_{twp} \le \sum_{\tau=1}^{t} YNW_{\tau wp}, \forall t, w, p$$

Expansion can be made only when opening is done.

Constraint 7:

$$\sum_{w}\sum_{m} XRCW_{tuwmp} + \sum_{w}\sum_{m} XRNW_{tuwmp}$$
$$= (rtn_{tup})(\sum_{w}\sum_{m} XFCW_{t-1wump} + \sum_{w}\sum_{m} XFNW_{t-1wump}), \forall t, u, p$$

Number of all returned items to the warehouses will be the return rate of the previous outflow to customers.

Constraint 8:

$$\sum_{w}\sum_{r}\sum_{m} XCWCR_{twwrmp} + \sum_{w}\sum_{r}\sum_{m} XCWNR_{twwrmp} = \sum_{u}\sum_{m} XRCW_{tuwmp}, \forall t, w, p$$

Balance equation. The amount transported from the current warehouse to repair centers in both the current and new warehouse *w* is same as the amount sent to the repair center at current warehouse from customer points.

Constraint 9:

$$\sum_{w}\sum_{r}\sum_{m} XNWCR_{twwrmp} + \sum_{w}\sum_{r}\sum_{m} XNWNR_{twwrmp} = \sum_{u}\sum_{m} XRNW_{tuwmp}, \forall t, w, p$$

Balance equation. The amount transported from the new warehouse to repair centers in both the current and new warehouse *w* is same as the amount sent to the repair center at the new warehouse from customer points.

Constraint 10:

$$\sum_{w}\sum_{m}\sum_{p} XCWCR_{twwrmp} + \sum_{w}\sum_{m}\sum_{p} XNWCR_{twwrmp}$$
$$\le capCR_{twrp} + (\sum_{p} ECPCR_{twrp})(YECR_{twrp}), \forall t, w, r$$

Storage in the current repair center cannot exceed the capacity limit unless expanded.

Constraint 11:

$$\sum_{w}\sum_{m}\sum_{p} XCWNR_{twwrmp} + \sum_{w}\sum_{m}\sum_{p} XNWNR_{twwrmp}$$
$$\le (capNR_{twrp})(YNR_{twrp}) + (\sum_{p} ECPNR_{twrp})(YENR_{twrp}), \forall t, w, r$$

Storage in the new repair center cannot exceed the capacity limit unless opened and expanded.

Constraint 12:

$$\sum_{t} YNR_{twrp} \leq 1, \forall w, r, p$$

$$YNR_{twrp} \leq YNW_{twp}, \forall t, w, p$$

New opening is made only once
New repair center cannot be open unless new facility is open

Constraint 13:

$$YNR_{twrp} + YENR_{twrp} \leq 1, \forall t, r, p$$

New opening and expansion cannot be made simultaneously.

Constraint 14:

$$YENR_{twrp} \leq \sum_{\tau=1}^{t} YNR_{twrp}, \forall t, w, r, p$$

Expansion can be made only when opening is done.

Constraint 15:

$$XQCR_{twrp} = \sum_{w} \sum_{m} XCWCR_{twwrmp} + \sum_{w} \sum_{m} XNWCR_{twwrmp}, \forall t, r, p$$

Constraint 16:

$$XQNR_{twrp} = \sum_{w} \sum_{m} XCWNR_{twwrmp} + \sum_{w} \sum_{m} XNWNR_{twwrmp}, \forall t, r, p$$

Balance equation. The amount sent for quality check at the current repair center is the same as the amount sent to the repair center. Same for NR.

Constraint 17:

$$XRPCR_{twrp} + \sum_{d} XMCR_{twrdp} + \sum_{e} XLCR_{twrep} = XQCR_{twrp}, \forall t, w, r, p$$

Constraint 18:

$$XRPNR_{twrp} + \sum_{d} XMNR_{twrdp} + \sum_{e} XLNR_{twrep} = XQNR_{twrp}, \forall t, w, r, p$$

Balance equation. The amount of in-house repairing, outsourced items and recycled items for remanufacturing is the same as the amount sent to quality checking.

Constraint 19:

$$XRPCR_{twrp} + XRPNR_{twrp} = (rpPortion)(XQCR_{twrp} + XQCR_{twrp}), \forall t, w, r, p$$

Balance equation. The amount of in-house repairing represents 88% of returned product.

Constraint 20:

$$\sum_{d} XMCR_{twrdp} + \sum_{d} XMNR_{twrdp} = (rmPortion)(XQCR_{twrp} + XQNR_{twrp}), \forall t, w, r, p$$

Balance equation. The amount of outsourcing represents 5% of returned product.

Constraint 21:

$$\sum_e XLCR_{twrep} + \sum_e XLNR_{twrep} = (rlPortion)(XQCR_{twrp} + XQNR_{twrp}), \forall t, w, r, p$$

Balance equation. The amount of recycling represents 7% of returned product.

Constraint 22:
Non negativity constraints for all decision variables.

Monte Carlo simulation

Why Monte Carlo simulation?

In scenario construction only ranged parameters were considered in order to accommodate the variation. In addition to ranged parameters, some decision variables in the reduced model and full models that were represented in ranges to avoid nonlinearity, were also considered in scenario construction. Ranged parameters include fonw, fhcw, fhnw, distc_tuwmp, distn_tuwmp, distc_twump, distn_twump, fonr, fecr, fenr, rpcp, rpnp. Decision variables expressed in ranges include PFCW, PFNW, ECPCW, ECPNW, ECPCR, ECPNR, TPORTION_tmp, TPORTION_tuwmp, CPR, NPR, PMCR, PMNR. Therefore, a total of 24 parameters and variables were considered for scenario generation in our study.

Data points for parameters and variables obtained in the ranges of a distribution specified by UPS in each scenario were called "estimated parameters" due to the fact that the resulting data points are not accurate values for the parameters in UPS operation. Scenario components comprised by these estimated parameters imply the difficulty of obtaining accurate data for the organization.

Considering the fact that scenarios are a combination of all estimated parameters, after solving both models with estimated parameters, the best efforts were made by incorporating error variation seeking the “true parameters”, given each of the estimated parameters in profit computation, resulting in the hierarchy of scenario and sub-scenario in the data structure. Therefore, there are numerous sub-scenarios devised to consider and solve in this study.

When the formulation was converted from a nonlinear to a linear one, the approach that would be promising is enumeration in order to obtain an optimal solution. However, the ranges of ranged parameters and variables are vastly wide. For example, PFCW (price) for a laptop is ranged between 250 and 1750 and the ECPCW (expansion amount for current warehouse) is almost infinite. As a consequence, scenario and sub-scenario constructions close to enumeration were discouraged.

As an alternative to enumeration for solving the problems, a loose formulation in devising scenarios – taking some values within ranges in a more loosed interval – is a possible option. Clearly, how loose the interval is among values in a range commands the nearness to the optimal solution. Hence, deriving five values for an estimated parameter and three values for a true parameter for the corresponding estimated parameter was constructed to be solved, which results in $15^{12} \times 5^{12}$ scenarios.

(Note: 15 indicates that there are 15 (=5$\times$ 3 values for true parameters per parameter) different set of values for each estimated parameter, and 12 indicates twelve parameters). In the second term 5 indicates that there are five set of values for each ranged decision variable and 12 indicates the amount of those variables). Clearly, this implies too many scenario and sub-scenario compositions. Even though the number of scenario and sub-scenario combinations is unmanageable, an initial attempt was made to solve all scenario and sub-scenario formulations using commercial software. In reality, as was expected, the system faced its capacity limit very quickly due to the large data structure and number of scenarios.

To circumvent this system problem we adapted to a Monte Carlo simulation by first generating a number randomly from the uniform distribution to represent an estimated value for each parameter, and later did one more generation under a given estimated parameter to represent a true parameter for the estimated one by varying 2 to 4 percent for non-price parameters, and 3 to 5% for price parameters in profit computation. This range of error variation was provided by UPS. For estimated and true parameters, a uniform distribution was singled out by UPS and it is also a common statistical distribution to drive parameters in logistics system (Jayaraman et al, 1999).

Procedure of scenario generation

A more detailed procedure of generating scenarios for pricing used in the simulation is indicated in table 10.

Table 10
Scenario generation for pricing

Scenario *i* generation:
Step 1) Estimated parameter generation: From data of UPS drawn once randomly from uniform distribution for each parameter given in ranges with single value fixed.
Step 2) Price generation for reduced model: Upon estimated parameters generated in the previous step generate once prices for each product randomly within the ranges of three products: Printer: \$45-\$300, Laptop: \$250-\$1,750, Cell phone: \$50-\$175.
Step 3) Parameter " a" generation in the demand model of Ln(demand+ error (0, σ))= Ln (a) + (b)(Ln(price)): Error term will be drawn once from the normal distribution with mean 0 and standard deviation σ. Since demand is given for each of three products parameter "a" is obtained. The same parameters of "a" and "b" in the demand model for reduced model will be used in the full model under the scenario.

Step 4) Solve the model for objective value of the reduced model
Fixing price, demand, “a”, and “b” in the demand function solve the model obtaining an objective value. Perform feasibility check to see if all the constraints are met.

Step 5) True parameter generation:
Step 4) will produce optimal set of decision variables with respect to estimated parameters (i.e. a set of estimated parameters per scenario)
Generate errors once for each of estimated parameters obtained in step 1) by varying 2 to 4 % for non-price related parameters and 3 to 5% for price-related parameters.
Using these true parameters obtained by errors compute profit of the reduced model

Step 6) Store profit for reduced model:
Store the profit if all the constraints are met (feasibility check).

Step 7) Price generation for full model:
Generate prices once from three price ranges of each product. Using parameter “b” and “a” obtained in step 3) compute demand from demand function adjusted with error;
ie. Ln(demand+ error $(0, \sigma)$)= Ln (a) + (b)(Ln(price)).

Setp 8) Solve the model for objective value of full model
Applying the same set of estimated parameters used in the reduced model combined with price and demand obtained in step 7) solve for objective value of full model. Perform feasibility check to see if all the constraints are met.

Step 9) Store profit for full model:
Using the same set of true parameters for each estimated parameter used in the reduced model compute profit from profit calculator and store it if all the constraints are met (feasibility check).

Step 10) Repeat:
Repeat step 7) and 9) 100 times.

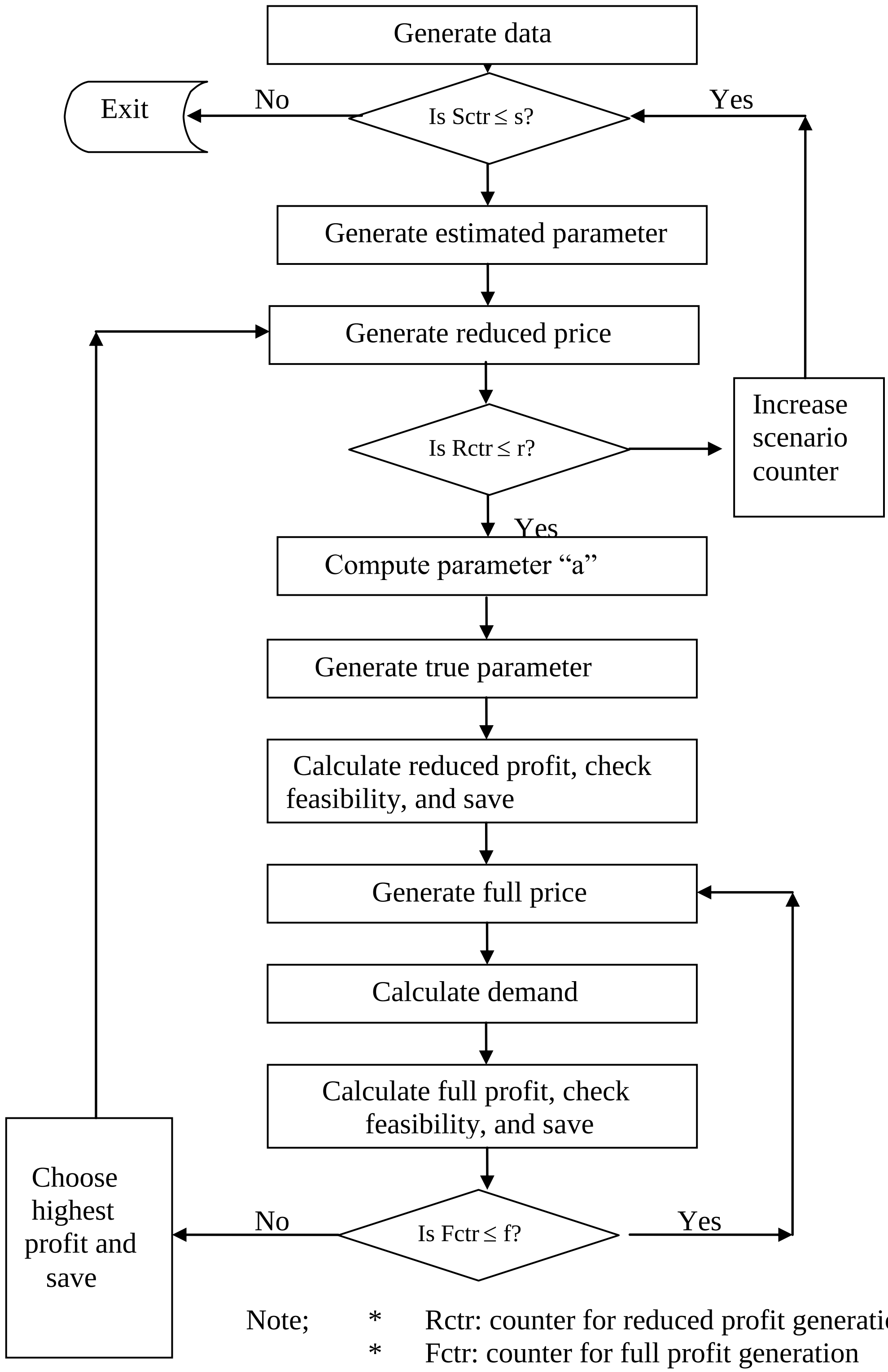
Step 11) Store largest profit:
Choose the largest profit obtained in step 10) to represent the profit for full model.

Remark) Step 2) to step 10) represents one replication of profit for both reduced and full models from parameters adjusted with errors upon estimated parameters.

Step 12) Repeat:
Repeat step 2) through step 11) 100 times

Remark) After step 12) each model has 100 replicated profits ready for test within a scenario.

Figure 6 presents the flow diagram for simulation encompassing the scenario generation



Note;
* Rctr: counter for reduced profit generation
* Fctr: counter for full profit generation
* Sctr: counter for scenario

Figure 6: Flow diagram for simulation

UPS operations in the simulation model

Overview of simulation

Three products, cellular phones, laptops, and printers are considered in our study. Even though UPS handles more than these three items in their supply chain business only these three products were chosen since these three represents the most transaction volume for UPS. In the model manufacturing firms such as Motorola, Dell, Toshiba, and Hewlett Packard serve as clients for UPS.

The logistics operation activities in the simulation start with moving items for these four UPS clients. Without a loss of generality we assume that the clients constantly maintain enough capacities to meet customers demand. UPS is currently running five facilities. Motorola is a cellular phone producer in the model and its products are transported to the warehouse located in Los Angeles, CA. Similarly, the laptops of Toshiba and Dell are carried to the warehouses in Cincinnati, OH and Dallas, TX, respectively. The warehouse in San Jose, CA is committed to the movement of printers from Hewlett-Packard. Generally each of the three products is first shipped to nearby facilities for transshipment. All the products are then brought to Louisville, KY, a hub for the UPS operation, before they are delivered to the two end customers in the model. This procedure states the forward logistics since it involves the movement of brand new products produced by the OEM (Original Equipment Manufacturer).

At the same time, customers collect products returned by individual consumers for varied reasons before the warranty expires. These product returns done during the warranty period are called "commercial returns" and these items, in general, have minor or no defects at all (Guide et al, 2005). These products are first shipped from customers to nearby warehouses, from where they are reversely transported to the hub in Louisville, KY, for repair services at the end of their journey. Currently the Louisville hub operates four repair centers, which is captured in the model, as well. When products are gathered in the hub, each repair center checks the quality of them first and then decides the subsequent treatment for the returned items.

UPS currently performs three treatments on returned products: repair, remanufacturing, and recycling. Repair services are performed in the repair centers at the hub. However, the remanufacturing services and recycling services are outsourced to other specialized firms. In the simulation two remanufacturing and recycling firms were considered for outsourcing services, respectively. Product movement occurs via either air or ground transportation between clients, warehouses, and customers. Hence, two transportation modes were considered in the model. This explains the current flow of items in UPS.

Part of the model is intended to study the expansion of current operating facilities for both forward and reverse logistics activities. The expansion of current facilities is an option for UPS, and UPS is also currently considering opening new facilities at four new domestic candidate locations. Those four include Atlanta, GA, Chicago, IL, Harrisburg, PA, and Memphis, TN, all of which are committed to handling only laptops. Among these, Memphis, TN will serve as a hub like the one in Louisville, KY. In the model the repair center in the Memphis hub functions is the same as the repair center in Louisville. Four of them are also operating in the model.

The model became somewhat complicated when it has to accommodate the expansion decisions of current warehouses, repair centers and opening and expansion decisions in the new locations for both forward and reverse flows. In the simulation the initial forward flow from clients is made to designated current and new warehouses for transshipment when the flow arrives at each hub. Regardless of where the products were delivered to the customers, the returned products will be transported to the nearest facility. In other words, depending on the location of customers, the returned products can be delivered to either current or new facilities, whichever option realizes the most profit. Then the facilities move the items to a nearby hub, where the remaining reverse actions are performed. This operation is well depicted in figure 2.

All of the data was formulated in array structures in the simulation. The simulation runs for two planning time horizons.

<u>Demand generation</u>

Choice of demand function

Two functions are widely used in the literature to explain unknown demand: a linear model and a nonlinear model (multiplicative model).

Choi (1991), McGuire and Staelin (1983), and Jeuland and Shugan (1988), used a linear demand model expressed as

$Q = a - bp$,

Where,

a is a fundamental market demand

b is a price elasticity.

Even though this straight demand line has been applied in many studies, according to Nicholson (1992) the method may be inappropriate for empirical work because it implies that different price level reactions to the price changes will be quite different, i.e, price elasticity fluctuates. Based on the experiences of industry practitioners, a nonlinear model (multiplicative model) is most widely used for empirical analysis in the industry. The function could be written as

$$Q = aP^{b},$$
$$Where, a > 0 \; and \; is \; a \; constant$$
$$b \leq 0 \; and \; is \; an \; elasticity$$

An alternative way of writing this function by taking the natural log would be:

$$ln\, Q = ln\, a + b\, ln\, P$$

Nicholson (1992) also argued that this log-log linear function (nonlinear model) is suitable for empirical work since demand functions of this sort fit historical data well, and it exhibits a constant elasticity of demand along its entire region. Accordingly, the log-log linear function is applied to explain the current demand in the reduced model and optimal price and demand pair in the full model for the analysis.

Parameter "a" derivation in the demand function

The reduced model in our study is the current best practice regarding the topic available, both in the industry and academic fields as indicated in the literature; while the full model proposes some advanced characteristics by newly incorporating other useful variables associated with the topic. This study places a hard emphasis on profit differences between the two models by adding the new decision variable of pricing into the full model. Therefore, scrutinizing the relationship between price and demand function is an essential part of our study.

Incorporating an error term, the demand function can be rewritten that

$Q = aP^b + e, where, e \sim N(0, \partial)$.

For the reduced model, given the demand for each of three products, such as 12,000 for cellular phones, 700 for laptops, and 7,000 for printers, the demand for 12,000 of cellular phones, for example, can be expressed as 12,000 = $aP^b + e(0, \partial)$. Converting this into a log-log linear function will result in Ln (12,000 + $e(0, \partial)$) = Ln (a) + (b)(Ln(p)).

Since the prices of each products are also given in ranges, generating a price for a product in the uniform distribution, and an error term from the normal distribution, with a mean of zero and a standard deviation of 4% of the demand rate for each product, will leave out the two unknowns - i.e. parameters “a” and “b” in the demand function. Therefore, once we fix one of the two parameters we can obtain the other parameter. In our study we fixed parameter “b”, a slope, to obtain parameter “a”. Parameter ‘b” states a price elasticity. A price elasticity is a record of how quantity (or demand) changes (in percent terms) in response to a percentage change in price (Nicholson, 1992).

Usually price elasticity is negative, meaning that quantity and price moves in opposite directions. When elasticity is less than negative 1 it is termed elastic, when it is exactly negative 1 it is called unit elastic, and a elasticity larger than negative 1 is termed inelastic (Nicholson, 1992). Hence, an attempt was made by varying and mixing b=-025,-.5, -0.75, -1, -1.25, -1.5,-1.75, and -2 among the three products to define the behavior of demand. In the full model the same parameters of “a” and “b” were applied to derive demand for the model with prices.

Demand function generation in the full model

As is indicated in Table 1, the full model is executed 100 times per reduced model to represent the maximum profit with demand given parameter "a" generated. Hence, demand generation in the full model is quite opposite to the parameter "a" generation performed in the reduced model since we are given parameter "a" in the reduced model for the full model. Even though it is a conceptually a reverse process for obtaining demand, given the price range and parameters "a" and "b", a non-straight forward issue lies in front. As presented above, Ln (demand $+e(0,\partial)$) = Ln (a) + (b)(Ln(p)). Given the right hand side of the equation as constant after generating price from the uniform distribution, a difficulty is that the standard deviation for error is a random generation from normal distribution with 4% of demand, which is not known yet. To alleviate this problem an algorithm to approximate the demand rate has been applied and it is:

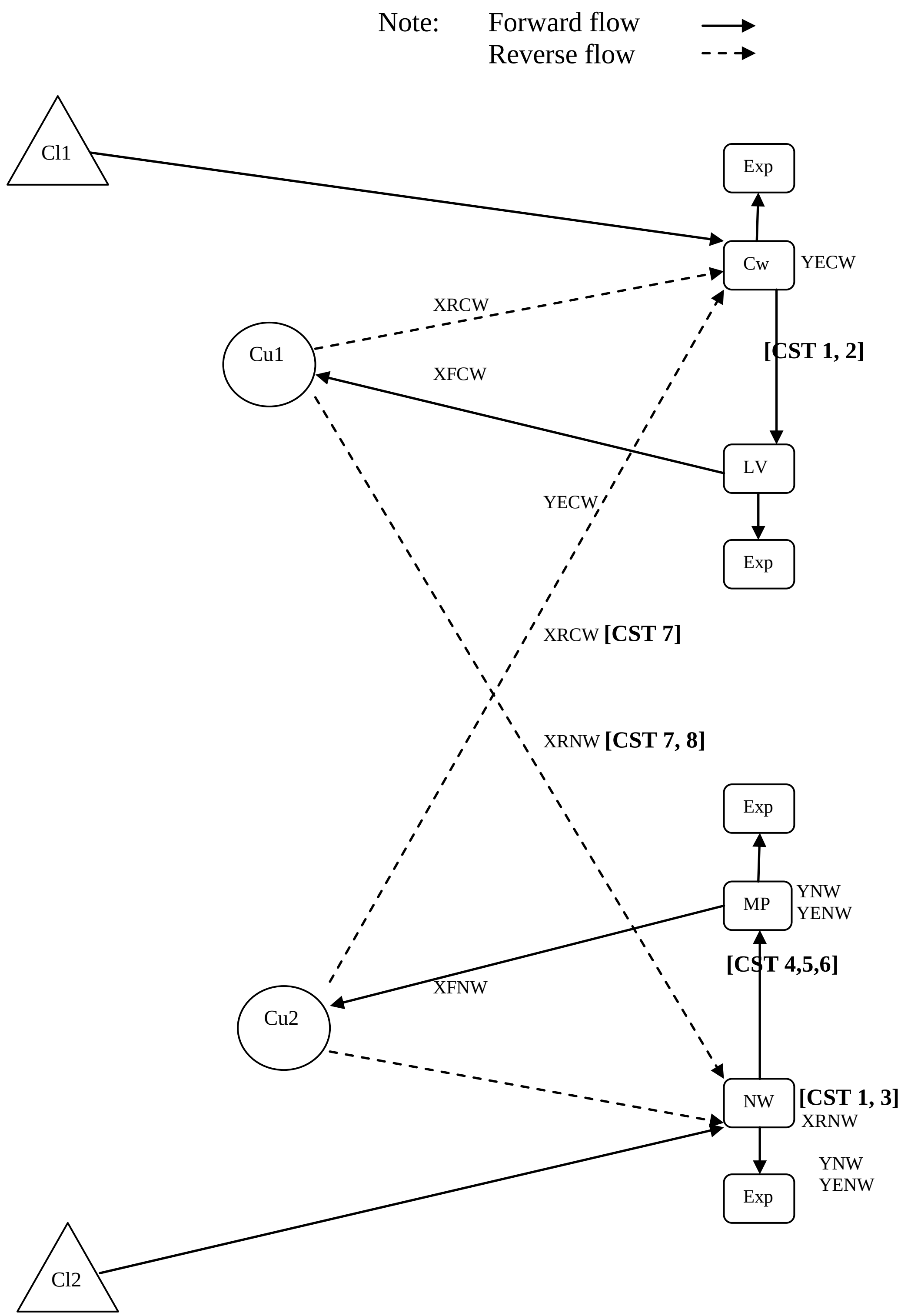
1) Generate low demand range applying 90 % of right hand side of demand function for products i.e. aP^b of demand function Q+e = aP^b. (Note that aP^b is a constant after obtaining a random draw for price). Similarly, repeat the same procedure for a high demand range applying 110 % of the right hand side of the demand function for products. Considering random generation of $\pm 4\%$ for errors from the normal distribution, $\pm 10\%$ variation from the right hand side fits well to the demand rate.
2) Generate a demand Q randomly between the low and high range obtained in step 1.
3) Assuming the demand rate obtained in step 2) is correct, generate a temporary demand rate applying random error generation using the demand in step 2) (i.e.

4) standard deviation in the normal distribution is obtained using 4% of the demand.)

5) Since the temporary demand rate may or may not be equal to the right hand side comparison of both sides need to be made.

6) Since achieving exactness on both sides takes an enormous amount of temporary demand generation, the algorithm allows ± 1 deviation from the real demand rate on the right hand side. (Note that the right hand side of the demand function composed of "a", "b", and price are different from those in the reduced model since the prices for the full model are each time newly generated in 100 replication.) Repeat previous steps until step 6) is achieved.

In brief, the demand realized in the full model on simulation is an error and price adjusted one based on the error adjusted demand in the reduced model since it uses the same parameter "a" and "b" from the reduced model.


Note: Forward flow
Reverse flow
Cl1
Exp
Cw
YECW
XRCW
Cu1
XFCW
[CST 1, 2]
LV
YECW
Exp
XRCW [CST 7]
XRNW [CST 7, 8]
Exp
MP
YNW
YENW
[CST 4,5,6]
XFNW
Cu2
NW
[CST 1, 3]
XRNW
YNW
YENW
Exp
Cl2

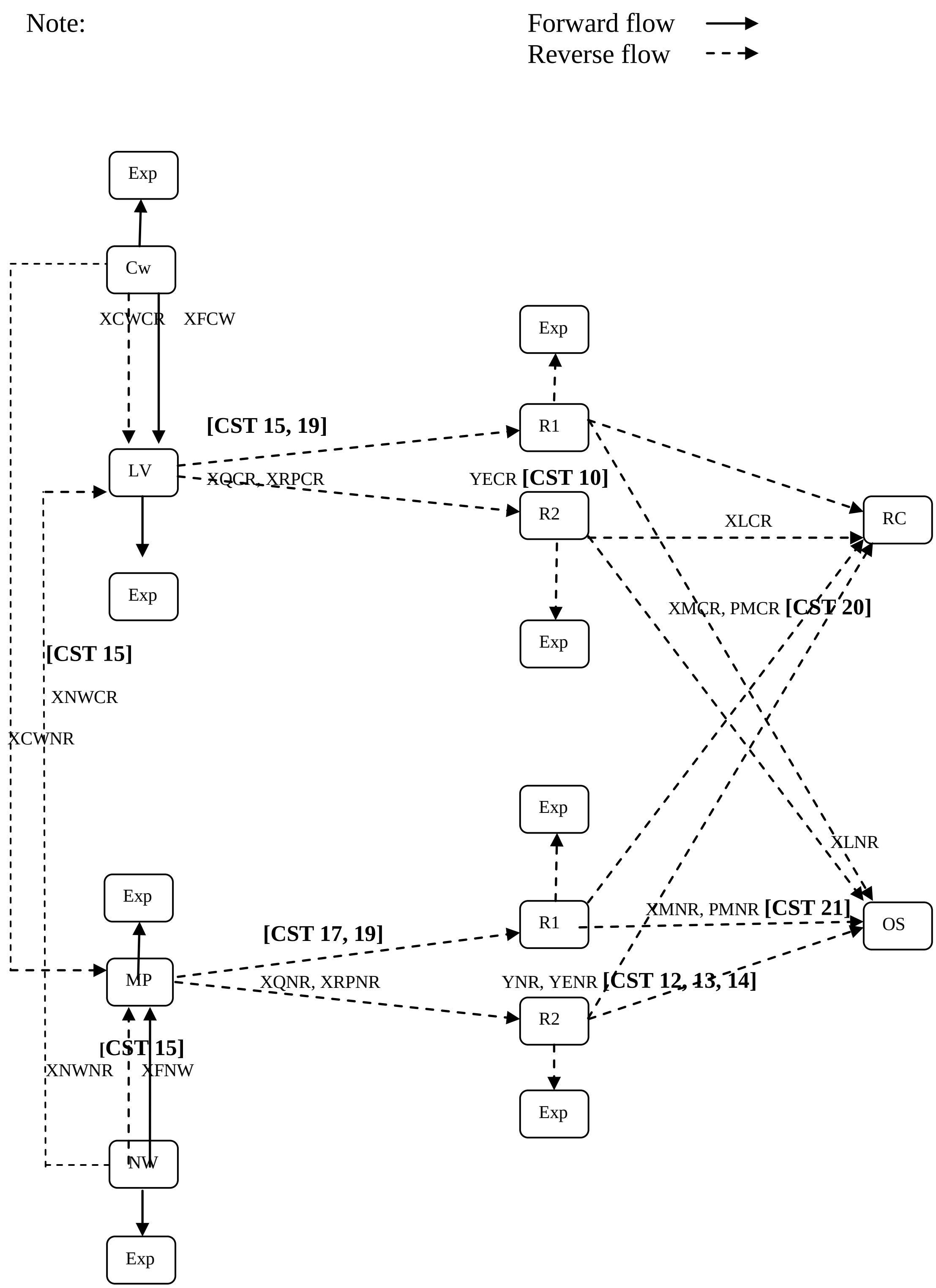


Figure 7. Flow diagram of UPS logistics operations

Node Notation:

Figure 8. Node notation

Objective value Calculation

Added variables in the full model

Fundamentally the full model is differentiated from the reduced model in that it has more variables, largely in three categories containing all variables in the reduced model. The additional variables in each category in the full model are as follows;

1) Category 1 : Pricing

$PFCW_{twump}$: Service charge for forward movement service of product *p* from client *l* and current warehouse *w* to customer *u* via mode *m* at time *t*

$PFNW_{twump}$: Service charge for forward movement service of product *p* from facility *w* of client *l* and current warehouse *w* to customer *u* via mode *m* at time *t*

CPR_{tuwmp} : Unit service revenue of UPS for returned products *p* to current warehouse *w* at time *t*

NPR_{tuwmp} : Unit service revenue of UPS for returned products *p* to new warehouse *w* at time *t*

2) Category 2 : Transportation method

$TPORTION_{tmp}$: Proportion of transportation mode of air and ground between facilities *w* at time *t*

$TPORTION_{tuwmp}$: Proportion of transportation mode of air and ground from customer *u* to facilities *w* at time *t*

3) Category 3 : Outsourcing cost for remanufacturing

$PMCR_{twrdp}$: Outsourcing cost of remanufacturing for returned product *p* in repair center *r* at current warehouse *w* to *d* at time *t*

$PMNR_{twrdp}$: Outsourcing cost of remanufacturing for returned product *p* in repair center *r* at new warehouse *w* to *d* at time *t*

Hence, the solution procedures between the reduced and full models are slightly different depending on the added variables in the full model at each of hypothesis test.

Treatment of added variables in hypothesis test

In hypothesis test for pricing, the prices for each of the three products are generated once in the reduced model, whereas the full model does this one hundred times, fixing all other variables in the rest of the categories but category 1. In UPS the prices (i.e. service charges for product movement paid by its clients) are currently fixed in the varied ranges, not decided optimally with respect to facility decisions, and thus one random generation explains it.

On the other hand, since the full model considers price effects in facility decisions by optimally incorporating price in the model, which results in nonlinear programming, generating prices100 times randomly to single out the highest profit, implying an alternative to solving nonlinear formulation optimally. Similarly, in the hypothesis test for transportation methods the current transportation method is applied to represent transportation in the reduced model. However, the full model pursues maximum profit with respect to transportation methods by generating 100 times in the full model. The hypothesis test for other categories of outsourcing costs or combinations of categories will follow the same logic, seeking maximum profit in the full model.

Profit Calculation

Non-model components for profit calculation

The UPS supply chain management team has involvement in providing logistics service for its clients, such as Motorola, Dell, Toshiba, HP, and so on. Major functions in logistics services that the firm provides include warehousing for forward services, collection, and reprocessing for reverse flows. Even though our models, particularly the full model, represent much of the logistics activities in UPS it does not explain the entire UPS business environment in rich detail. Both the full and the reduced model mainly decide the binary decision of facility opening, with expansion and pricing included in the full model. Based on the decisions from both models, we need to calculate profits accurately in the context of the UPS real business environment.

Guide et al (2006) emphasizes that the ultimate interest of top managers in a firm is whether the project or operation will enhance the profit within the firm. Hence one of the good ways for evaluating superiority of the models would be to compare the profits that the models generate with the real business environments of the firm, UPS in our case. The first task for profit calculation is to identify the factors that are in the real business environments but are not in the full or reduced model. We summarize those components as follows.

1) Reduction of the salvage value of current warehouses over a time planning horizon: since the salvage value of the current warehouse in Cincinnati is $66, in Dallas it is $56, Los Angeles is $161, Louisville is $37, and in San Jose it is $88 per square foot, as indicated in www.reis.com and UPS uses a discount rate of 12 %, salvage value reduction is calculated as follows.

- Cincinnati, OH: 66/sqft *312,500 *0.12 / 365= $6,780
- Dallas, TX: 56/sqft *312,500 *0.12 / 365=$5,753
- Los Angeles, CA: 161/sqft *312500 *0.12 / 365=$16,541
- Louisville, KY: 37/sqft *1250000 *0.12 / 365=$15,205
- San Jose, CA: 88/sqft *312500 *0.12 / 365=$9,041

2) Similarly, reduction of salvage value of new warehouses over a planning time horizon:

- Atlanta, GA: 55/sqft *135000 *0.12 / 365=$2,441
- Chicago, IL: 67/sqft *135000 *0.12 / 365=$2,973
- Harrisburg, PA: 56/sqft *135000 *0.12 / 365=$2,485
- Memphis, TN: 30/sqft *250000 *0.12 / 365=$2,465

3) truck driver’s pay rate over a planning time horizon= $3,240;

4) truck depreciation value over a planning time horizon = $225

5) truck maintenance value over a planning time horizon = $225

7) Employees salary over a planning time horizon = $25,600

Profit calculator

Incorporating all the non-model factors described in the above section, profit is calculated using the functions as follows over a single planning time horizon;

$$\sum_t \sum_w \sum_u \sum_m \sum_p (PFCW_{twump})(XFCW_{twump})$$
$$+\sum_t \sum_w \sum_u \sum_m \sum_p (PFNW_{twump})(XFNW_{twump})$$

Total service revenue paid by client *l* for forward flow of product *p* from warehouse *w* to customer *u* via mode *m*.

$$-(\sum_t \sum_w \sum_p (fonw_{twp})(capNW_{twp})(YNW_{twp}))$$

Total fixed cost for opening new warehouse *w* at time *t*

$$-(\sum_t \sum_w \sum_p (fecw_{twp})(g_p)(ECPCW_{twp})(YECW_{twp})$$
$$+\sum_t \sum_w \sum_p (fenw_{twp})(g_p)(ECPNW_{twp})(YENW_{twp}))$$

Total fixed cost for expanding current warehouse and new warehouse *w* at time *t*

$$-(\sum_t \sum_w \sum_u \sum_m \sum_p (fhcw_{twup})(XFCW_{twump}) + \sum_t \sum_w \sum_u \sum_m \sum_p (fhnw_{twup})(XFNW_{twump})$$

Total storage or handling cost for product *p* in warehouse *w* at time *t*.

$$-(\sum_t \sum_w \sum_u \sum_m \sum_p \begin{matrix} ((tcost_{tmp})(TPORTION_{tmp}) \\ ((distc_{twump})(XFCW_{twump}) + (distn_{twump})(XFNW_{twump})))) \end{matrix}$$

Total transportation cost for product *p* from warehouse *w* to customer *u* via mode *m* for forward service at time *t*.

$$+(\sum_t \sum_u \sum_w \sum_m \sum_p (CPR_{tuwmp})(XRCW_{tuwmp})$$
$$+\sum_t \sum_u \sum_w \sum_m \sum_p (NPR_{tuwmp})(XRNW_{tuwmp}))$$

Total service revenue for reverse flow for product *p* from *u* to warehouse *w* via mode *m* at time *t*. This equation describes that the service revenue paid by clients will be optimally decided in the model. Therefore the UPS will use this price in negotiating with its clients.

$$-(\sum_t \sum_u \sum_w \sum_m \sum_p \begin{matrix} ((tcost_{tmp})(TPORTION_{tuwmp}) \\ ((distc_{tuwmp})(XRCW_{tuwmp}) + (distn_{tuwmp})(XRNW_{tuwmp})))) \end{matrix}$$

Total transportation cost of reverse flow for product *p* from customer *u* to warehouse *w* via mode *m* at time *t.*

$$-\left(\sum_t \sum_u \sum_w \sum_m \sum_p (fhcr_{twp})(XRCW_{tuwmp}) + \sum_t \sum_u \sum_w \sum_m \sum_p (fhnr_{twp})(XRNW_{tuwmp})\right)$$

Total storage cost for returned products before they are shipped to a repair center via mode *m* at time *t*.

$$-\left(\sum_t \sum_w \sum_r (fonr_{twr})(capNR_{twrp})(YNR_{twrp})\right)$$

Total fixed cost for opening a new repair center *r* at time *t*

$$-\left(\sum_t \sum_w \sum_r \sum_p (fecr_{twrp})(g_p)(ECPCR_{twrp})(YECR_{twrp})\right.$$
$$\left.+\sum_t \sum_w \sum_r \sum_p (fenr_{twrp})(g_p)(ECPNR_{twrp})(YENR_{twrp})\right)$$

Total fixed cost for expanding a repair center *r* at time *t*

$$-\left(\sum_t \sum_w \sum_w \sum_r \sum_m \sum_p \begin{matrix}((tcost_{tmp})(distcc_{twwrmp})(TPORTION_{tmp}))\\ (XCWCR_{twwrmp})\end{matrix}\right.$$
$$+\sum_t \sum_w \sum_w \sum_r \sum_m \sum_p \begin{matrix}((tcost_{tmp})(distcn_{twwrmp})(TPORTION_{tmp}))\\ (XCWNR_{twwrmp})\end{matrix}$$
$$+\sum_t \sum_w \sum_w \sum_r \sum_m \sum_p \begin{matrix}((tcost_{tmp})(distnc_{twwrmp})(TPORTION_{tmp}))\\ (XNWCR_{twwrmp})\end{matrix}$$
$$\left.+\sum_t \sum_w \sum_w \sum_r \sum_m \sum_p \begin{matrix}((tcost_{tmp})(distnn_{twwrmp})(TPORTION_{tmp}))\\ (XNWNR_{twwrmp})\end{matrix}\right)$$

Total transportation cost for returned item *p* from warehouse *w* to repair center *r* via mode *m* at time *t*.

$$-\left(\sum_t \sum_w \sum_r \sum_p (rcqp_{twrp})(XQCR_{twrp})\right.$$
$$\left.+\sum_t \sum_w \sum_r \sum_p (rnqp_{twrp})(XQNR_{twrp})\right)$$

Total in-house quality checking cost.

$$-\left(\sum_t \sum_w \sum_r \sum_p (rpcp_{twrp})(XRPCR_{twrp})\right.$$
$$\left.+\sum_t \sum_w \sum_r \sum_p (rpnp_{twrp})(XRPNR_{twrp})\right)$$

Total in-house repairing cost.

$$-\left(\sum_t \sum_w \sum_r \sum_d \sum_p (PMCR_{twrdp})(XMCR_{twrdp}) + \sum_t \sum_w \sum_r \sum_d \sum_p (PMNR_{twrdp})(XMNR_{twrdp})\right)$$

Total outsourcing cost for remanufacturing for product *p* outsourced to *d* from repair center *r* at time *t*. All remanufacturing is done by outsourcing. Therefore UPS needs to decide the contract price for remanufacturing to different manufacturers on outsourcing.

$$-\left(\sum_t \sum_w \sum_r \sum_e \sum_p (rlcp_{twrep})(XLCR_{twrep}) + \sum_t \sum_w \sum_r \sum_e \sum_p (rlnp_{twrep})(XLNR_{twrep})\right)$$

Total recycling cost from Louisville and Memphis repair centers to recycling facilities *e* for product *p*.

– Reduction of salvage value of current warehouses over a planning time horizon

– Reduction of salvage value of new warehouses over a planning time horizon

– Total truck driver’s pay over a planning time horizon

– Total truck depreciation value over a planning time horizon

– Total truck maintenance cost over a planning time horizon

– Total Employee’s salary over a planning time horizon

CHAPTER FOUR

DATA

With the permission of the data provider, Brian Vowels, we include current data in this section.

Sets

Set	Description	Example
L	Clients of UPS	HP, Toshiba, Motorola, and Dell
W	Warehouse	▪ Current locations: • Cincinnati, OH, • Dallas, TX, • Los Angeles, CA, • Louisville, KY, • San Hose, CA. ▪ New candidates: • Atlanta, GA, • Chicago, IL, • Harrisburg, PA, • Memphis, TN.
R	Repair centers	▪ Current locations: • Louisville, KY. ▪ New candidates: • Memphis, TN.
U	Customers in the market	Wholesalers/Retailers
M	Transportation mode	Ground and air
T	Time periods	Days
D	Outsourced company	Manufacturer
E	Recycling facilities	Recycling company
P	Products	Cellular Phone, Laptop Computer, and Printer

Parameters for the business of UPS

Parameters	Description	Values
$ranged\_PFCW_{twump}$	Unit service revenue of UPS for forward movement paid by her current clients *l* at time *t*	▪ Cell Phone: $ 50-$175 ▪ Laptop: $ 250-$1,750 ▪ Printer: $ 45-$300

$ranged\_PFNW_{twump}$	Unit service revenue of UPS for forward movement paid by her new clients *l* at time *t*	▪ Laptop: $250-$1,750
$fonw_{twp}$	Unit fixed cost for opening new warehouse *w* at time *t*	▪ Product unit : $11.2 to $22.4
$capCW_{twp}$	Capacity of current warehouse *w* at time *t*.	▪ Cincinnati : 312,500 units ▪ Dallas : 312,500 units ▪ Los Angeles : 312,500 units ▪ Louisville : 1,250,000 units ▪ San Jose: 312,500 units
$capNW_{twp}$	Capacity of new warehouse *w* at time *t*	▪ Atlanta : 135,000 units ▪ Chicago : 135,000 units ▪ Harrisburg : 135,000 units ▪ Memphis : 250,000 units
$fecw_{twp}$	Unit fixed cost for expanding current warehouse *w* for product *p* at time *t*	▪ Cincinnati: 12.2 cents per product unit ▪ Dallas: 9.2 cents per product unit ▪ Los Angeles: 19.2 cents Per product unit ▪ Louisville: 12.2 cents per product unit ▪ San Jose: 12.2 cents per product unit
g_p	Unit size of product p	▪ Printer : 1 ▪ Laptop: 1/3 ▪ Cell phone: 1/7
$ranged\_ECPCW_{twp}$	Expansion amount of current warehouse *w* for product *p* at time *t*	▪ uniform (100000, 2000000)
$ranged\_ECPNW_{twp}$	Expansion amount of new warehouse *w* for product *p* at time *t*	▪ uniform (100000, 2000000)
$fenw_{twp}$	Unit fixed cost of expanding new warehouse *w* for product *p* at time *t*	▪ Atlanta: 12.2 cents per product unit ▪ Chicago: 9.2 cents per product unit ▪ Harrisburg: 12.2 cents per product unit ▪ Memphis: 12.2 cents per product unit

$fhcw_{twup}$	Operating or handling cost of product p in current warehouse w at time t	▪ Product unit : $13.50 to $22.50
$fhnw_{twup}$	Operating or handling cost for product p in new warehouse w at time t	▪ Product unit : $13.50 to $22.50
$tcost_{tmp}$	Unit transportation cost for air and ground mode at time t	▪ Air: • Cell phone : $ 0.000015 • Laptop : $ 0.00024 • Printer : $ 0.02 ▪ Ground: •Cell phone : $ 0.0000077 • Laptop : $ 0.000156 • Printer : $ 0.015
$ranged\_TPORTION_{tmp}$	Proportion of transportation mode of air and ground into and out of two hubs	▪ Louisville: Cell phone by air 100%, Other products by ground 100% for both inflow and outflow ▪ Memphis: Cell phone by air 100%, Other products by ground 100% for both inflow and outflow
$ranged\_TPORTION_{tuwmp}$	Proportion of transportation mode of air and ground from customer u to facilities w except two hubs for reverse flow	▪ Cincinnati: Each product 80% by ground and 20 % by air ▪ Dallas: Each product 80% by ground and 20 % by air ▪ Los Angeles: Each product

		80% by ground and 20 % by air ▪ San Jose: Each product 80% by ground and 20 % by air ▪ Atlanta: Each product 80% by ground and 20 % by air ▪ Chicago: Each product 80% by ground and 20 % by air ▪ Harrisburg: Each product 80% by ground and 20 % by air
$distc_{tuwmp}$	Distance from customer *u* to current warehouse *w* via mode *m* for product *p* at time *t*	▪ uniform (150, 3000 miles)
$distc_{twump}$	Distance from current warehouse *w* to customer *u* via mode *m* for product *p* at time *t*	▪ uniform (150, 3000 miles)
$distn_{tuwmp}$	Distance from customer *u* to new warehouse *w* via mode *m* for product *p* at time *t*	▪ uniform (150, 3000 miles)
$distn_{twump}$	Distance from new warehouse *w* to customer *u* via mode *m* for product *p* at time *t*	▪ uniform (150, 3000 miles)
$ranged\_CPR_{twmp}$	Unit service revenue of UPS for returned product *p* at current warehouse *w* paid by her clients *l* at time *t*	▪ Cell phone: \$35-\$69 ▪ Laptop: \$162-\$507 ▪ Printer: \$59-\$111
$ranged\_NPR_{twmp}$	Unit service revenue of UPS for returned product	▪ Cell phone: \$35-\$69

	p at new warehouse *w* paid by her clients *l* at time *t*	▪ Laptop: $162-$507 ▪ Printer: $59-$111
$fonr_{twr}$	Unit fixed cost for opening new repair center *r* in warehouse *w* at time *t*	▪ Product unit : $11.2 to $22.4
$ranged\_ECPCR_{twrp}$	Expansion amount of repair center in current warehouse *w* for product *p* at time *t*	▪ uniform (100000, 2000000)
$ranged\_ECPNR_{twrp}$	Expansion amount of repair center in new warehouse *w* for product *p* at time *t*	▪ uniform (100000, 2000000)
$capCR_{twrp}$	Capacity of current repair center *r* in warehouse *w* at time *t*	▪ Louisville: 37,500 units
$capNR_{twrp}$	Capacity of new repair r at warehouse *w* at time *t*	▪ Memphis: 7,500
$fecr_{twrp}$	Unit fixed cost for expanding repair center at current warehouse *w* for product *p* at time *t*	▪ Product unit : 9.2 to 12.2 cents
$fenr_{twrp}$	Unit fixed cost for expanding repair center at new warehouse *w* for product *p* at time *t*	▪ Product unit : 9.2 to 12.2 cents
$fhcr_{twp}$	Unit operating cost at current warehouse *w* for product *p* at time	▪ Cell Phone: $0.5 ▪ Laptop: $1 ▪ Printer: $1
$fhnr_{twp}$	Unit operating cost at new warehouse *w* for product *p* at time	▪ Cell Phone: $0.5 ▪ Laptop: $1 ▪ Printer: $1
$distcc_{twwrmp}$	Distance from current warehouse *w* to repair Center *r* in other current warehouse *w* via mode *m* for product *p* at time *t*	▪ 99 miles from Cincinnati to Louisville ▪ 836 miles from Dallas to Louisville ▪ 2083 miles from Los Angeles to Louisville ▪ 2389 miles from San Jose to Louisville
$distcn_{twwrmp}$	Distance from current warehouse *w* to repair center *r* in new warehouse *w* via mode *m* for	▪ 483 miles from Cincinnati to Memphis ▪ 453 miles from Dallas to Memphis

	product *p* at time *t*	▪ 1793 miles from Los Angeles to Memphis ▪ 2057 miles from San Jose to Memphis
$distnc_{twwrmp}$	Distance from new warehouse *w* to repair center *r* in current warehouse *w* via mode *m* for product *p* at time *t*	▪ 421 miles from Atlanta to Louisville ▪ 297 miles from Chicago to Louisville ▪ 574 miles from Harrisburg to Louisville ▪ 385 miles from Memphis to Louisville
$distnn_{twwrmp}$	Distance from new warehouse *w* to repair center *r* in other new warehouse *w* via mode *m* for product *p* at time *t*	▪ 383 miles from Atlanta to Memphis ▪ 534 miles from Chicago to Memphis ▪ 931 miles from Harrisburg to Memphis
$rcqp_{twrp}$	Unit quality checking cost for product *p* at repair center *r* in current warehouse *w* at time *t*	▪ Cell Phone: $1 ▪ Laptop: $1 ▪ Printer: $1
$rnqp_{twrp}$	Unit quality checking cost for product *p* at repair center *r* in new warehouse *w* at time *t*	▪ Cell Phone: $1 ▪ Laptop: $1 ▪ Printer: $1
$rpcp_{twrp}$	Unit repair cost for product *p* at repair center *r* in current warehouse *w* at time *t*	▪ Cell phone: uniform($15, $45) ▪ Laptop: uniform ($112,$412) ▪ printer: uniform ($27, $72)
$rpnp_{twrp}$	Unit repair cost for product *p* at repair center *r* in new warehouse *w* at time *t*	▪ Cell phone: uniform($15, $45) ▪ Laptop: uniform ($112,$412) ▪ printer: uniform ($27, $72)
$ranged\_PMCR_{twrdp}$	Unit outsourcing cost at repair center *r* in current warehouse *w* for product p at time *t*	▪ Cell Phone: $ 12 ▪ Laptop: $ 22.50 ▪ Printer: $ 18

$ranged\_PMNR_{twrdp}$	Unit outsourcing cost at repair center *r* in new warehouse *w* for product p at time *t*	▪ Cell Phone: $ 12 ▪ Laptop: $ 22.50 ▪ Printer: $ 18
$rlcp_{twrep}$	Unit recycling cost for product p at repair center r in Louisville to e at time t	▪ Cell Phone: $ 1.5 ▪ Laptop: $ 5 ▪ Printer: $ 4.25
$rlnp_{twrep}$	Unit recycling cost for product p at repair center r in Memphis to e at time t	▪ Cell Phone: $ 1.5 ▪ Laptop: $ 5 ▪ Printer: $ 4.25
$ranged\_CDMD_{tup}$	Demand rate of each product for current facilities	▪ Motorola Cell. phone: 12,000/day ▪ Dell laptop: 200/day ▪ Toshiba laptop: 500/day ▪ HP printer: 7,000 /day
$ranged\_NDMD_{tup}$	Demand rate for new facilities	▪ Dell laptop: 200/day ▪ Toshiba laptop: 500/day
rtn_{tup}	Return rate	▪ 10% of outflow
rpPortion	Repair rate	▪ Each product: 88%
rmPortion	Remanufacturing rate	▪ Each product: 5%
rlPortion	Recycle rate	▪ Each product: 7%

Decision variables

Decision variables	Description
$PFCW_{twump}$	service charge for forward movement service of product *p* from client *l* and current warehouse *w* to customer *u* via mode *m* at time *t*
$XFCW_{twump}$	amount of forward flow for product *p* from current warehouse *w* to customer *u* via mode *m* at time *t*
$ECPCW_{twp}$	expansion amount of current warehouse *w* at time *t*
$PFNW_{twump}$	service charge for forward movement service of product *p* from facility *w* of client *l* and current warehouse *w* to customer *u* via mode *m* at time *t*
$XFNW_{twump}$	amount of forward flow for product *p* from new warehouse *w* to customer *u* via mode *m* at time *t.*
$ECPNW_{twp}$	expansion amount of new warehouse *w* at time *t*
$TPORTION_{tmp}$	proportion of transportation mode of air and ground between facilities *w* at time *t*
$TPORTION_{tuwmp}$	proportion of transportation mode of air and ground from

	customer *u* to facilities *w* at time *t*
CPR_{tuwmp}	unit service revenue of UPS for returned products *p* to current warehouse *w* at time *t*
NPR_{tuwmp}	Unit service revenue of UPS for returned products *p* to new warehouse *w* at time *t*
$ECPCR_{twrp}$	expansion amount of repair center r for product p in current warehouse w at time t
$ECPNR_{twrp}$	expansion amount of repair center r for product p in new warehouse w at time t
$XRCW_{tuwmp}$	amount of storage for returned product *p* from customer location *u* to current warehouse *w* at time *t* before they are shipped to repair center.
$XRNW_{tuwmp}$	amount of storage for returned product *p* from customer location *u* to new warehouse *w* at time *t* before they are shipped to repair center.
$XCWCR_{twwrmp}$	amount of transportation for returned product *p* from current warehouse w to repair center in other current warehouse *w* via mode *m* at time *t*.
$XCWNR_{twwrmp}$	amount of transportation for returned product *p* from current warehouse w to repair center in new warehouse *w* via mode *m* at time *t*.
$XNWCR_{twwrmp}$	amount of transportation for returned product *p* from new warehouse w to repair center in current warehouse *w* via mode *m* at time *t*.
$XNWNR_{twwrmp}$	amount of transportation for returned product *p* from new warehouse w to repair center in other new warehouse *w* via mode *m* at time *t*.
$XQCR_{twrp}$	amount of in-house quality checking for returned product *p* in repair center at current warehouse *w* at time *t*
$XQNR_{twrp}$	amount of in-house quality checking for returned product *p* in repair center at new warehouse *w* at time *t*.
$XRPCR_{twrp}$	amount of in-house repairing for returned product *p* in repair center at current warehouse *w* at time *t*.
$XRPNR_{twrp}$	amount of in-house repairing for returned product *p* in repair center at new warehouse *w* at time *t*.
$PMCR_{twrdp}$	outsourcing cost of remanufacturing for returned product *p* in repair center *r* at current warehouse *w* to *d* at time *t*
$XMCR_{twrdp}$	amount of outsourcing for remanufacturing for returned product *p* in repair center *r* at current warehouse *w* to *d* at time *t*
$PMNR_{twrdp}$	outsourcing cost of remanufacturing for returned product *p* in repair center *r* at new warehouse *w* to *d* at time *t*
$XMNR_{twrdp}$	amount of outsourcing for remanufacturing for returned product *p* in repair center *r* at new warehouse *w* to *d* at time *t*.
$XLCR_{twrep}$	amount of recycling for returned product p in repair center at Louisville to e at time t

$XLNR_{twrep}$	amount of recycling for returned product p in repair center at Memphis to e at time t
$CDMD_{tup}$	demand rate for current facilities of product *p* for customer *u*
$NDMD_{tup}$	demand rate for new facilities of product *p* for customer *u*
YNW_{twp}	binary variable to open new warehouse *w* at time *t*
$YECW_{twp}$	binary variable to expand current warehouse *w* at time *t*
$YENW_{twp}$	binary variable to expand new warehouse *w* at time *t*
YNR_{twrp}	binary variable to open new repair center *r* at time *t*
$YECR_{twrp}$	binary variable to expand current repair center in *r* at time *t*
$YENR_{twrp}$	binary variable to expand repair center in *r* at time *t*

CHAPTER FIVE

ANALYSIS AND RESULTS

Analysis of hypotheses

Analysis for H1:

H1: "The profit of the full model, incorporating an optimal price for items that UPS carries will be significantly larger than that of the reduced model."

Hypothesis statement H1 encompasses the effects of pricing or service charges for products that UPS transports for its customers to clients for forward flows, and reversely, for return flows. Price elasticity was applied in assessing the demand curve in the full model. However, currently UPS does not have solid information regarding the price elasticity associated with its business. As a consequence, analysis for pricing was conducted assuming different values for price elasticity, namely price elasticity= -0.25, -0.5, -0.75,-1,-1.25,-1.5,-1.75, and -2. We omit the negative sign for price elasticity for convenience and use E to denote elasticity throughout the analysis.

1) E=0.25

In this study the simulation was run such that 100 values were observed with the generation of each parameter, i.e., 100 values in each scenario, duplicating 100 times, which results in 100 scenarios and 100,000 observations in total. Average values for the profit of the two models, and differences of profit between the full and reduced model, was computed in each scenario. Using the value in each scenario the confidence interval for the profit difference can be constructed. Since each scenario has a confidence interval there are a total of 100 confidence intervals to analyze for each price elasticity. Illustrating all 100 confidence interval is bulky in the space of this work. Hence summary statistics for each elasticity were prepared to catch information on the average for profit differences in actual values and percentage ratios, computed by dividing the profit difference by the profit of reduced model.

Table 11
Summary statistics for E=0.25 for H1

	Percentage	Actual profit difference
Mean	0.77	$ 2,455,649
Std. Dev	0.70	$ 1,057,492
Sample size	100	100
Std. Error	0.07	$ 105,749
t-statistics	1.98	1.98
Confidence interval	0.14	$ 209,829
Lower limit	0.63	$ 2,245,820
Upper limit	0.91	$ 2,665,478

All 100 confidence interval constructions show positive intervals, both in percentage and actual profit differences, implying that the profit for the full model is significantly larger than that for the reduced model with a price elasticity of E=0.25. As is shown in Table 11 the confidence intervals are ranged from 63 % to 91% with a mean of 77%.

The above analysis reveals some insights in the light of profit. In order to assess the impact of optimal price selection upon revenue we need to isolate the revenue from the profit. The outcome of the location selection was that there was no facility candidate to open. Hence, the revenue source due to price is limited to the current products: cellular phones, laptops, and printers. In the forward flow the average reduced prices for cellular phone, laptop, and printer are $111, $974, $180, respectively and the average full prices for these items are $162, $1494, and $272. In the reverse flow the average reduced prices for cellular phones, laptops, and printers are $52, $338, and $82 and the full prices are $51, $345, $85, respectively. Also demands for the full model were observed as 10,972 for cellular phones, 626 for current laptops, and 6,298 for printers. The demands of the reduced model, which are the current transaction volume were used, with 12,000 for cellular phones, 700 for laptops (both current and new ones), and 7,000 for printers. The flow amount for the reverse operation was taken as 10% of the forward flow. Table 12 indicates the revenue improvement based on products and models considering two planning time horizons to match with the simulation running.

Table 12
Percentage improvement of revenue for E=0.25 for H1

	Forward flow			Reverse flow			Total
	Cell. Phone	laptop	printer	Cell. Phone	laptop	printer	
Full	$3,535,029	$1,862,216	$3,396,148	$115,129	$42,447	$102,957	$9,053,928
Reduced	$2,700,833	$1,388,950	$2,401,963	$123,513	$46,777	$115,457	$6,777,495
Difference	$834,196	$473,265	$ 994,184	$-8,384	$-4,330	$-12,499	$2,276,433
Improvement	31%	34%	41%	-7%	-9%	-10%	34%

We observe that the improvement of forward flow is ranged from 31% to 41%, while the reverse flow marked negative improvements, resulting in an overall improvement of 34%. All negative improvements in return process sound a bit surprising. The reason why the model realized the negative improvements is ascribed to the fact that the volume for reverse flow was taken to be 10% of the forward flow, which might not be optimal, differing from the optimal selection between price and demand, combined with incorporating errors made in forward flows. Generally the demands in the forward flow of the full model were lower than those in the reduced model, due to higher price. Naturally the volume of reverse flow, taken as 10% in the full model, is also lower than in the reduced model. Furthermore the price increase in the full model does not offset the loss of transaction volume. As a consequence, the revenue improvement of the full model generated a negative improvement in the return flow. This phenomenon may improve as UPS adjusts the price range of each product for reverse flow.

2) E=0.5

All 100 confidence interval constructions also show same tendency as E=0.25, that no interval includes non positive values. This fact proves the statistical significance in the largeness of the profit in the full model, in comparison to that in the reduced model. Table 13 shows that the mean of the percentage of profit improvement is 55%, bringing a lower limit of 46% and an upper limit of 65%. Compared with the mean improvement of profit with E=0.25, the magnitude of the profit increase diminished from 77% to 55%.

Table 13
Summary statistics for E=0.5 for H1

	Percentage	Actual profit difference
Mean	0.55	$ 1,770,640
Std. Dev	0.49	$ 747,800
Sample size	100	100
Std. Error	0.05	$ 74,780
t-statistics	1.98	1.98
Confidence interval	0.10	$ 148,379
Lower limit	0.46	$ 1,622,260
Upper limit	0.65	$ 1,919,020

With respect to the revenue improvement implied in Table 14, the range of improvement became 19% through 26%. We also observe a negative improvement of the reverse flow, ranging from -21 % to -14%, as we did at E=0.25. Even though the negative improvement looks large, the overall improvement turned out to be 20% due to the lower volume of reverse flow.

Table 14
Percentage improvement of revenue for E=0.5 for H1

	Forward flow			Reverse flow			Total
	Cell. Phone	laptop	printer	Cell. Phone	laptop	printer	
Full	$3,226,758	$1,674,179	$2,998,384	$106,146	$39,317	$90,956	$8,135,741
Reduced	$2,705,040	$1,397,200	$2,380,000	$123,600	$46,662	$114,192	$6,767,694
Difference	$521,717	$276,978	$618,383	$-17,453	$-7,344	$-24,253	$1,368,047
Improvement	19%	20%	26%	-14%	-16%	-21%	20%

3) E=0.75

Examining confidence intervals for a profit difference with E=0.75 we discovered also that all 100 intervals are positive implying that the profit of the full model incorporating price is statistically significant. The mean of the percentage improvement in profit is 37%, ranging from 31% to 44%, as indicated in Table 15.

Table 15
Summary statistics for E=0.75 for H1

	Percentage	Actual profit difference
Mean	0.37	$ 1,214,873
Std. Dev	0.32	$ 512,137
Sample size	100	100
Std. Error	0.03	$ 51,213
t-statistics	1.98	1.98
Confidence interval	0.06	$ 101,619
Lower limit	0.31	$ 1,113,254
Upper limit	0.44	$ 1,316,492

Table 16 was prepared by isolating the price component of revenue. In Table 16 the percentage improvement for forward flow ranged between 10% and 13%, whereas the reverse flow showed between -29% and -19%, resulting in an overall improvement of 10%.

Table 16
Percentage improvement of revenue for E=0.75 for H1

	Forward flow			Reverse flow			Total
	Cell. Phone	laptop	printer	Cell. Phone	laptop	printer	
Full	$3,022,800	$1,553,735	$2,695,635	$99,954	$38,564	$82,028	$7,492,718
Reduced	$2,736,456	$1,402,697	$2,391,886	$123,628	$46,756	$115,609	$6,817,033
Difference	$286,343	$151,038	$303,748	$-23,673	$-8,192	$-33,581	$675,684
Improvement	10%	11%	13%	-19%	-18%	-29%	10%

4) E=1

We have examined all 100 confidence intervals constructed for E=1. The observation is that all 100 intervals realized positive values, suggesting that the profit of the full model is still significantly larger than that of the reduced model. Compared to a mean of E less than 1, the mean improvement of E=1 becomes shrunken to 25%. Table 17 uncovers the details of the summary statistics.

Table 17
Summary statistics for E=1 for H1

	Percentage	Actual profit difference
Mean	0.25	$ 825,354
Std. Dev	0.21	$ 342,375
Sample size	100	100
Std. Error	0.02	$34,237
t-statistics	1.98	1.98
Confidence interval	0.04	$ 67,934
Lower limit	0.21	$ 757,420
Upper limit	0.29	$ 893,289

Theoretically it is called unit elastic when the price and demand rates change proportionally when E=1. Deviating from this characteristic of the unit elastic concept a notable observation was made on the improvement of laptops that marked 24% when other products achieved merely a 2% and 4% change in the forward flow. Also negative improvements were realized in other reverse flow cases, except for laptops. A positive improvement for laptops in the reverse flow is not surprising due to the high improvements made on laptops in the forward flow. The overall improvement recorded was 7% in this case, which is a decrease from the change at the previous price elasticity.

Table 18
Percentage improvement of revenue for E=1 for H1

	Forward flow			Reverse flow			Total
	Cell. Phone	laptop	printer	Cell. Phone	laptop	printer	
Full	$2,843,662	$1,732,918	$2,448,658	$96,431	$56,064	$75,725	$7,253,458
Reduced	$2,727,720	$1,395,216	$2,390,153	$123,895	$46,707	$115,507	$6,799,199
Difference	$115,941	$337,701	$58,504	$-27,463	$9,356	$-39,782	$454,259
Improvement	4%	24%	2%	-22%	20%	-34%	7%

5) E=1.25

When E=1.25 the mean improvement turns out to be 25%, which is close to that with E=1. The confidence interval ranges are similar to E=1 as well. By examining 100 constructions all of them showed positive intervals, implying again statistical significance of the profit in the full model. Summary statistics are noted in Table 19 for E=1.25.

Table 19
Summary statistics for E=1.25 for H1

	Percentage	Actual profit difference
Mean	0.25	$ 834,437
Std. Dev	0.18	$ 386,088
Sample size	100	100
Std. Error	0.02	$38,608
t-statistics	1.98	1.98
Confidence interval	0.04	$ 76,608
Lower limit	0.21	$ 757,829
Upper limit	0.28	$ 911,046

The closeness between E=1 and E=1.25 was observed in revenue improvement due to price and demand selection for both models, as indicated in Table 18 and Table 20. Prices for cellular phones and printers between the two cases are pretty alike for both flows, around $\pm 4\%$ but a phenomenal improvement of 77% was made in laptops, thus marking an overall percentage improvement of 18%.

Table 20
Percentage improvement of revenue for E=1.25 for H1

	Forward flow			Reverse flow			Total
	Cell. Phone	laptop	printer	Cell. Phone	laptop	printer	
Full	$2,839,988	$2,491,031	$2,334,392	$98,745	$204,291	$78,347	$8,046,795
Reduced	$2,726,282	$1,400,823	$2,437,273	$123,609	$46,819	$11,4983	$6,849,790
Difference	$113,706	$1,090,208	$-102,881	$-24,863	$157,471	$-36,635	$1,197,005
Improvement	4%	77%	-4%	-10%	346%	-33%	18%

6) E=1.5

As is the case of the previous price elasticity these results show that all confidence intervals are positive. The mean percentage started to rise at this elasticity. Table 21 shows the summary statistics of the profit differences.

Table 21
Summary statistics for E=1.5 for H1

	Percentage	Actual profit difference
Mean	0.38	$ 1,566,285
Std. Dev	0.25	$ 997,900
Sample size	100	100
Std. Error	0.03	$ 99,790
t-statistics	1.98	1.98
Confidence interval	0.05	$ 198,005
Lower limit	0.33	$ 1,368,280
Upper limit	0.44	$ 1,764,291

Revenue improvement at this elasticity demonstrates more radical outcomes, as noted in Table 22. The ranges of improvement for the forward flow run -2% through

135%, and the reverse flow runs from -26% through 681%. This is mainly contributed by cellular phones and laptops; the overall improvement integrating all these three items was recorded as 41%.

Table 22
Percentage improvement of revenue for E=1.5 for H1

	Forward flow			Reverse flow			Total
	Cell. Phone	laptop	printer	Cell. Phone	laptop	printer	
Full	$3,357,281	$3,302,046	$2,349,820	$160,089	$364,326	$85,005	$9,618,569
Reduced	$2,712,240	$1,408,168	$2,412,092	$123,749	$46,644	$115,290	$6,818,185
Difference	$645,041	$1,893,877	$-62,272	$36,340	$317,682	$-30,284	$2,800,385
Improvement	23%	135%	-2%	29%	681%	-26%	41%

7) E=1.75

It is clear that all the confidence intervals would pass a statistical significance test by looking at the mean of 74% at this elasticity. The lower and upper limits of the intervals are 64% and 84 % in average, as described in Table 23.

Table 23
Summary statistics for E=1.75 for H1

	Percentage	Actual profit difference
Mean	0.74	$ 3,115,227
Std. Dev	0.50	$ 2,064996
Sample size	100	100
Std. Error	0.05	$ 206,499
t-statistics	1.98	1.98
Confidence interval	0.10	$ 409,740
Lower limit	0.64	$ 2,705,487
Upper limit	0.84	$ 3,524,967

Table 24 gives information on the percentage improvement of revenue at E=1.75. The ranges are very wide on the forward flow, from 14% to 277%, and on the reverse flow from -3% to 1031%, realizing a 91% improvement overall.

Table 24
Percentage improvement of revenue for E=1.75 for H1

	Forward flow			Reverse flow			Total
	Cell. Phone	laptop	printer	Cell. Phone	laptop	printer	
Full	$4,202,842	$5,275,518	$2,777,351	$224,101	$529,648	$111,690	$13,121,152
Reduced	$2,735,282	$1,397,533	$2,418,947	$123,564	$46,792	$115,458	$6,837,577
Difference	$1,467,560	$3,877,985	$358,404	$100,537	$482,856	$-3,768	$6,283,575
Improvement	53%	277%	14%	81%	1031%	-3%	91%

8) E=2

A very large mean percentage was realized as the price elasticity hit 2. The percentage improvement is quite remarkable as elasticity increases. At E=2 the mean percentage increase turned out to be 141%, which is the highest among all elasticity values examined in this study. Table 25 depicts this phenomenon well.

Table 25
Summary statistics for E=2 for H1

	Percentage	Actual profit difference
Mean	1.41	$ 5,955,526
Std. Dev	0.97	$ 3,903,213
Sample size	100	100
Std. Error	0.10	$ 390,321
t-statistics	1.98	1.98
Confidence interval	0.19	$ 774,482
Lower limit	1.22	$ 5,181,043
Upper limit	1.60	$ 6,730,008

Examining the price contribution on revenue also showed the same direction as the profit and followed in the footsteps of profit in the mean improvement of both profit and revenue. Revenue improvement gaps between the smallest and largest among the three items are very wide. Table 26 reveals revenue improvements, recording 169% overall.

Table 26
Percentage improvement of revenue for E=2 for H1

	Forward flow			Reverse flow			Total
	Cell. Phone	laptop	printer	Cell. Phone	laptop	printer	
Full	$5,193,517	$8,390,208	$3,631,212	$285,240	$751,426	$160,126	$18,411,730
Reduced	$2,720,105	$1,402,902	$2,434,257	$123,307	$46,846	$115,332	$6,842,750
Difference	$2,473,412	$6,987,306	$1,196,955	$161,933	$704,579	$44,793	$11,568,980
Improvement	90%	498%	49%	131%	1504%	38%	169%

9) Conclusive analysis of H1:

Conclusion on hypothesis test

Through examining H1 with different price elasticities an important conclusion can be drawn that the profit of the full model is significantly larger than that of the reduced model. Even though we have not taken all of the price elasticity of demand into consideration, the observation made from the systematic and representative values of elasticity confirms this conclusion.

Price elasticity issues

Since UPS does not know the price elasticity of the industry as a whole, integrating varied elasticity would help find the driving force of profitability in the future supply chain operations of the firm.

In the economic theory of price elasticity of demand, the demand is called "inelastic" when the elasticity is less than 1, implying that the percentage change of demand due to price change is smaller than the percentage change of price. In other words, demand is not sensitive to price changes when it is inelastic. On the other hand, the price elasticity is called "elastic" when the demand is sensitive to price changes, i.e. if elasticity is larger than 1. If elasticity is 1 the elasticity is called "unit elastic".

Based on these elasticity characteristics we observe some trends in profit and revenue realization. Both profit and revenue improvements have declined in the inelastic region as the elasticity approaches to 1 from 77%, through 55%, to 37% for profit and from 34%, through 20%, to 10% for revenue.

On unit elastic the mean profit increase is 25% while the revenue increase was recorded as 7%. In the case of an elastic situation, compared to an inelastic one, an overall large improvement was observed in both profit and revenue realization. Starting with a mild improvement of 25% for profit and 18% for revenue at E=1.25, improvements became 141% for profit and 169% for revenue at E=2.0. Even though this phenomenon of different ranges could be expected according to the theory of price elasticity, the magnitude dependant on different products would provide useful insights to UPS for its supply chain business.

From figure 9 the trend of profit and revenue increase looks alike in a U shape. However, the magnitude of the two shows with the crossing point at E=1.5. Before the crossing point the profit improvement is larger, but the opposite is observed after the crossing point. This may be explained by the cost factors associated with the full model having more impact on the profit when the elasticity is small. By the same token, the revenue decided by price and corresponding demand plays a much larger role in deciding profit in the high elastic region in deciding profit, rather than cost factors which are relatively constant throughout the varied elasticity. In other words, UPS would gain more benefit by optimally choosing price and demand when the elasticity is large.

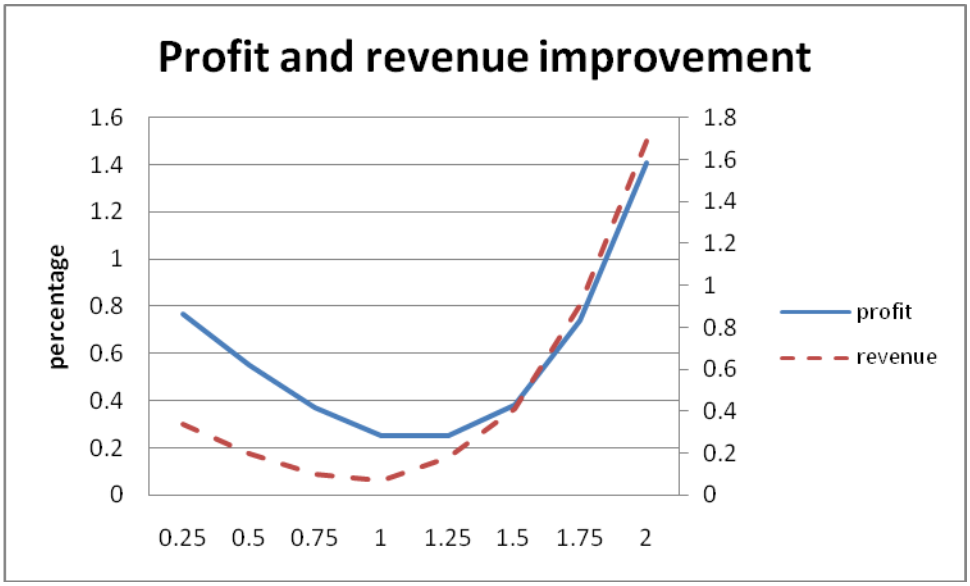


Figure 9. Profit and revenue improvement for H1

Figure 10 illustrates the improvement ratios for revenue among the products. The figure reveals for UPS that the laptop realizes the most revenue, followed by cellular phones for UPS. The printers would bring in the least revenue. One of the general conclusions that may be made from the figure is that UPS would be more lucrative in terms of revenue over the high area of price elasticity with a fixed price range for each product, except printers.

In the higher region of elasticity the figure also illustrates the striking difference in improvement in laptops in comparison to that in cellular phones and printers, even though improvement ratios across the products are indistinguishable at the inelastic region.

Plausible reasons for the profit superiority of laptops could be the wider range of its price and randomness associated with errors derived from normal distribution in deciding demand at a given price.   Since the laptop customers have more choices from which to select an optimal value, due to the wider range of price, the chances are high for singling out a better value for demand as the sensitivity of demand in reaction to price change becomes larger.

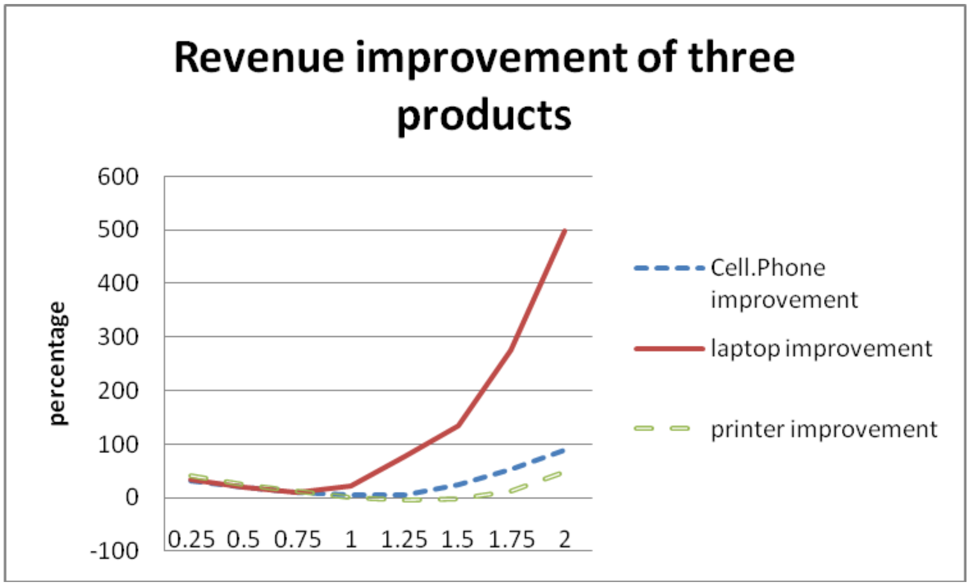


Figure 10.   Revenue improvement of three products for H1

Breaking down the overall revenue in a more detailed manner across products by price and demand will shed more light for grasping the interconnections between price and demand that comprise revenue.   Figures 11, 12, and 13 were prepared based on Table 27 by taking a percentage increase of price and demand from the previous period. Note that this percentage change is not completely proportional to that of demand due to price changes for randomness associated with demand selection at a given price.

Laptops and cellular phones exhibit somewhat different signals on the percentage change from that with printers, which provides the least benefit to UPS. Both laptops and cellular phones have high jumps of demand at around E=1 and 1.25 and shows a moving tendency of both components toward the center, passing E of 1 and 1.25, while printers show little central tendency in the elastic region. This phenomenon can be explained by the following reasoning. Since there is a random error component in the demand selection, the demand and price ratio are not exactly tied to the theoretical elasticity values. Hence there could be a higher demand computed than the percent change in price. Especially the E=1 and 1.25 are the least sensitive region in the elastic area. However, for randomness or a difference of price range, if the demand was calculated higher than expected in the insensitive area, the impact is relatively large, and thus caused a huge jump in the revenue since the previous area is generally flat in the revenue curve. As a consequence, the increase in demand well offsets the decrease in price resulting in the high increase ratio of demand for laptops and cellular phones.

At the very volatile area of the elastic region a central moving tendency was observed in the two lucrative products of laptops and cellular phones that explain the balancing of the demand increase and price decrease would provide sound revenue structure to UPS around the elastic area.

Therefore, a conclusion can be drawn that, in the high elastic zone, UPS needs to be more careful with selecting prices since lowering price does not consequently guarantee higher demand and higher revenue. In other words maintaining a relatively high price at the highly elastic region, expecting some reduction of demand due to high price, might be a good pricing strategy for UPS compared to the other elastic or inelastic regions.

Table 27
Price and demand changes by price elasticity for H1

E	Model	Price/ Demand	Forward			Reverse		
			Cell.Ph.	Laptop	Printer	Cell.Ph.	Laptop	Printer
0.25	Full	Price	$160	$1482	$275	$52	$335	$83
		Demand	11038	628	6177	1103	63	618
	Reduced	Price	$113	$992	$172	$51	$334	$82
		Demand	12000	700	7000	1200	70	700
0.5	Full	Price	$159	$1445	$275	$52	$339	$83
		Demand	10132	579	5452	1013	58	545
	Reduced	Price	$113	$998	$170	$52	$339	$83
		Demand	12000	700	7000	1200	70	700
0.75	Full	Price	$159	1371	$274	$53	$340	$84
		Demand	9492	566	4908	949	57	491
	Reduced	Price	$114	$1001	$170	$52	$334	$83
		Demand	12000	700	7000	1200	70	700
1	Full	Price	$156	$1081	$272	$53	$350	$84
		Demand	9079	800	4485	908	80	449
	Reduced	Price	$114	$997	$170	$52	$333	$82
		Demand	12000	700	7000	1200	70	700
1.25	Full	Price	$137	$446	$255	$53	$374	$84
		Demand	10346	2795	4563	1035	280	456
	Reduced	Price	$113	$1000	$174	$51	$334	$82
		Demand	12000	700	7000	1200	70	700
1.5	Full	Price	$111	$339	$231	$53	$377	$83
		Demand	15001	4863	5080	1500	486	508
	Reduced	Price	$113	$1005	$172	$51	$333	$82
		Demand	12000	700	7000	1200	70	700
1.75	Full	Price	$99	$372	$206	$53	$373	$83
		Demand	21101	7088	6721	2111	709	672
	Reduced	Price	$113	$998	$172	$51	$334	$82
		Demand	12000	700	7000	1200	70	700
2	Full	Price	$95	$411	$191	$52	$368	$83
		Demand	27159	10200	9464	2716	1020	964
	Reduced	Price	$113	$1002	$173	$51	$334	$82
		Demand	12000	700	7000	1200	70	700

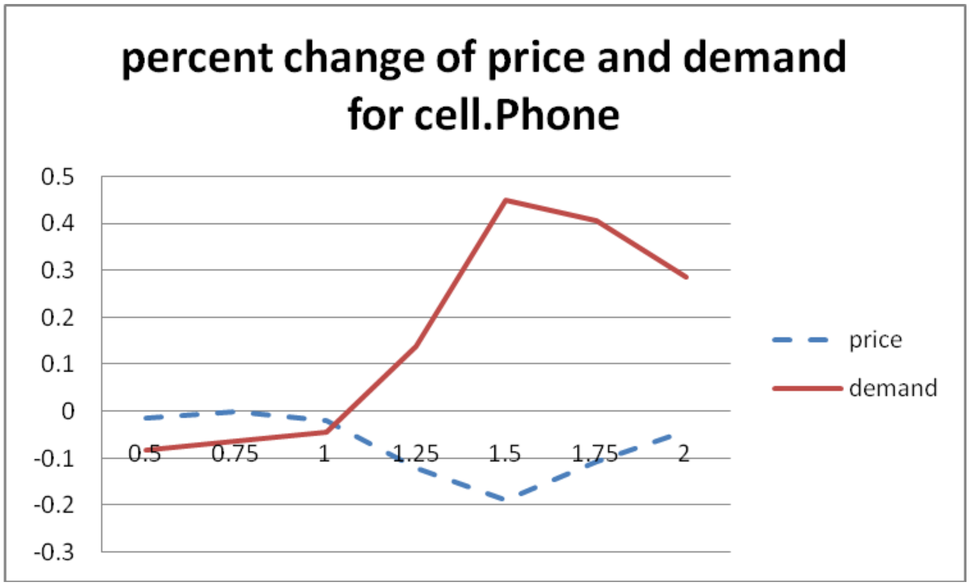


Figure 11. Percentage change of price and demand for cellular phone for H1

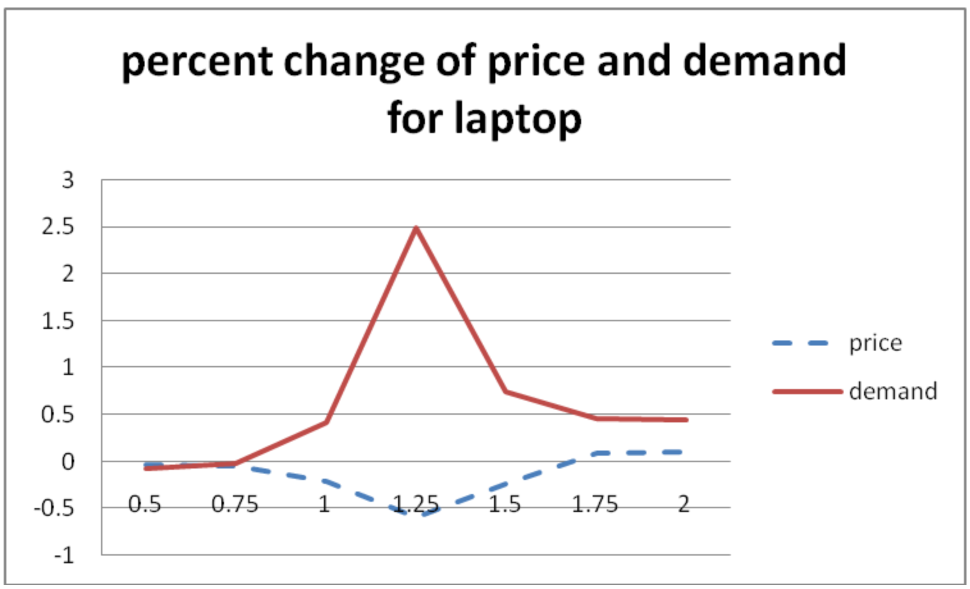


Figure 12. Percentage change of price and demand for laptop for H1

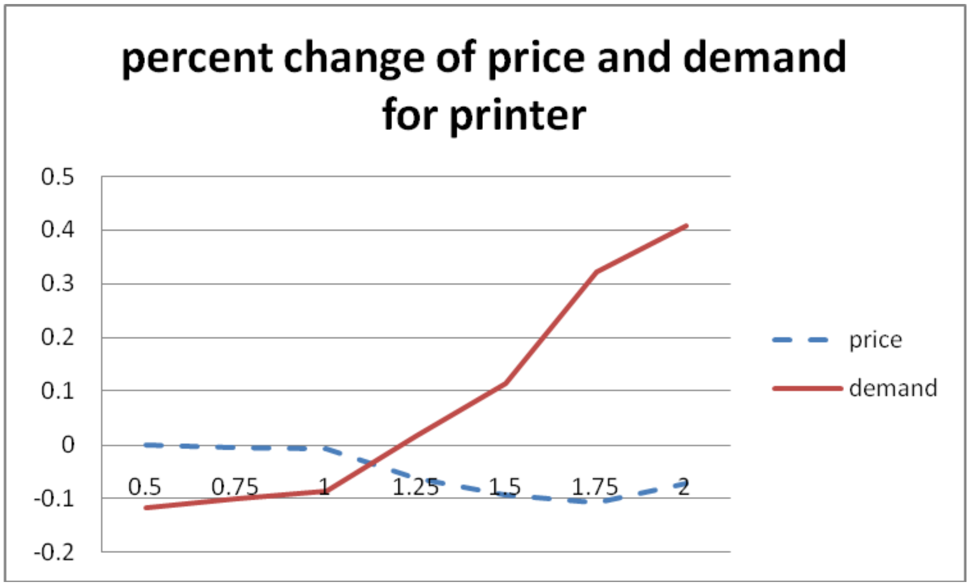


Figure 13. Percentage change of price and demand for printer for H1

Before concluding this section let us take a macro point of view on the behavior of the revenue of each product for the forward flow in the full model.

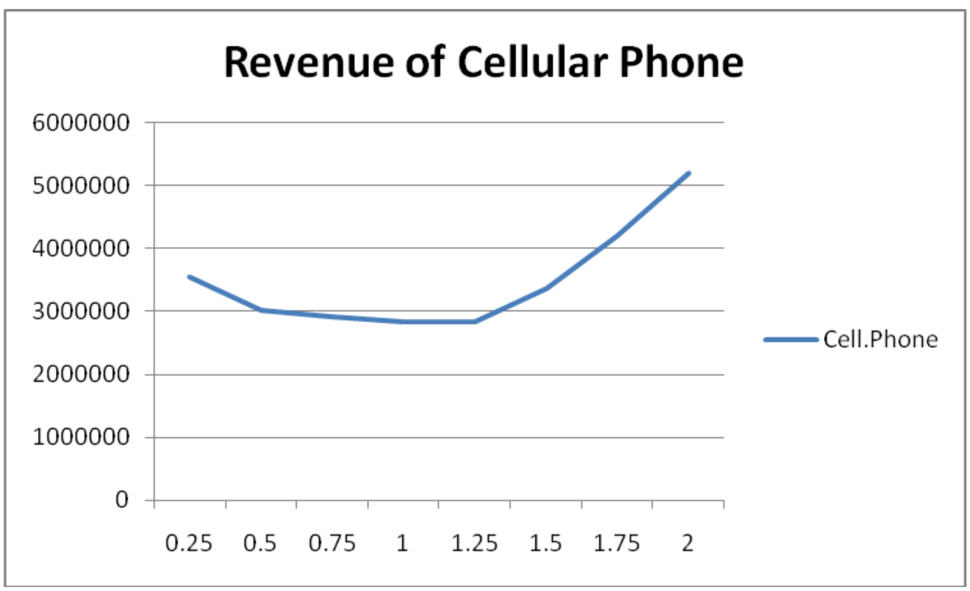


Figure 14. Revenue of cellular phone in the full model for H1

Figure 14 shows the revenue realized for UPS from cellular phones. At the inelastic region the cellular phones struggled in generating profits for UPS. At E=1.25 the revenue reached the bottom. Breaking balance between the elastic and inelastic area, the highly elastic area exhibits a good upward curve for revenue formulation.

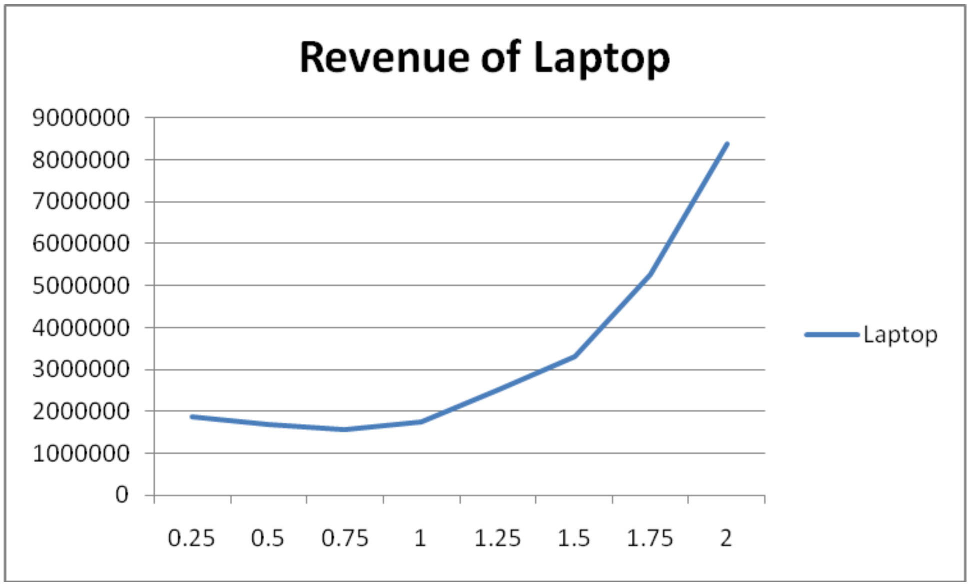


Figure 15. Revenue of laptop in the full model for H1

Figure 15 on revenue of laptops clearly shows the trend of profit generation in that elastic area is very favorable to UPS while the inelastic area reveals a flat revenue acheivement.

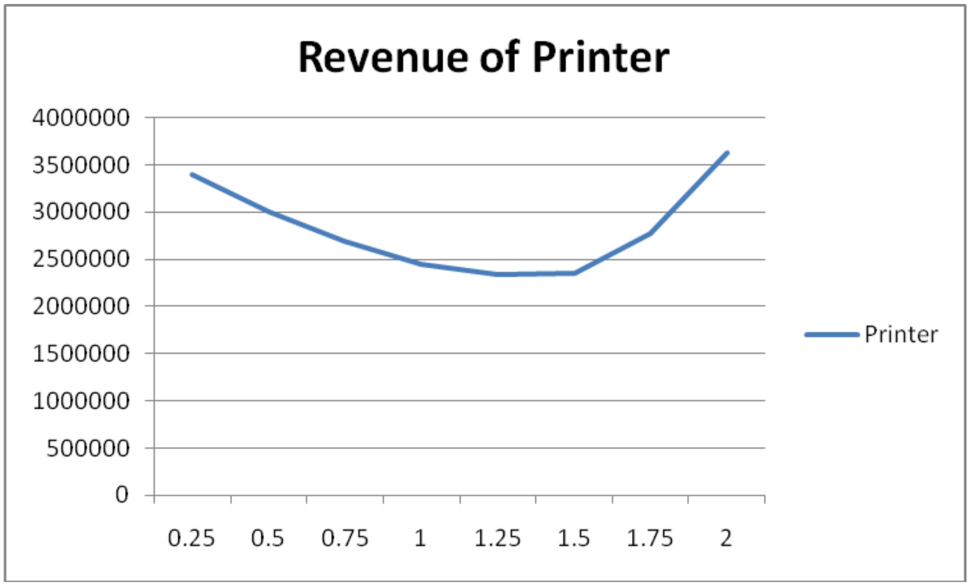


Figure 16. Revenue of printer in the full model for H1

Showing the revenue shape for the printer in figure 16, the curve implies that UPS should react carefully if the elasticity of printers falls around E=0.75 through 1.5. The extreme areas of both the elastic and inelastic regions for printers are favorable to UPS. In concluding the analysis for H1, we need to mention that:

1) The full model is statistically significant in profit realization for UPS compared to the reduced model, i.e. incorporating a pricing component in the model will be promising for the firm.

2) The analysis of revenue generation by incorporating pricing components suggests that UPS will be better off when the price elasticity of each product falls on the more elastic boundary than the inelastic one.

3) Even though business is lucrative at the elastic region, which generally comes from a higher demand due to lowering prices, maintaining a relatively high price

might be a good pricing strategy for UPS in a very highly elastic region since the benefit of high prices will cancel off the harm from reduction of demand.

4) Based on the three products that UPS carries, generally the laptop is the most lucrative item, followed by cellular phones. Printers currently generate the least benefit to UPS.

Analysis for H2:

H2: **"**The profit of the full model, incorporating optimal transportation modes of moving items that UPS carries, will be significantly larger than that of the reduced model."

Currently UPS carries out its logistics business using two major transportation modes, namely, air and ground. The two methods imply two different strategic connotations, i.e. cost efficiency vs. responsiveness in the circumstances of the supply chain. Despite the different strategic implications our object is to provide insight on the allocation of optimal movement modes applied in the UPS business on the basis of cost efficiency.

In our study the simulation is designed for seeking optimal pricing, transportation modes, and outsourcing costs for remanufacturing. Since this hypothesis states only the issue of allocating optimal transportation modes for the UPS logistics business, the prices of each product for the full model are identical to those for the reduced model. This will remove the price effect, leaving the simulation a purely transportation mode effect. The outcome of simulation running is noted in Table 28, summarizing major statistics on the profit difference between the two models by allocating the movement methods optimally in the full model.

Table 28
Summary statistics for optimal transportation mode for H2

	Percentage	Actual profit difference
Mean	0.21	$ 773,840
Std. Dev	0.10	$ 159,466
Sample size	100	100
Std. Error	0.01	$ 15,946
t-statistics	1.98	1.98
Confidence interval	0.02	$ 31,641
Lower limit	0.19	$ 742,199
Upper limit	0.23	$ 805,482

Presently UPS moves all three products via air for incoming to their warehouses from its customers and outgoing from its hub in Louisville, KY to clients. Trucking is a major means for moving products across the warehouse networks, mainly heading to the hub at Louisville, KY for both forward and return flows. The reduced model contains this current allocation of moving methods, while the full model seeks for optimal allocation. The profit difference found in Table 28 is 21%. This explains that by allocating transportation means optimally UPS can improve its profit by an average of 21%. The lower limit and upper limit for the confidence interval turned out to be 19% and 23%, respectively. Also, examining all 100 constructions of the confidence interval shows that all 100 intervals are significant. A more in-depth analysis was conducted to observe the behavior of the allocation pattern for transportation modes across the products.

In the analysis we found that a correlation between the two means of air and ground for each product with respect to profit difference does not exist. In other words the optimal allocation is completely random and is understandable since the costs and distances between locations of warehouse, customers, and consumers are designed to be random in the simulation. Therefore the study of this hypothesis needs to highlight the statistical significance of profit difference rather than identifying correlations or patterns in transportation mode allocation.

Despite this non-significant correlation a few interesting phenomena were observed throughout the analysis regarding this hypothesis. One is that each optimal mode for cellular phones and laptops show a continuum of allocation ranging from 0% to 100%, while printer allocation shows all extreme values of 0% (or close to 0%), 100%(or close to100%) implying not much between-values in printer selection.

This difference may be ascribed to the following observation. The unit transportation costs of cellular phones and laptops are not much different between the two modes. However, the cost difference for printers is relatively larger than that of cellular phones and laptops. Due to this large unit cost difference for printers from the other two products, printers are more vulnerable to selection of optimal movement modes than that with other cost structures, especially when all the randomly selected travel distances matter. In other words, this high vulnerability of printers leads to more extreme selection, whereas the lesser vulnerability of cellular phones and laptops have a higher chance of picking up between values.

Another observation is that the average of air transportation modes for cellular phones reads 54%, suggesting ground transportation modes of 46%, and laptops 51%

meaning 49% of the ground transportation mode, and 53% for printer suggesting 47% of ground transportation method. Hence, generally speaking, a balanced mixture on the two modes will provide a benefit to UPS in terms of its transportation methods.

In summary a few remarks can be made on the hypothesis,

1) We observed statistical significance for incorporating optimal transportation modes into the model.
2) Depending on the distance UPS may consider an all-air or all-ground transportation option for printer movements.
3) A generally balanced mixture, in average, between the two transportation modes across products might bring benefits to UPS.

Analysis for H3:

H3: "The profit of the full model, incorporating optimal outsourcing costs of items that UPS carries for remanufacturing, will be significantly larger than that of the reduced model."

Reverse logistics activities for UPS include moving items in the return flow and checking the conditions of the returned products. Some of the products do not require much, or even no, treatment. A portion of the items will be outsourced for remanufacturing. This hypothesis is concerned with deciding the outsourcing cost. Currently about 5% of the returned products are outsourced for remanufacturing. Table 29 below provides information on the simulation data.

Table 29
Summary statistics for optimal outsourcing cost for H3

	Percentage	Actual profit difference
Mean	0.00	$ 2,281
Std. Dev	0.00	$ 408
Sample size	100	100
Std. Error	0.00	$ 40
t-statistics	1.98	1.98
Confidence interval	0.00	$ 81
Lower limit	0.00	$ 2,200
Upper limit	0.00	$ 2,362

As is observed the actual difference in profit between the models is $2,281 and the test is significant theoretically. However, the percentage improvement is virtually 0%. Therefore, since given the fact that the magnitude of profits for both models is large, the difference of $2,281 is trivially small, and an improvement is not made, we can draw a conclusion that selecting the optimal outsourcing cost using this model does not benefit UPS much with current reverse volume. The plausible reason why the test result is virtually insignificant is that the return volume is only 10% of the forwarded volume and furthermore the outsourcing portion is merely 5% of the returned items. This small volume explains the test result.

The overall conclusion for this section is that the proportion of outsourcing is not likely to be increasing for the UPS business as time goes on. Hence, as is uncovered, incorporating outsourcing costs for remanufacturing alone is not very promising under the company's current logistics operations.

<u>Analysis for H4</u>:

H4: “The profit of the full model, incorporating optimal transportation modes of moving items that UPS carries and outsourcing costs of items that UPS carries for remanufacturing, will be significantly larger than that of the reduced model.”

Summary statistics denoted in Table 30 suggests that the combination effect between the selection of an optimal transportation mode and outsourcing cost for remanufacturing does not exist. Rather combining the two decision variables in the full model resulted in the reduction of profit, an inverse effect.

Table 30
Summary statistics for optimal transportation mode combined with outsourcing cost for H4

	Percentage	Actual profit difference
Mean	0.20	$ 769,381
Std. Dev	0.09	$ 157,019
Sample size	100	100
Std. Error	0.01	$ 15,702
t-statistics	1.98	1.98
Confidence interval	0.02	$ 31,156
Lower limit	0.18	$ 738,225
Upper limit	0.22	$ 800,537

The reason for this inverse effect can be explained as follows. Clearly the lower the outsourcing cost, the better the profit for the firm. When the outsourcing costs for remanufacturing or transportation mode are singled out alone, the lowest value will represent the most profit in each scenario. However, if either of the two costs is the lowest in the simulation, it does not necessarily realize the highest profit when one lowest cost is combined with a non optimal selection in the other cost structure. Of course, if both the outsourcing costs and the cost for the transportation modes are lowest, the cost combined for both of the components will generate the highest profit. However, the final optimal profit that the simulation selects is not always the combination of the lower of the two, which explains the shortage in the profit when those two are combined one with another.

Figure 17 illustrates the difference of the optimal outsourcing cost between the two hypotheses of H3 and H4 for each of the three products, out of which cellular phones make the largest, and laptops the least, difference.

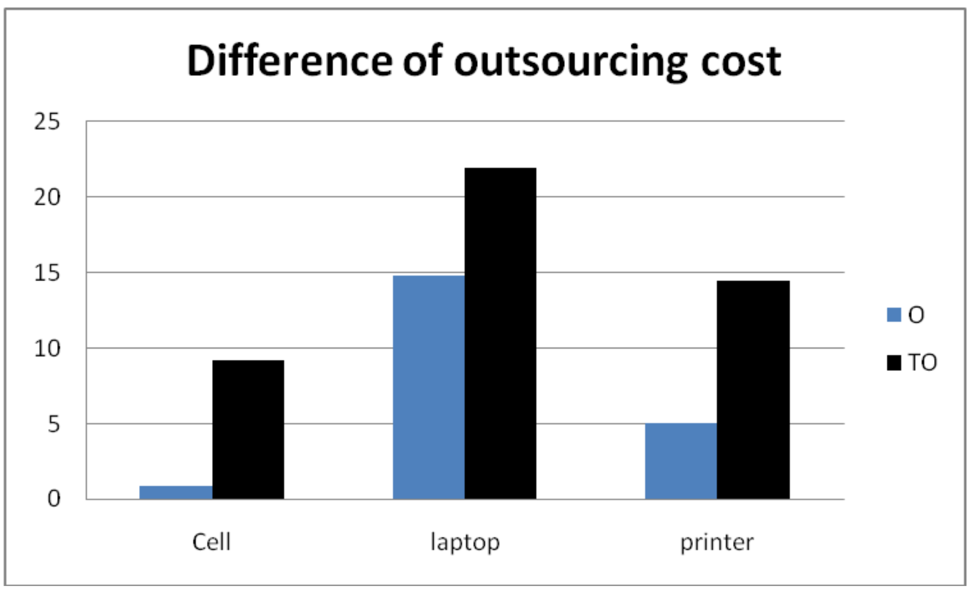


Figure 17. Comparison of the difference of outsourcing cost for three products for H4
Note: O denotes outsourcing cost for remanufacturing, TO denotes transportation mode and outsourcing cost for remanufacturing

<u>Analysis for H5</u>:

H5: "The profit of the full model, incorporating optimal price of items that UPS carries and optimal transportation modes of moving items that UPS carries, will be significantly larger than that of the reduced model."

1) E=0.25

We followed the same method for constructing confidence interval as we did for price only. We observe that all 100 confidence intervals are significant and, as is shown in table 31, the average confidence interval of the 100 constructions is high enough that the lower limit is $2,819,453 and the upper limit is $3,218,593.

Table 31
Summary statistics for E=0.25 for H5

	Percentage	Actual profit difference
Mean	0.92	$ 3,019,023
Std. Dev	0.74	$ 1,005,875
Sample size	100	100
Std. Error	0.07	$ 100,587
t-statistics	1.98	1.98
Confidence interval	0.15	$ 199,569
Lower limit	0.78	$ 2,819,453
Upper limit	1.07	$ 3,218,593

2) E=0.5

Table 32 denotes the summary statistics for E=0.5. It marked a lower mean percentage of profit improvement than in the case of E=0.25. The analysis also indicates that all 100 confidence intervals are significant.

Table 32
Summary statistics for E=0.5 for H5

	Percentage	Actual profit difference
Mean	0.67	$ 2,248,545
Std. Dev	0.52	$ 686,499
Sample size	100	100
Std. Error	0.07	$ 68,649
t-statistics	1.98	1.98
Confidence interval	0.10	$ 136,216
Lower limit	0.57	$ 2,112,329
Upper limit	0.78	$ 2,384,761

3) E=0.75

The same conclusion is drawn with respect to significance of the hypothesis as the previous two, even though some downward trend is witnessed as the elasticity moves toward the higher region. Table 33 provides summary statistics for E=0.75.

Table 33
Summary statistics for E=0.75 for H5

	Percentage	Actual profit difference
Mean	0.48	$ 1,660,570
Std. Dev	0.33	$ 436,664
Sample size	100	100
Std. Error	0.03	$ 43,666
t-statistics	1.98	1.98
Confidence interval	0.07	$ 86,643
Lower limit	0.41	$ 1,573,926
Upper limit	0.54	$ 1,747,213

4) E=1

Table 34 presents the information on the confidence interval for E=1. The average of 100 intervals shows a 35% increase in profit in the full model. All 100 confidence intervals were inspected and the result is that all are significant. In the inelastic area the profit is shown decreasing and the unit elastic point shows lower profit than the inelastic horizon.

Table 34
Summary statistics for E=1 for H5

	Percentage	Actual profit difference
Mean	0.35	$ 1,254,883
Std. Dev	0.21	$ 266,471
Sample size	100	100
Std. Error	0.02	$ 26,647
t-statistics	1.98	1.98
Confidence interval	0.04	$ 52.873
Lower limit	0.31	$ 1,202,009
Upper limit	0.39	$ 1,307,757

5) E=1.25

Table 35 contains the statistics on the case of E=1.25. It is interesting that both the case of price only and the combination of price and transportation realized the least improvement in profit when E=1.25. The average improvement of profit from the reduced model to the full model is 34% and the lower and upper limits are 31% and 37%, respectively. The test result is significant.

Table 35
Summary statistics for E=1.25 for H5

	Percentage	Actual profit difference
Mean	0.34	$ 1,346,777
Std. Dev	0.15	$ 398,772
Sample size	100	100
Std. Error	0.02	$ 39,877
t-statistics	1.98	1.98
Confidence interval	0.03	$ 79,125
Lower limit	0.31	$ 1,267,652
Upper limit	0.37	$ 1,425,903

6) E=1.5

Examining all 100 intervals we found that all are significant. Even though the profit difference between E=1 and 1.25 are minimal the profit difference from E=1.25 to E=1.5 is quite large. It is manifest that the upward trend presents in the upper elasticity horizon. Table 36 illustrates the summary statistics for the case of E=1.5

Table 36
Summary statistics for E=1.5 for H5

	Percentage	Actual profit difference
Mean	0.52	$ 2,222,092
Std. Dev	0.22	$ 1,011,675
Sample size	100	100
Std. Error	0.02	$ 101,167
t-statistics	1.98	1.98
Confidence interval	0.04	$ 200,738
Lower limit	0.48	$ 2,021,353
Upper limit	0.57	$ 2,422,830

7) E=1.75

The upward trend in profit difference between the two models is also confirmed at E=1.75 indicated in Table 37. The average percentage mean marked is 93% and the lower limit turns out to be an 84% increase and an upper limit of 102%. Of course, all 100 of the test statistics are significant.

Table 37
Summary statistics for E=1.75 for H5

	Percentage	Actual profit difference
Mean	0.93	$ 4,006,240
Std. Dev	0.43	$ 2,054,919
Sample size	100	100
Std. Error	0.02	$ 205,491
t-statistics	1.98	1.98
Confidence interval	0.09	$ 407,740
Lower limit	0.84	$ 3,598,500
Upper limit	1.02	$ 4,413,981

8) E=2

Table 38 summarizes the statistics for the case of E=2. It is shown that all 100 intervals passed the significance test.

Table 38
Summary statistics for E=2 for H5

	Percentage	Actual profit difference
Mean	1.69	$ 7,286,051
Std. Dev	0.88	$ 3,799,201
Sample size	100	100
Std. Error	0.09	$ 379,920
t-statistics	1.98	1.98
Confidence interval	0.17	$ 753,844
Lower limit	1.52	$ 6,532,207
Upper limit	1.86	$ 8,039,895

9) Conclusive analysis for H5

Table 39 informs us about the profit difference for price only and the combination of price and transportation mode. An in-depth analysis using a pictorial pattern in Figure 18, based on two different components incorporated into the full model, was conducted as to the behavior of profit realization.

Table 39
Comparison of profit difference for price only, and price and transportation mode combined for H5

E	Percentage			Profit difference		
	Price only	Price and transportation	Difference	Price only	Price and transportation	difference
0.25	0.77	0.92	0.15	$2,455,649	$3,019,023	$573,374
0.5	0.55	0.67	0.12	$1,770,640	$2,248,545	$477,905
0.75	0.37	0.48	0.11	$1,214,873	$1,660,570	$445,697
1	0.25	0.35	0.1	$825,354	$1,254,883	$429,479
1.25	0.24	0.34	0.1	$864,837	$1,346,777	$481,940
1.5	0.38	0.52	0.14	$1,566,285	$2,222,092	$655,807
1.75	0.74	0.93	0.19	$3,115,227	$4,006,240	$891,013
2	1.41	1.69	0.28	$5,955,526	$7,286,051	$1,330,525

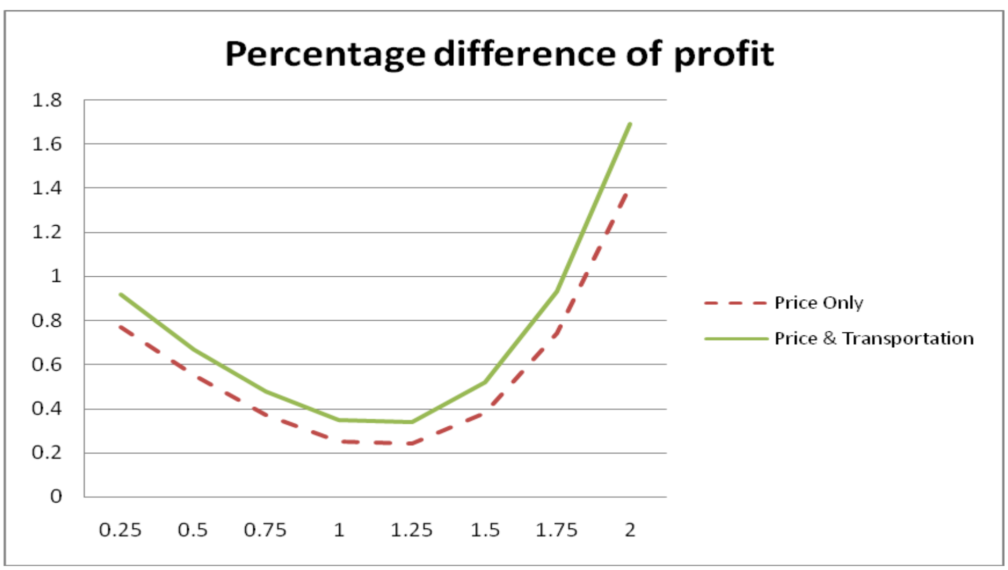


Figure 18. Percentage difference of profit between price and transportation mode selection for H5

Figure 18 illustrates the the profit difference between the two models in percentage, prepared based on table 39 and comprising two graphs; price only and combined price and transportation modes. Roughly, it gives a U-shape with respect to price elasticity. Incorporating transportation modes in the model is more beneficial to UPS when the price elasticity lies at both of the end zones, suggesting less benefit around the middle of the price elasticity area. For example, the improvement to the full model made by incorporating transportation mode in addition to pricing to the full model was found to be 15% with E=0.25 when it was 10% at the unit elastic point.

The same phenomenon, but a better outcome, was found on the other extreme of the elasticity zone as well. Even though a 10% through 15% difference does not sound large the magnitude of the actual profit difference is remarkable, as is evidenced in Table 39.

Between the two extreme elasticity zones, the higher elasticity illustrates more difference in profit generation by taking transporation modes into consideration than in its opposite region. In more detail, the rate increase is expedited in the higher elasticity region 4% (from E=1.25 to 1.5) through 9% (from E=1.75 to 2.0), while the other side shows a flatness of 0% (from E=1 to 1.25) through 3% (from E=0.5 to 0.25) in improvement.

We can infer from this phenomenon that there is some synergy effect between price and movement mode selection when price and demands are diversified by varying the price elasticity. This inference is well understood since there are more chances to choose an optimal profit by combining price and demand factors with transportation mode than when fixing them. This observation is also consistent with the fact that the higher the price elasticity the higher the increase in profit since the higher elasticity region tends to show a higher probability of profit optimality, as witnessed in the analysis of hypothesis 1.

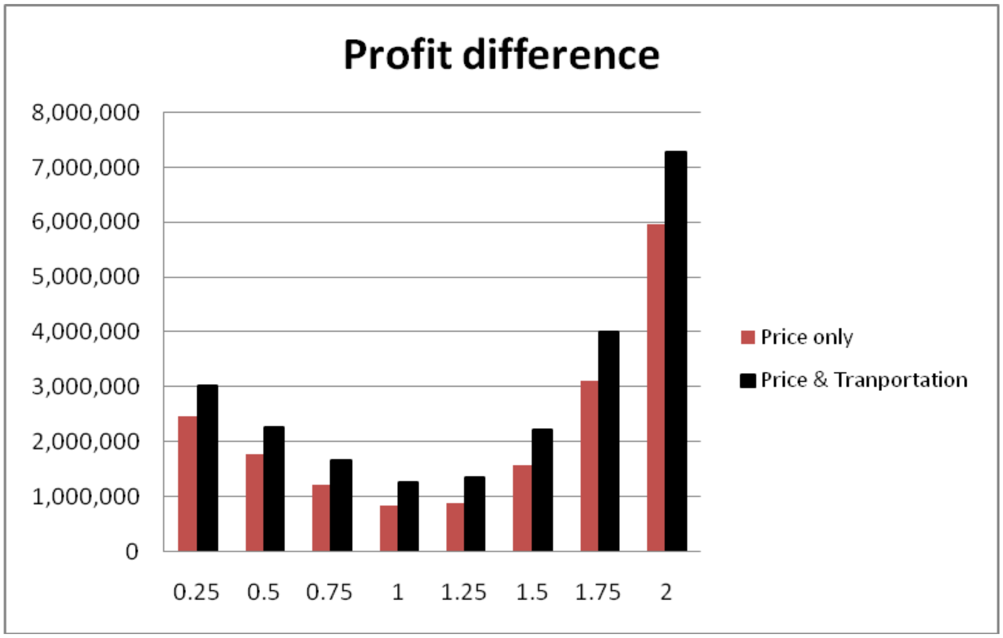


Figure 19. Difference of profit between price and transportation mode selection for H5

Profit difference between the price only and the combination of price and transportation mode selection in figure 19, demonstrates consistency with figure 18 in the shape of those two components. The profit difference was ranged from \$429,479 with E=1, to \$1,330,525 with E=2, for UPS by adding the selection of transportation mode on pricing indicated in table 39.

In our discussion of this section we suggested the possibility of a synergy or combination effect in profit realization for UPS through combining the optimal selection of price and transportation mode. Hence, it is worthy to investigate the source of the synergy effect on both of the extreme zones of price elasticity by examining in the model the revenue and cost factors in the model which comprise profit for the firm. This synergy effect, or combination effect, was assessed by providing two different perspectives; the revenue improvement of each product and the revenue contribution of the products to UPS.

i) <u>Revenue improvement of each product</u>

This methodology is concerned with identifying revenue and cost components by contrasting the revenue improvement of each product between hypotheses 1 and 5. Therefore the method will measure the absolute improvement of its own, whereas the other method, applied later, is to comprehend the relative improvement of each of the products comprising the whole reveneue for UPS.

Table 40
Revenue improvement ratio for H5

	Cell. Phone		Laptop		Printer		Total	
E	P	P&T	P	P&T	P	P&T	P	P&T
0.25	31%	32%	34%	33%	41%	41%	34%	34%
0.5	19%	20%	20%	20%	26%	25%	20%	20%
0.75	10%	11%	11%	11%	13%	12%	10%	10%
1	4%	4%	24%	24%	2%	5%	7%	8%
1.25	4%	4%	8%	8%	-4%	16%	18%	26%
1.5	24%	21%	134%	153%	-3%	63%	41%	69%
1.75	54%	52%	277%	303%	15%	135%	92%	142%
2	91%	88%	498%	543%	50%	260%	169%	257%

The table provides information on revenue improvement in proportion across products on the variety of price elasticity.

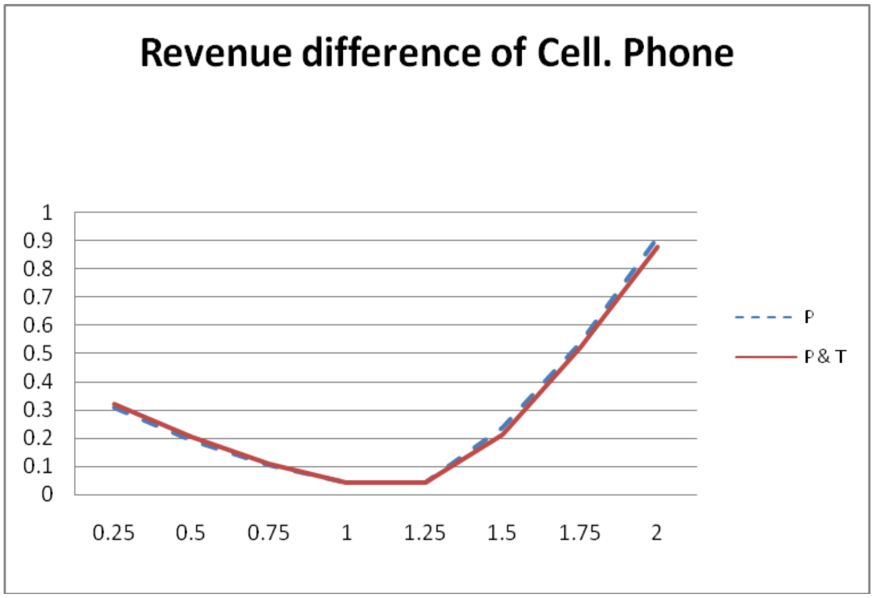


Figure 20. Revenue difference of cellular phone between price only and combination of price and transportation mode for H5
Note: P denotes price only, P&T denotes price and transportation mode.

The figure 20 implies that the difference in revenue improvement for cellular phones between the two components, i.e. P and P&T, is not very distinctive across price elasticity. Due to the closeness of the two, the revenue portion of combining price and transportation mode has not contributed to the profit, but the cost saving, stemmed from optimal transportation mode selection, might have done so.

We can also draw a conclusion that the synergy, or combination effect, shown at both sides of the elasticity horizon in the analysis of hypothesis 5, by adding movement mode to pricing, is not influenced by the revenue part of cellular phones for the same reason of being tied together. As is evidenced in table 39 and figure 20 above, the revenue improvement generated in P&T is edged up on the inelastic horizon for cellular phones, but the opposite signal was observed on the other side of the elasticity horizon.

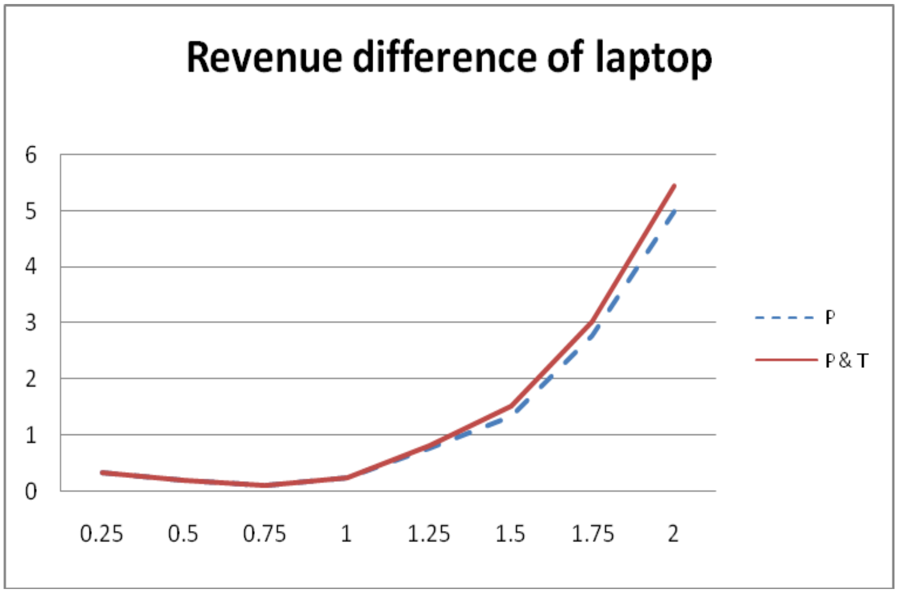


Figure 21. Revenue difference of laptop between price only and combination of price and transportation mode for H5
Note: P denotes price only, P&T denotes price and transportation mode

It is observed that the behavior of the revenue differnces of laptops for P and P&T looks similar to those of cellular phones in that the two graphs are tied together. Based on an eyeball estimation of the graphs in figure 21 it is premature to firmly conclude that the price and transportation components of laptops are a major source of synergy effects on the profit for UPS. Particlularly, the inelastic region of the figure illustrate little combination effect, a conclusion strenthened by the table as well.

Table 40 shows that the difference between P and P&T in revenue improvement is zero up to E=1.25. However, it should not be disregaded that there exists some evidence that combining the two components has a positive influence in revenue generation, for exmple, at E=1.75 the revenue improvement was from 277% of Price only to 303% of P&T and E=2.0 from 498% to 543% even though those increments are less dramatic than those for printers, whose discussion will follow hereafter.

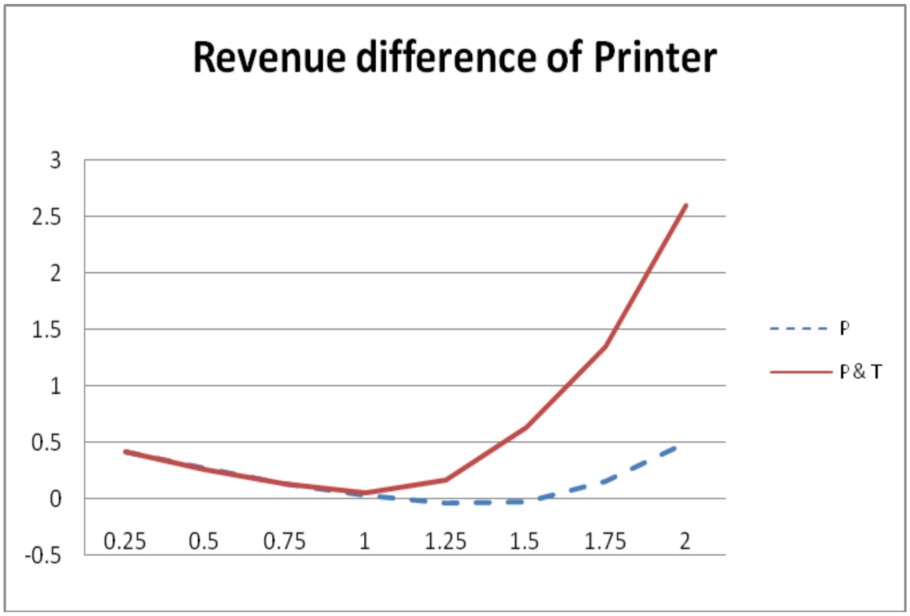


Figure 22. Revenue difference of printers between price only and the combination of price and transportation mode for H5
Note: P denotes price only, P&T denotes price and transportation mode

The pattern of the two factors shown for printer revenue improvement in figure 22 is quite different from the previous two; cellular phones and laptops. Even though the two components of P and P&T in the low region of the elasticity horizon are indistinguishable in formulation, the opposite area shows a radical hike by combining transportation modes with price. Therefore the combination effect is great for printers in revenue generation at this particular price elasticity. In other words, the pure cost saving effect by optimal transportation mode selection in the upper region of elasticity might be relatively less than that of cellular phones and laptops, but considering both the factors of movement method and price simultaneously for printers has contributed more profit for the firm due to high revenue realization than due to the cost savings originating from the combination of price and transportation modes in certain values of price elasticity.

How is this phenomenon informative to UPS?   The revenue hike shown in figure 22 suggests that UPS put more emphasis on their printer business if the price elasticity of the printer falls in the high region in the firm's logistics operation by varying price, demand, and transportation mode.

At this juncture we would like to pinpoint a striking contrast in the conclusions for the three products between hypothesis 1 and 5.   In hypothesis 1, when price is the sole decision variable added to the full model, the laptop was the most lucrative business for UPS, followed by cellular phones in terms of revenue generation.   However, hypothesis 5, which studies the combination of pricing and transportation mode selection, leads to the opposite conclusion, that printers are a major revenue source for UPS.

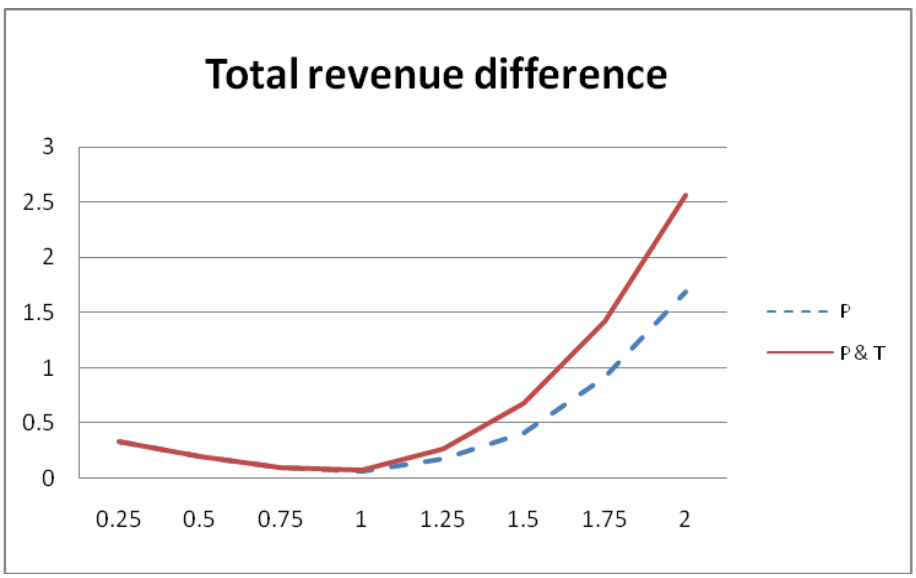


Figure 23.   Revenue difference of all three products between price only and a combination of price and transportation mode for H5
Note: P denotes price only, P&T denotes price and transportation mode

The shape of the graph above, contributed mainly by printer data, representing the two factors of price and transportation method demonstrates a combination effect in the high elasticity region when taking all three products into consideration. The table reads that all three products do not make any difference in the combination effect in the inelastic and unit elastic zone, but the synergy effects emerges at E=1.25 from 18% for price only, to 26% for price and transportation. Beyond the emerging point the gap between the two factors in the table are getting wider, for example, at E=1.5 from 41% to 69%, E=1.75 from 92% to 142%, and E=2 from 169% to 257%.

ii) <u>Revenue contribution of products to UPS</u>

The above analysis provides insight on the percentage change in revenue for each product across price elasticity. In addition to that, UPS might be interested in how much revenue each individual product has contributed to the firm when the price and transaction volume of each product is varied. This perspective will provide UPS with the relative importance of their logistics business for the three items that it carries. For example, on price only the revenue difference between the full and reduced model for cellular phones is $834,196, for laptops $473,265, and printers $994,184, with a price elasticity of E=0.25. Since the total difference is $2,301,647, an addition of the three, the proportion of contribution made by cellular phones is 36% ($834,196/$2,301,647), laptops 21%, and printers 43%. Similarly, a computation of the relative revenue contribution of each product for a combination of price and transportation can be obtained. The computed revenue differences and percentages are presented in Table 41 below.

Table 41
Revenue contribution of products for H5

E	P/PT	Difference	Cell. ph.	Laptop	Printer	Total
0.25	P	Rev. diff.	$834,196	$473,265	$994,184	$2,301,647
		Percentage	36%	21%	43%	100%
	PT	Rev. diff.	$851,565	$461,336	$989,242	$1417080
		Percentage	37%	20%	43%	100%
0.5	P	Rev. diff.	$521,717	$276,978	$618,383	$1,417,080
		Percentage	38%	20%	44%	100%
	PT	Rev. diff.	$541,373	$276,043	$599,170	$1,416,587
		Percentage	38%	19%	42%	100%
0.75	P	Rev. diff.	$286,343	$151,038	$303,748	$741,131
		Percentage	39%	20%	41%	100%
	PT	Rev. diff.	$294,359	$151,904	$302,286	$748,550
		Percentage	39%	20%	40%	100%
1	P	Rev. diff.	$115,941	$337,701	$58,504	$512,148
		Percentage	23%	66%	11%	100%
	PT	Rev. diff.	$114,577	$339,865	$116,312	$570,755
		Percentage	20%	60%	20%	100%
1.25	P	Rev. diff.	$113,706	$1,090,208	-$102,881	$1,101,033
		Percentage	10%	99%	-10%	100%
	PT	Rev. diff.	$120,118	$1,132,859	$401,660	$1654,638
		Percentage	7%	68%	24%	100%
1.5	P	Rev. diff.	$645,041	$1,893,877	-$62,272	$2,476,646
		Percentage	26%	76%	-3%	100%
	PT	Rev. diff.	$575,534	$2,146,778	$1,563,672	$4,285,984
		Percentage	13%	50%	36%	100%
1.75	P	Rev. diff.	$1,467,560	$3,877,985	$358,404	$5,703,949
		Percentage	26%	68%	6%	100%
	PT	Rev. diff.	$1,398,342	$4,212,230	$3,333,265	$8,943,846
		Percentage	16%	47%	37%	100%
2	P	Rev. diff.	$2,473,412	$6,987,306	$1,196,955	$10,657,673
		Percentage	23%	66%	11%	100%
	PT	Rev. diff.	$2,373,793	$7,595,654	$6,486,237	$16,455,684
		Percentage	14%	46%	39%	100%

Figure 24 illustrates the revenue contribution when the price factor was a major decision variable added in the full model, which was studied in the analysis of hypothesis 1. UPS might be very interested in this figure since the figure implies the relative importance of the three items through the price range and current transaction volume.

Given the current pricing and demand scheme it is evident in figure 24 that cellular phones and printers are superior to laptops in the low elasticity region in the relative contribution of revenue to UPS. However, laptops rather outperform in the high elasticity region. Particularly at E=1 and 1.25 a dramatic hike of the laptop contribution is observed. Hence, as the price elasticity climbs up, the laptop is a cash cow for UPS when we incorporate only the price factor to the full model.

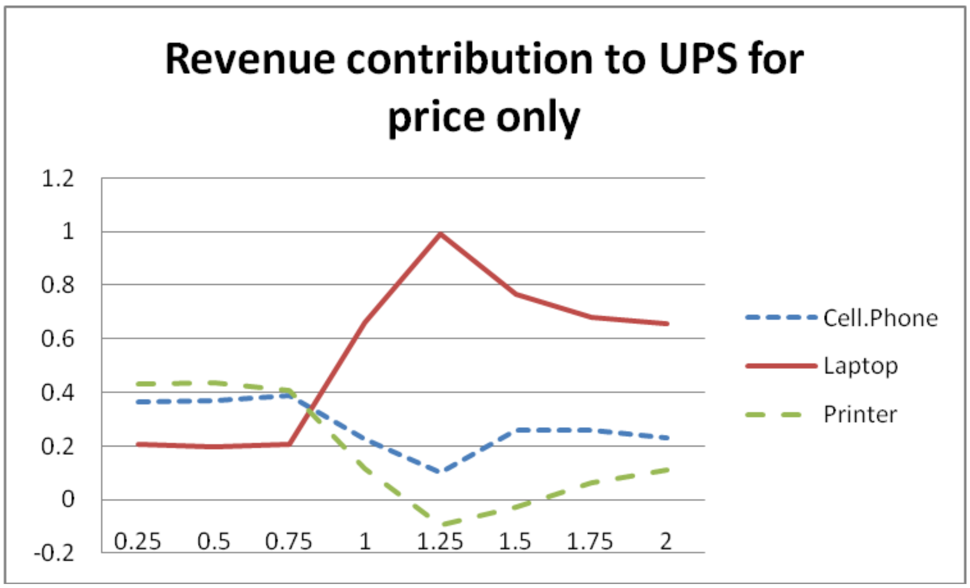


Figure 24. Revenue contribution of the three products to UPS for price only for H5

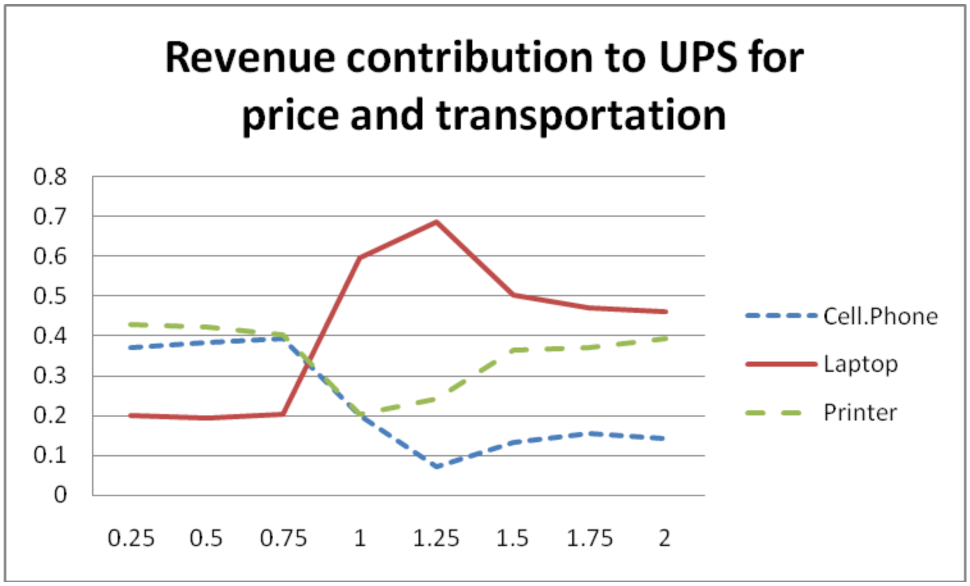


Figure 25. Revenue contribution of three products to UPS for the combination of price and transportation modes for H5

Figure 25 also indicates the outperformance of laptops for UPS in revenue generation in the case of pricing and transporation modes combined. It is noteworthy that printers are second to laptops when the transportation factor is added to the price factor in the full model shown in figure 25, whereas the cellular phone took second place on price only as the elasticity increases shwon in figure 24. This suggests that a combination effect of price and transportation for printers is, relatively, higher when the elasticity is large in terms of the contribution of reveneu to UPS. It makes sense to observe this phenomenon since the cost of transportation for printers is higher than for the other products, the deviation of optimal selection for price and transportation will be larger with a given movement distance, resulting in touching a wider range of values in optimal selection, which enabled the printer to outperform the cellular phone.

Nonetheless, the higer deviation effect does not offset the volume effects of laptops, causing an inferior performance of printers to laptops. This insinuates a probability of high revenue generation for UPS by printers if the transaction volume of printers is larger in the future. This assertion is fortified by examining the fact in figure 25 that laptops and printers in revenue contribution are merging to the center as the elasticity value becomers larger.

The following figures will reveal more details on the revenue proportion of each product, differentiated by incorporating price and a combination of price and transportation across ealsticity.

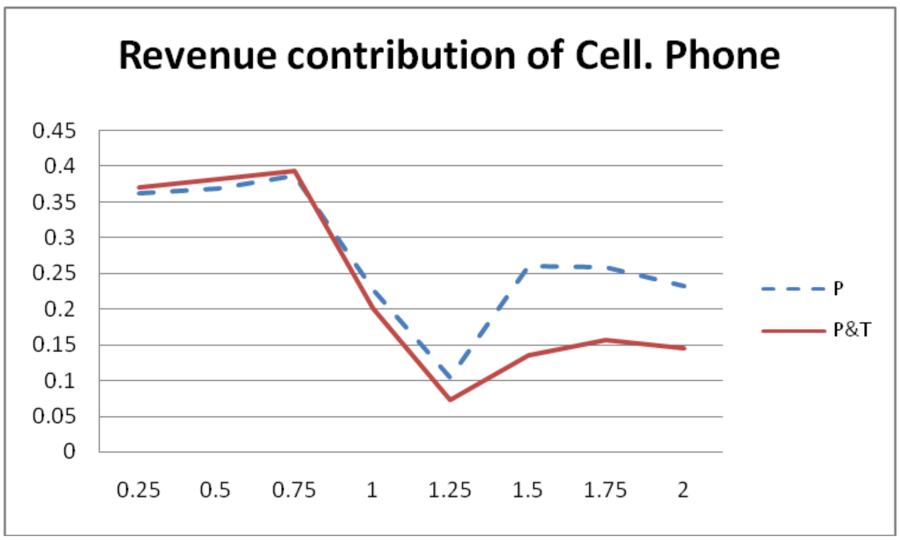


Figure 26. Revenue contribution of cellular phone for price only and combination of price and transportation mode for H5
Note: P denotes price only, P&T denotes price and transportation mode

Roughly, the patterns of P and P&T graphs exhibit a bumpy but parallel structure with different magnitudes between them at the high elasticity horizon. Figure 26 also suggests a large revenue contribution made by cellular phones ranging from 35% through 40% when elasticity is 0.25, 0.5, and 0.75. This might be informative to UPS since the behavior of price, or a combination of price and transportation, in the model studied above did not delineate the definite benefit realized by the three items in the lower elasticity region. Beyond the point of E=1.25 in figure 26, the revenue contribution for price only is stabilized to be around 25%, with a lower achievement in revenue contribution to UPS when price and transportation mode are considered simultaneously. Hence, the synergy or combination effect for cellular phones is hardly detected.

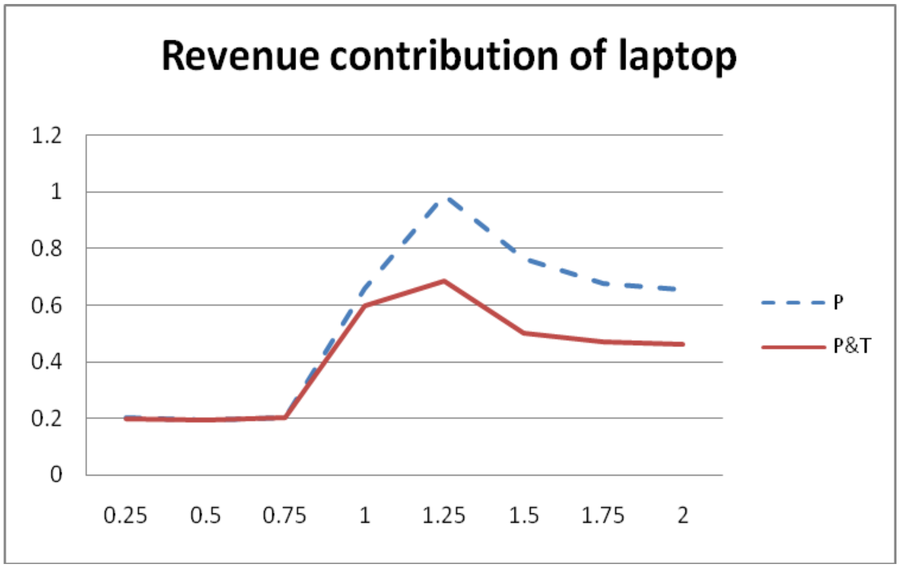


Figure 27. Revenue contribution of laptop for price only and combination of price and transportation mode for H5
Note: P denotes price only, P&T denotes price and transportation mode

Relatively, laptops bring a limited contribution of revenue to the firm at E=0.25, 0.5, and 0.75 indicated in figure 27. However, at E=1.25 laptops marked a phenomenal record that virtually all revenue is realized by the laptops when the firm only incorporates price to the model. However, even though combining price and transportation could not compete with price only at E=1.25, it still shows about 70% of the high contribution. This outcome informs UPS that if the price elasticity of the items it carries are all around 1.25 the company will place much stress on the business dealing with laptops. Similar to the case of cellular phones, a synergy effect in laptops was not detected. Nonetheless, the laptop is still very lucrative for UPS when the elasticity goes high since the revneue contribution made by laptops ranges from around 50% to 70%.

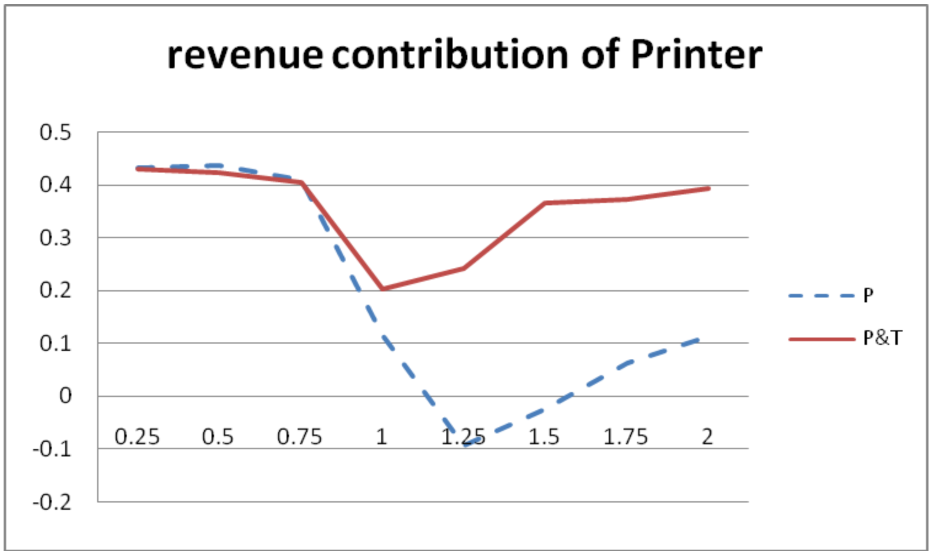


Figure 28. Revenue contribution of printer for price only
and combination of price and transportation mode for H5
Note: P denotes price only, P&T denotes price and transportation mode

The printers are unique in that they generate a synergy effect by combining price and transportation mode in the high elasticity zone even though the lower region is barely distinguishable between the two graphs, as illustrated in figure 28. The combination effect is large for printers, such that about 20% to 30% more revenue can be expected to be generated in the elasticity region by considering the two decision variables together in the model. This synergy effect might be ascribed to the high unit cost of transportation for printers, which provides a wider selection in optimality when the two components are together in the model.

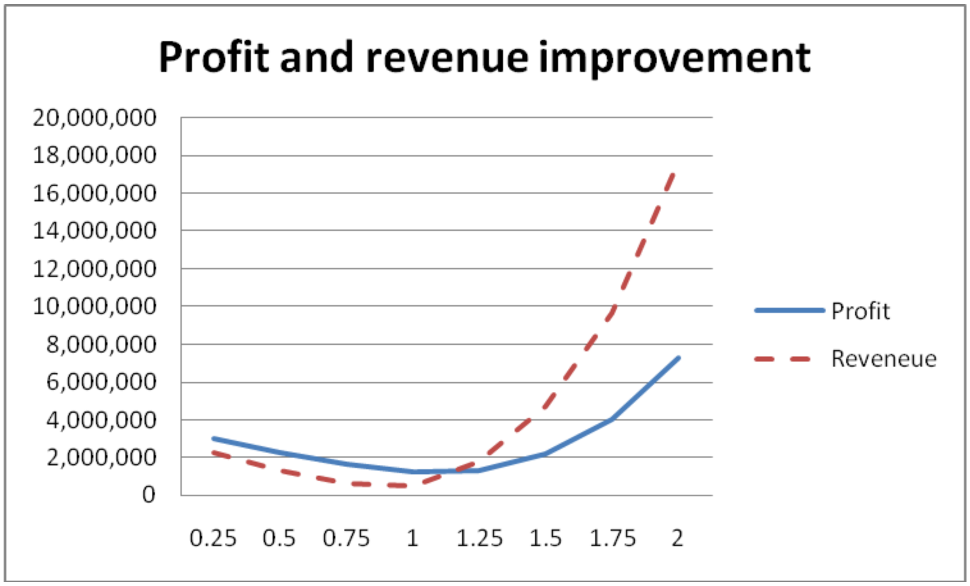


Figure 29. Profit and revenue improvement across price elasticity fo PT for H5

Figure 29 might be insightful to UPS with respect to the role played by price and transportation mode selection, combined in the full model. The figure illustrates consistency with figure 9 on profit and revenue improvement for price only, demonstrating higher profit than revenue in the low elasticity region, but the opposite in the high elasticity area.

However, the two figures are very different with respect to two factors of profit and revenue in magnitude. In figure 29 a crossing point is E=1.25. Before the crossing point the profit and revenue improvement ,by selecting price and transportation mode optimally, exhibit a little and parallel gap. However, the profit improvement is much larger as elasticity travels beyond the crossing point. In contrast to this magnitude, figure 9 looks opposite, denoting a higher gap in the inelastic region and little gap in the elastic area. It is projected that the cost advantage of the optimal transportation method, combined with price, is very high and the cost effects of other parameters obtained through scenario run in the simulation are relatively small. This could be informative to UPS in its logistics business that other cost parameters are not seriously critical to the business of the firm, but the cost of transportation can be well utilized through optimal decisions about transportation methods in the full model, connected with price choice. Before moving to the next analysis we need to summarize the important findings in this section.

1) The full model is significant statistically in profit realization for UPS, compared to the reduced model. This suggests that UPS might need to somehow consider incorporating optimal selection of price and transportation mode simultaneously for their future logistics business.

2) By adding the transportation modes in optimal selection we observe a probability of a synergy or combination effect. Two methods for assessing synergy effects were implemented; the revenue improvement of each product and the revenue contribution of each product to UPS.

- Based on the Revenue improvement of each product;

Cellular phones and laptops did not show a strong signal that they contributed to the synergy effect by realizing revenue of each. On the other hand, the printer at the high end zone of price elasticity turned out to have contributed much to the synergy effect due to revenue generation, as indicated by the wide gap between P and P&T in figure 22.

- Based on Revenue contribution of each product to UPS;

In contrast to the conclusions drawn from the previous method of revenue improvement made by each product, it is evident that the laptop plays a major role and impact on revenue contribution among all products.   Nonetheless, laptops and cellular phones do not exhibit combination effect of optimal price and transportation modes, while printers shows combination effect at elastic regions.

Analysis for H6:

H6: “The profit of the full model, incorporating optimal price of items that UPS carries and outsourcing costs of items that UPS carries for remanufacturing, will be significantly larger than that of the reduced model.”

This hypothesis is to examine how much benefit can be extracted for UPS by running the full model, incorporating two components of price and outsourcing cost simultaneously.

1) E=0.25

Table 42
Summary statistics for E=0.25 for H6

	Percentage	Actual profit difference
Mean	0.79	$ 2,457,487
Std. Dev	0.72	$ 1,049,587
Sample size	100	100
Std. Error	0.07	$ 104,958
t-statistics	1.98	1.98
Confidence interval	0.14	$ 208,260
Lower limit	0.64	$ 2,249,226
Upper limit	0.93	$ 2,665,747

Compared to the price only run the mean percentage denotes a 2% increase when price is combined with outsourcing options.   Note that the mean percentage increase was

77% for price only and here the increase is 79%, as indicated in Table 42. Close examination of constructed confidence intervals all turned out to be significant.

2) E=0.5

Table 43
Summary statistics for E=0.5 for H6

	Percentage	Actual profit difference
Mean	0.55	$ 1,774,404
Std. Dev	0.48	$ 735,336
Sample size	100	100
Std. Error	0.05	$ 73,533
t-statistics	1.98	1.98
Confidence interval	0.09	$ 145,906
Lower limit	0.46	$ 1,628,497
Upper limit	0.65	$ 1,920,310

When price elasticity is 0.5 the same conclusion was drawn as was for price only with respect to the significance of the test. The full model realized 55% more profit than the reduced model, and the full model contributed $3,764 more by applying the optimal combination of price and outsourcing costs than it did by doing price only.

3) E=0.75

Table 44
Summary statistics for E=0.75 for H6

	Percentage	Actual profit difference
Mean	0.38	$ 1,218,779
Std. Dev	0.33	$ 512,618
Sample size	100	100
Std. Error	0.03	$ 51,261
t-statistics	1.98	1.98
Confidence interval	0.06	$ 101,714
Lower limit	0.31	$ 1,117,064
Upper limit	0.44	$ 1,320,494

The table summarizes major statistics when E=0.75. The test outcome informs us that all constructions are significant. The mean difference marked was a 38% difference, realizing an actual difference of $1,218,779, edging up by $3,906 in comparison to the price only option.

4) E=1

Table 45
Summary statistics for E=1 for H6

	Percentage	Actual profit difference
Mean	0.25	$ 830,598
Std. Dev	0.22	$ 342,485
Sample size	100	100
Std. Error	0.02	$ 34,248
t-statistics	1.98	1.98
Confidence interval	0.04	$ 67,956
Lower limit	0.21	$ 762,641
Upper limit	0.30	$ 898,544

When price is unit elastic the outcome also shows significance in the hypothesis test. The difference of $5,244 between price only and a combination of the two decision variables in the full model for the case of E=1 is wider than any of the differences realized in the inelastic region.

5) E=1.25

Table 46
Summary statistics for E=1.25 for H6

	Percentage	Actual profit difference
Mean	0.24	$ 872,880
Std. Dev	0.16	$ 426,290
Sample size	100	100
Std. Error	0.02	$ 42,629
t-statistics	1.98	1.98
Confidence interval	0.03	$ 84,585
Lower limit	0.20	$ 788,295
Upper limit	0.27	$ 957,466

An interesting observation was made in this case. The difference in profit improvement between price only and the combination of the two was marked as $38,443. This value is remarkably high compared to others obtained in the inelastic region. Therefore, we can draw an insight that outsourcing costs can be well combined with price in terms of profit increments if the elasticity of products carried by UPS is 1.25. The significance test revealed all positive outcomes.

6) E=1.5

Table 47
Summary statistics for E=1.5 for H6

	Percentage	Actual profit difference
Mean	0.38	$ 1,551,795
Std. Dev	0.26	$ 1,017,843
Sample size	100	100
Std. Error	0.03	$ 101,784
t-statistics	1.98	1.98
Confidence interval	0.05	$ 201,962
Lower limit	0.33	$ 1,349,833
Upper limit	0.43	$ 1,753,757

The same upward trend in profit for the combination of the two factors is shown as in the case of price only from E=1.5. The mean improvement rate is 38%, and the lower limit is 33% with an actual difference of $1,349,833 and the upper limit is 43% with a $1,753,757 difference. All confidence intervals are significant.

7) E=1.75

Table 48
Summary statistics for E=1.75 for H6

	Percentage	Actual profit difference
Mean	0.73	$ 3,093,228
Std. Dev	0.50	$ 2,067,965
Sample size	100	100
Std. Error	0.05	$ 206,796
t-statistics	1.98	1.98
Confidence interval	0.10	$ 410,329
Lower limit	0.64	$ 2,682,899
Upper limit	0.83	$ 3,503,557

All confidence intervals passed the significance test. At E=1.75 the negative profit improvement of $22,000 was witnessed by adding outsourcing costs to price for optimal selection in the full model. Hence, there is some adverse effect at the high elasticity horizon.

8) E=2

Table 49
Summary statistics for E=2 for H6

	Percentage	Actual profit difference
Mean	1.41	$ 5,947,357
Std. Dev	0.98	$ 3,897,128
Sample size	100	100
Std. Error	0.10	$ 389,712
t-statistics	1.98	1.98
Confidence interval	0.20	$ 773,274
Lower limit	1.21	$ 5,174,082
Upper limit	1.60	$ 6,720,632

All confidence intervals have significant construction. The mean improvement rate of 141% is highest among all of the values examined. A negative difference of $8,169, whose magnitude is less than that when E=1.75, was also observed. Hence, the addition of the transportation outsourcing cost to price is not a recommended strategy for UPS when price elasticity is high.

Table 50
Outsourcing cost for remanufacturing for H6

E	Cellular phone	Laptop	Printer
0.25	$11.95	$22.78	$18.02
0.5	$12.04	$22.61	$17.92
0.75	$11.97	$22.48	$18.19
1	$11.92	$22.44	$18.02
1.25	$11.94	$22.06	$17.95
1.5	$12.00	$22.44	$18.04
1.75	$11.86	$22.56	$18.04
2	$11.94	$22.46	$17.87

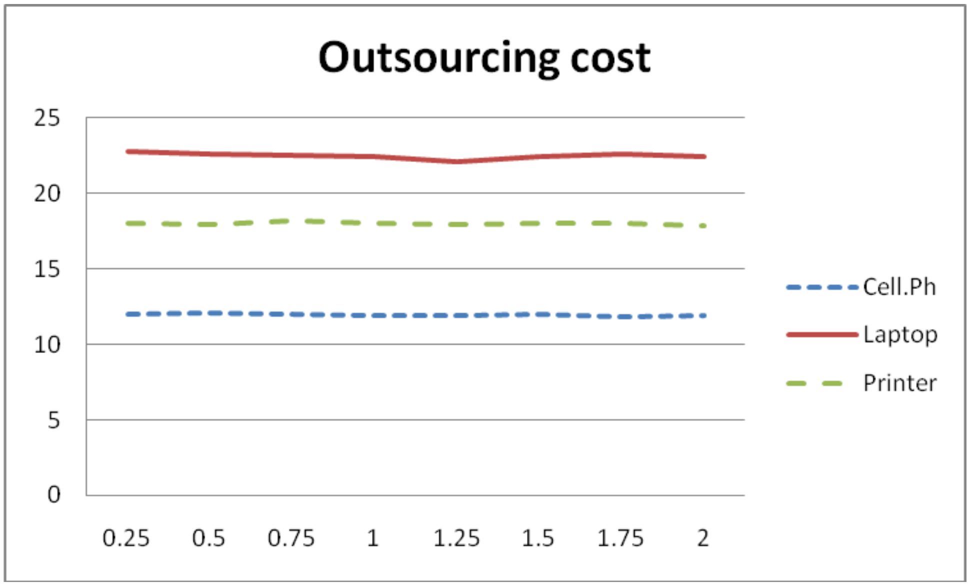


Figure 30. Outsourcing cost of three products for H6

Figure 30 illustrates the behavior of outsourcing costs across price elasticity for the three items. The outsourcing costs of remanufacturing for laptops is the highest at around $22, followed by printers around $18, and cellular phones about $12. It is also notable that there are not many fluctuations of all the products across price elasticity.

Analysis for H7:

H7: "The profit of the full model, incorporating optimal pricing of items that UPS carries, the optimal transportation modes of moving items that UPS carries, and outsourcing costs of items that UPS carries for remanufacturing, will be significantly larger than that of the reduced model."

This hypothesis is concerned with the full model's superiority when pricing, transportation modes, and outsourcing costs are considered simultaneously.

1) E=0.25

Table 51
Summary statistics for E=0.25 for H7

	Percentage	Actual profit difference
Mean	0.93	$ 3,009,764
Std. Dev	0.76	$ 1,014,016
Sample size	100	100
Std. Error	0.08	$ 101,401
t-statistics	1.98	1.98
Confidence interval	0.15	$ 201,202
Lower limit	0.78	$ 2,808,562
Upper limit	1.08	$ 3,210,967

All intervals constructed were positive. Compared with the case of adding price and transportation modes the actual profit difference is rather declined by adding outsourcing costs onto the two factors. Despite this fact the actual percentage improvement was better achieved by adding the outsourcing costs from 92% to 93%. This denotes that the reduced model for the case of hypothesis 7 generated profit relatively less than the reduced model did for hypothesis 5.

2) E=0.5

Table 52
Summary statistics for E=0.5 for H7

	Percentage	Actual profit difference
Mean	0.67	$ 2,261,643
Std. Dev	0.51	$ 679,717
Sample size	100	100
Std. Error	0.05	$ 67,971
t-statistics	1.98	1.98
Confidence interval	0.10	$ 134,870
Lower limit	0.57	$ 2,126,722
Upper limit	0.77	$ 2,396,514

When E=0.5 the profit improvement demonstrates a different realization compared with that when E=0.25, in that E=0.5 contributed more profit than E=0.25 did. By adding the outsourcing costs it generated a positive difference of $13,098 when E=0.5 whereas it marked a negative profit by adding outsourcing costs when E=0.25. All confidence intervals are significant.

3) E=0.75

Table 53
Summary statistics for E=0.75 for H7

	Percentage	Actual profit difference
Mean	0.50	$ 1,687,488
Std. Dev	0.35	$ 434,979
Sample size	100	100
Std. Error	0.03	$ 43,497
t-statistics	1.98	1.98
Confidence interval	0.07	$ 86,309
Lower limit	0.43	$ 1,601,178
Upper limit	0.56	$ 1,773,797

Test outcomes are all significant. Compared with hypothesis 5 on adding price and transportation modes the outsourcing cost effect is $26,981, which is relatively large considering the pure outsourcing cost is $2,280.

4) E=1

Table 54
Summary statistics for E=1 for H7

	Percentage	Actual profit difference
Mean	0.36	$ 1,272,402
Std. Dev	0.22	$ 271,132
Sample size	100	100
Std. Error	0.02	$ 27,113
t-statistics	1.98	1.98
Confidence interval	0.04	$ 53,798
Lower limit	0.31	$ 1,218,604
Upper limit	0.40	$ 1,326,201

Table 54 provides summary statistics when E=1. The mean difference reads as 36%. The lower limit is 31%, and the upper limit is 40%. All confidence intervals are significant.

5) E=1.25

Table 55
Summary statistics for E=1.25 for H7

	Percentage	Actual profit difference
Mean	0.35	$ 1,348,713
Std. Dev	0.16	$ 400,204
Sample size	100	100
Std. Error	0.02	$ 40,020
t-statistics	1.98	1.98
Confidence interval	0.03	$ 79,409
Lower limit	0.31	$ 1,269,303
Upper limit	0.38	$ 1,428,122

The confidence interval is wider when E=1.25 than that when E=1. The mean improvement ratio is lower when E=1.25 than that when E=1, but the actual profit difference is larger than that at E=1. All passed the significance test at this elasticity.

6) E=1.5

Table 56
Summary statistics for E=1.5 for H7

	Percentage	Actual profit difference
Mean	0.52	$ 2,197,414
Std. Dev	0.22	$ 1,018,142
Sample size	100	100
Std. Error	0.02	$ 101,814
t-statistics	1.98	1.98
Confidence interval	0.04	$ 202,021
Lower limit	0.48	$ 1,995,452
Upper limit	0.57	$ 2,399,495

When E=1.5 the summary statistics indicates that there is an upward trend in profit improvement from E=1.25. The lower limit reads $1,995,452 and the upper limit does $2,399,495. All are significant.

7) E=1.75

Table 57
Summary statistics for E=1.75 for H7

	Percentage	Actual profit difference
Mean	0.94	$ 4,014,472
Std. Dev	0.45	$ 2,059,925
Sample size	100	100
Std. Error	0.05	$ 205,992
t-statistics	1.98	1.98
Confidence interval	0.09	$ 408,733
Lower limit	0.85	$ 3,605,783
Upper limit	1.03	$ 4,423,206

Table 57 shows the summary statistics for E = 1.75. Compared to hypothesis 5, it marked a positive effect of outsourcing costs since the actual difference is larger for this hypothesis than hypothesis 5. All passed the significance test.

8) E=2

Table 58
Summary statistics for E=2 for H7

	Percentage	Actual profit difference
Mean	1.68	$ 7,206,120
Std. Dev	0.88	$ 3,778,414
Sample size	100	100
Std. Error	0.09	$ 377,881
t-statistics	1.98	1.98
Confidence interval	0.18	$ 749,798
Lower limit	1.51	$ 6,456,321
Upper limit	1.86	$ 7,955,919

Surprisingly the actual difference of hypothesis 7 is smaller than that of hypothesis 5. We will conduct an in-depth analysis on this issue in the following section. Test result says that all are significant. We have listed all the profit improvements corresponding with each hypothesis across price elasticity in this analysis section. Hence we are concerned with the difference between hypotheses 5 and 7 in profit improvement.

Table 59
Difference of Profit improvement between PT & PTO for H7

E	Difference
0.25	-$9,259
0.5	$13,097
0.75	$26,918
1	$17,519
1.25	$1,935
1.5	-$24,617
1.75	$8,231
2	-$79,930

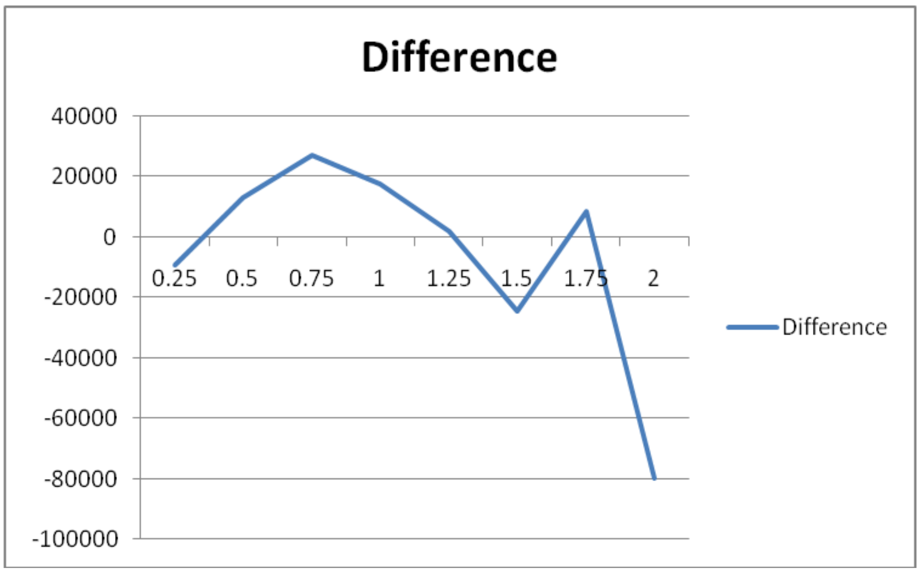


Figure 31. Difference of profit improvement between PT & PTO for H7

Figure 31 illustrates the difference in profit improvement between price and transportation, and adding outsourcing cost to the two decision variables. Except for E=0.25, the low area of the price elasticity shows stability by adding outsourcing cost optimization realizing all positive profit. On the other hand the upper area of the price elasticity shows instability by realizing both positive and negative profit in the region. Hence, adding the outsourcing costs is not always beneficial for the UPS logistics business in terms of profit generation, and UPS should be selective in considering outsourcing costs, depending on the price elasticity of the items that they carry.

Table 60
Percentage difference of revenue improvement between P to PT and PT to PTO for H7

E	Cell. Phone		Laptop		Printer	
	P to PT	PT to PTO	P to PT	PT to PTO	P to PT	PT to PTO
0.25	0.0097	-0.0034	-0.0120	-0.0136	-0.0018	-0.0206
0.5	0.0090	0.0023	-0.0008	-0.0084	-0.0111	-0.0117
0.75	0.0046	0.0020	0.0005	-0.0102	-0.0024	-0.0096
1	-0.0004	-0.0009	0.0011	-0.0079	0.0235	-0.0129
1.25	0.0025	-0.0062	0.0390	-0.0490	0.2051	-0.0177
1.5	-0.0249	-0.0058	0.1861	0.0315	0.6564	0.0260
1.75	-0.0190	0.0068	0.2569	-0.0010	1.200	-0.0195
2	-0.0329	0.0348	0.4558	-0.0503	2.100	-0.1840

Table 60 indicates the percent difference of revenue improvements computed by taking the percent difference between P and PT and PT and PTO. Even though the computed percent looks small in the table, like 0.0097 (or 0.97%), this small ratio should not be disregarded since the actual value converted from the ratio will be large. In addition, the table also contains a large percentage like 210%. Hence, drawing both a small and large percent ratio combined in the graph, separating P to PT and PT to PTO, will provide some insight on the behavior or direction of revenue growth for UPS.

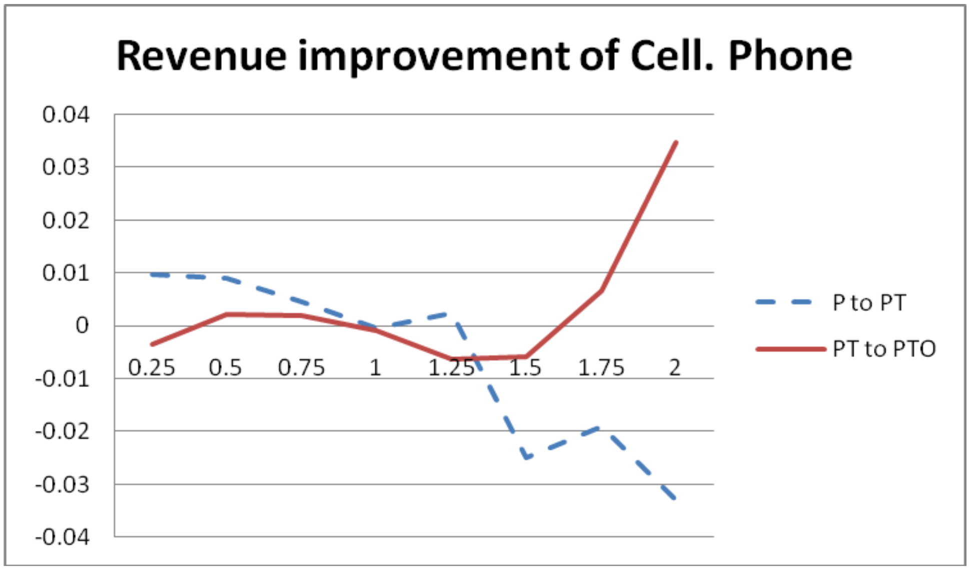


Figure 32. Revenue improvement of cellular phones for H7
Note: P denotes price only, PT denotes price and transportation mode,
PTO denotes price, transportation and outsourcing

Figure 32 constrasts the P to PT and PT to PTO in revenue improvement for cellular phones. As is shown, the two graphs run to opposite directions at the high elasticity horizon; P to PT goes downward and PT to PTO goes upward, while the two run roughly parallel at the low elasticity zone. The upward pattern of PT to PTO presents a combinaton effect of outsourcing cost to price and transporation modes in the high elasticity zone.

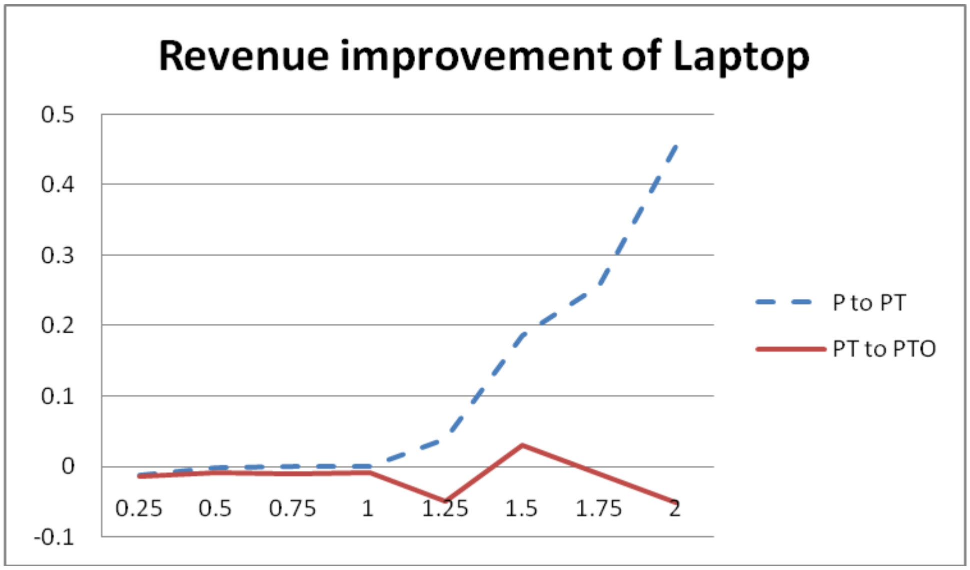


Figure 33. Revenue improvement of Laptop for H7
Note: P denotes price only, PT denotes price and transportation mode, PTO denotes price, transportation and outsourcing

While the P to PT graph exhibits a continuously increasing combination effect, the PT to PTO illustrates an instability of the combination effect at the high end zone of price elasticity. Both of the graphs suggest little combination effect at the low elasticy zone. Therefore, there is not much benefit originating from laptops that UPS can expect to profit from combining outsourcing costs to the full model.

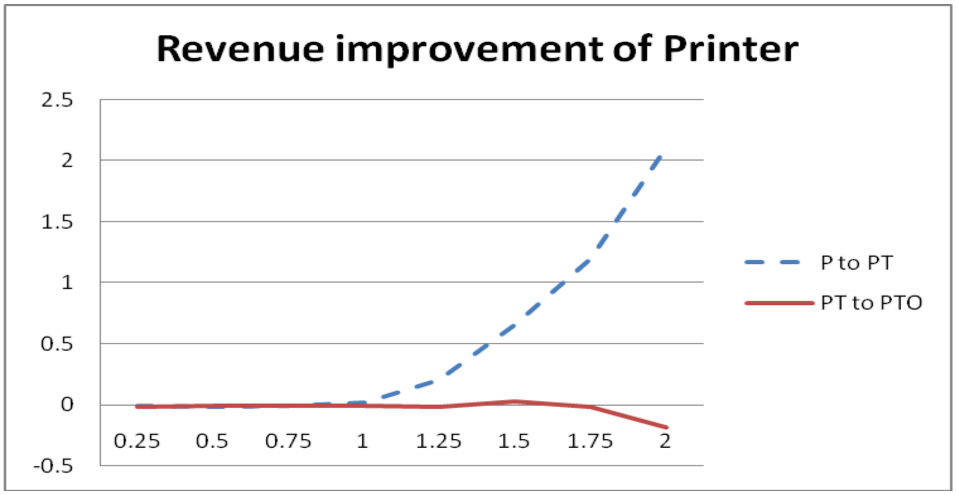


Figure 34. Revenue improvement of Printer for H7
Note: P denotes price only, PT denotes price and transportation mode,
PTO denotes price, transportation and outsourcing

The revenue improvement pattern of both graphs for printers is very much like that of laptops, illustrating little combination effect at the low end zone, great combination effect at high end zone of the elasticity for P to PT, and zero or negative improvement for PT to PTO. However, it must be noted that the magnitude of improvement for printers at the graph of P to PT is much larger than that of laptops, i.e., for example, 210% for printers vs. 45% for laptops.

Table 61
Percent difference of revenue contribution between P to PT and PT to PTO for H7

E	Cell. Phone		Laptop		Printer	
	P to PT	PT to PTO	P to PT	PT to PTO	P to PT	PT to PTO
0.25	0.0075	0.0080	-0.0052	-0.0025	-0.0022	-0.0054
0.5	0.0140	0.0134	-0.0006	-0.0004	-0.0134	-0.0094
0.75	0.0069	0.0279	-0.0009	-0.0102	-0.0060	-0.0168
1	-0.0256	0.0110	-0.0640	0.0287	0.0896	-0.0398
1.25	-0..307	-0.0057	-0.3055	0.0149	0.3361	-0.0092
1.5	-0.1262	-0.0051	-0.2638	-0.0022	0.3899	0.0074
1.75	-0.1001	0.0030	-0.2089	0.0008	0.3099	-0.0038
2	-0.0879	0.0102	-0.1940	0.0103	0.2819	-0.0204

Table 61 above is different in preparation from the table 60in that the table 61 denotes the difference of relative improvement from P to PT and PT to PTO by taking the revenue of all three products into consideration. In contrast, the table 60 denotes the improvement of each product itself in revenue. Since the analysis of considering all three products together reflects the practical price and transaction volume that constitutes overall revenue, the outcome from analysis below might be interesting to UPS.

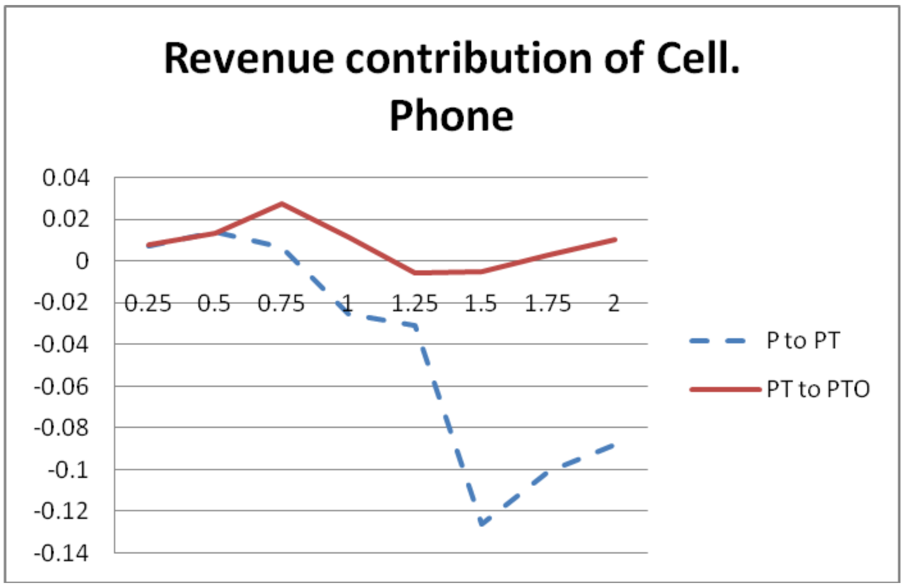


Figure 35. Revenue contribution of cellular phone for H7
Note: P denotes price only, PT denotes price and transportation mode,
PTO denotes price, transportation and outsourcing

By combining outsourcing costs into the model, in addition to price and movement methods, figure 35 suggests some benefit from cellular phones to the firm, relative to other products. It is noteworthy that in general high end zone for cellular phones indicates some positive combination effect.

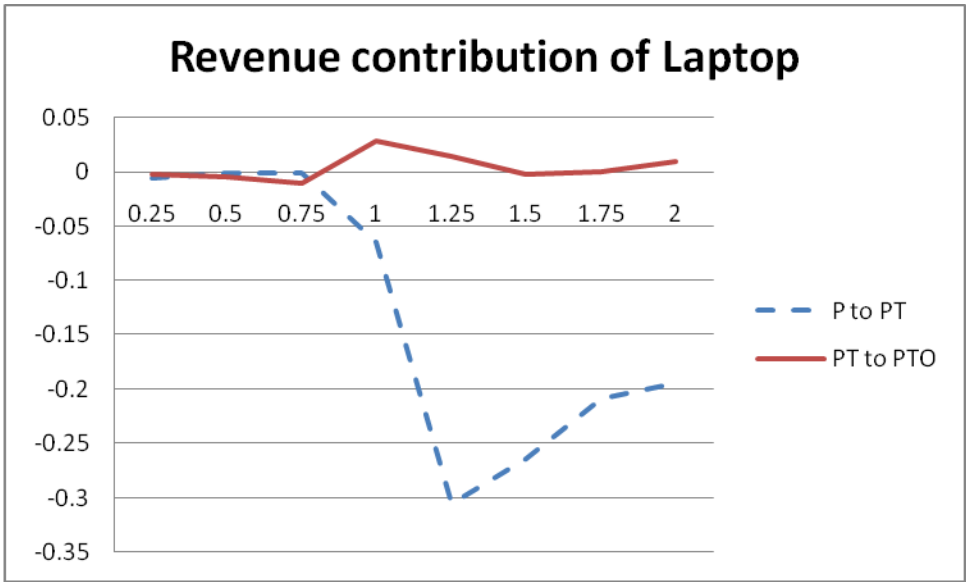


Figure 36. Revenue contribution of Laptop for H7
Note: P denotes price only, PT denotes price and transportation mode,
PTO denotes price, transportation and outsourcing

Laptop also denotes a positive combination effect at the middle and high end zone of the elasticity horizon shown in figure 36. Both cellular phones and laptops show the same pattern in P to PT and PT to PTO, and that majority of them also have a positive combination effect at the high end zone of price elasticity.

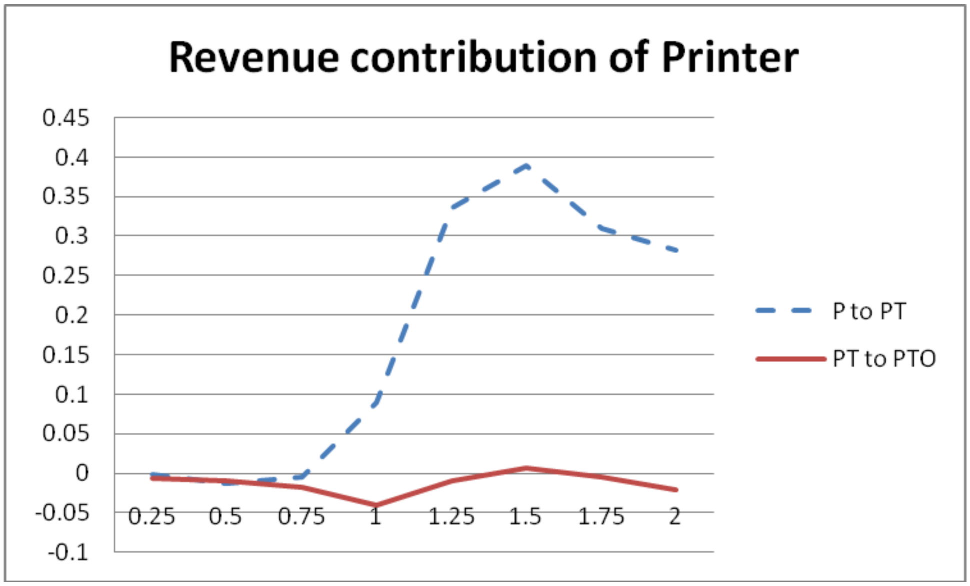


Figure 37. Revenue contribution of Printer for H7
Note: P denotes price only, PT denotes price and transportation mode,
PTO denotes price, transportation and outsourcing

Figure 37 demonstrates an opposite phenomenon to the previous two, namely cellular phones and laptops in the role of the profit contribution played by the two graphs, that is, P to PT exhibits a high contribution and PT to PTO does a low contribution for printers. It is explainable that the PT to PTO graph does not fluctuate much due to the small impact on the overall revenue structure for the relatively small amount realized through the full model.

In conclusion for the analysis of this section some findings need to be mentioned.

1) In terms of statistical significance, all passed the test

2) The low end of the price elasticity zone revealed little difference between P to PT and PT to PTO in revenue contribution. On the other hand, the opposite was observed in the elastic region, showing an increase in revenue contributions with cellular phones and laptops.

Conclusion

This analysis chapter has aimed to identify the effects of incorporating three new decision variables, namely, price, transportation modes, and outsourcing costs for remanufacturing, into the full model; superseding the integration of most of the developed frameworks in the current literature, which was denoted as the reduced model. Seven different hypotheses statements were developed, by combining the three components, for the purpose of a statistical test of significance for the two models under the environment of the UPS supply chain business. The analysis has demonstrated that all seven test hypotheses have passed the significance test, implying that all the three factors, alone or combined, makes the full model statistically different from the reduced model in profit generation. In addition to confirmatory analysis, an exploratory analysis was conducted aiming to delineate the profit and revenue structure for the firm with respect to the three components.

Among the seven hypotheses formulated for this study, hypothesis 1 needs to be paid the most attention since the magnitude of benefit that can be enjoyed by UPS is greatest with pricing optimization. UPS currently does not know the price elasticity of its operations, which is crucial for such an analysis. As a consequence, the confirmatory analysis was performed by considering eight different price elasticities, ranged from 0.25 to 2.0 with a step value of 0.25. The exploratory analysis of hypothesis1 provided some valuable information for UPS managers. In revenue generation, cellular phones performed best, followed by laptops on the high elasticity horizon. The revenue improvement of printers between the two models shows the worst benefit for UPS. The theory of price elasticity defines the relationship between a change of price and a corresponding change of demand. Analysis suggests that UPS might maintain high prices for each of the products, even if, according to theory of price elasticity, they expect some loss of demand due to high price.

For hypothesis 2 we attempted to define the impact of transportation modes on logistics operations for UPS. The company presently relies on air and ground transportation to move products for its customers. The finding in this hypothesis implies that UPS might consider an all-air or all-ground option for printers, and the other two products are appropriate shipped with a mixture of the two movement methods.

The third hypothesis studied optimal outsourcing costs for remanufacturing. The UPS logistics system encompasses both the forward and reverse flows of products. On product returns the firm checks the quality of the items and afterwards some portion of the returned items are outsourced for remanufacturing. Since the outsourcing costs have not been investigated in the context of the whole logistics system for UPS we attempted to derive optimal outsourcing costs for remanufacturing. Even if the statistical test indicates significance, the magnitude of contribution made by the component, does not carry significant meaning to the firm, mainly, at this time, due to the little volume outsourced.

Combining more than one factor is a more attractive analysis to do. Hypothesis 4 is a combination of transportation modes and outsourcing costs for remanufacturing simultaneously in the full model. Strictly speaking, the combination of transportation modes and outsourcing costs resulted in a loss of profit compared to the consideration of transportation modes alone in the full model. This inverse effect might stem from non optimal selection of either of the two variables.

Hypothesis 5 is concerned with identifying the behavior of price and transportation modes combined in the model. Since transportation method selection is the second most important factor - next to price - in our study, the combination of the two extracted some insights valuable for UPS. The major phenomenon is a synergy or combination effect, which was manifested by contrasting the price- only- option studied in hypothesis 1 and a combination of price and transportation modes. The effect was further investigated in revenue realization by two different angles; the revenue improvement of each product and the revenue contribution of each product to UPS. Based on the first method, cellular phones and laptops do not contribute much to the revenue for UPS, whereas printers proved to be a driving force of the synergy effect. Under the analysis section, applying a second method, laptops were the product that contributed to the synergy effect most, followed by printers. Even if the printers were the second most important item, in terms of the synergy effect, printers imply much profitability for UPS if the transaction volume increases in the future.

An optimal pricing and outsourcing cost combination effect is studied in hypothesis 6. The outsourcing cost, combined with transportation, turned out to be a flat or constant structure across price elasticity. Outsourcing costs for laptop was the highest, followed by printers and cellular phones.

All three components combined simultaneously were studied in hypothesis 7. The major focus in this section was to contrast between price and transportation combined, and all of the three combined. The low end of the price elasticity zone revealed little difference between P to PT and PT to PTO in revenue contribution. On the other hand, the opposite was observed in the elastic region, showing an increase in revenue contributions with cellular phones and laptops.

CHAPTER SIX

HEURISTIC ALGORITHM

Simulated annealing

The SA (Simulated Annealing) algorithm was first introduced by Kirkpatrick et al (1983), based on Metropolis et al (1953); it imitates the annealing of physical metals to solve combinatorial optimization or complex nonlinear problems frequently found in the disciplines of engineering and operations research. An SA algorithm is analogous to bouncing a ball over a mountain seeking downhill movement (better solution) and it also allows the ball to take uphill movement (bad solution) with some probability of avoiding the ball sticking to the local optimum. The algorithm consists in major components 1) acceptance probability, 2) deciding initial temperature, 3) temperature decrement rule, 4) Markov chain length, and 5) stopping criteria, which we will discuss in the following sections.

Acceptance probability

Kirkpatrick et al (1983), the inventor of SA, proposed an acceptance probability as follows to avoid being trapped in the local optimum.

$P(\Delta E) = \exp(-\Delta E / K(b)T)$,

Where, ΔE is the difference of the objective value.

K (b) is Boltzmann’s constant

T is a temperature

This probability of a specific energy state given some position and temperature is stemmed from Boltzmann's probability factor. Each time a solution is obtained from a neighborhood, the solution is compared to a base solution, deciding to retain the solution if the new solution demonstrates improvement, i.e. an increase in maximization and decrease in minimization, and the new solution is retained only when the acceptance probability is larger than a random generation between 0 and 1, even though the new solution performs ill. This random generation defines the SA stochastic.

Deciding initial temperature

Since the analogy of simulated annealing implies the melting process of a ball, the initial temperature should be sufficiently high so that most of the moves are accepted over the domains of decision variables so as not to miss the global optimum. Many authors who studied simulated annealing heuristics have followed rules for deciding on the initial temperature pertaining to their own specific problems, mainly based on the acceptance probability function given the initial probability P_0. A study with minor adaptations to the acceptance probability, applying a deviation of objective values in the initial solution was also found. For example, Raza and Akgunduz (2008) applied SA in deciding economic lot scheduling problem. They took an approach that the initial temperature T_0 is acceptable if $T_0 >> \sigma$, where σ is standard deviation of objective function at an initial temperature T_0. It was assumed that the variation in the cost function is a normal distribution and it is expected that at T_0 a neighbor, whose objective value is 3σ worse than the seed solution, will be accepted. Hence they used an equation for the initial temperature as $T_0 = -(3/\ln(P_0)\sigma$.

Initial probability, serving as the acceptance rate for solutions with worse performance, will have impacts on the efficiency of the algorithm and hence should be singled out carefully. In this study we set the initial temperature T_0 such that the average decrease of acceptance probability P_0 would be 80%. In other words, there is an 80% chance that a change which decreases the objective function will be accepted. Hence, with several seed solutions given P_0, we can observe the behavior of the alteration of objective values to comprehend the initial temperature by applying the probability acceptance function.

Temperature decrement rule

At each temperature the temperature is reduced when the transitions reach the equilibrium state of the Markov chain. Usually the control parameter (1-α) is chosen to be small so that α is ranged between 0.8 and 0.99 in most SA algorithm applications (Sait & Youssef, 1999). Even though it required more computational effort with a small value of the control parameter, this computational effort will have a trade off with easiness to reach an equilibrium state at each temperature. In our study if the temperature is k the iteration is T_k, then the temperature for (k+1) the iteration is computed as T_{k+1} = αT_k,where α could be 0.95.

Markov chain length

The SA algorithm is modeled after the Markov chain. That is, once a temperature is given then the transition matrix, or transition probability, from one state to another is independent of the iteration and also independent of the previous temperature. Since the transition probability is served by the acceptance probability we should determine the number of iterations at each temperature for transition. In deciding on the iteration length L, Sayarshad & Ghoseiri (2009) used the size of the problem. Eglese (1990) suggested considering the defined neighborhood.

Stopping criteria

The SA should be able to terminate when a certain termination condition is met, i.e. when the temperature is frozen or close to zero. Hence, we will decide the T_f of frozen temperature. This does not guarantee the stopping in all cases since it only indicates the transition from one state to another. Accordingly, we need another criterion to terminate, that is, when the objective value does not improve at a certain number of trials the algorithm also stops. In our study the maximum iteration at a given temperature for termination is same as the Markov chain length.

Algorithm

Step 1: Select the initial temperature T_0, cooling rate α, termination criteria setting

all the decision variables = 0,

objective value (ϕ) = 0,

k (iteration counter) = 0,

c (inner counter) = 0,

Markov length L=1,000

<u>Comments</u>: this defines an initial setup.

Step2: Perturb the decision variables. Increase revenue variables by 1, decrease cost variables by 1, alternate to increase and decrease volume variables by 1. Generate random numbers for indices of *w*,*u*,*m*,*r*,*p*.

Comments: *w* is an index for warehouse. Since there are nine warehouses (5 current and 4 new ones) generate random number between 0 and 1 so that each warehouse is assigned by 0.11apart (0.11=1/9). For example, warehouse 1 in Cincinnati is assigned, if the random number is 0 through 0.11. Warehouse 2 in Dallas is assigned if the random number generated is 0.12 through 0.23 and so on. Other indices will also be assigned by the random number generation as *w* is done.

Step 3: Perform feasibility check by examining constraints. If failed, go to step 2.

Step 4: Compute objective value.

Step 5: Generate random number between 0 and 1 for acceptance of bad objective value.

Step 6: If $\Delta\phi = \phi^k - \phi^* \geq 0$ or random number $\leq \exp(-\Delta\phi / KT)$, $\phi^* = \phi^k$. c = c+1.

Step 7: If c < L, go to step 2. Otherwise k = k+1.

Step 8: Decrease temperature by the rule of temperature decrement.

Step 9: Terminate if termination condition is met. Otherwise go to step 2.

Step10: Report ϕ^* and decision variables.

CHAPTER SEVEN

DISSERTATION SUMMARY

Environmental concern (Wann 1999) and the current marketing strategy that "the customer is king" have spurred both manufacturing firms and retailers to implement strategies to facilitate product returns from end customers. Reverse logistics, indicating the process of this return flow, encompasses such activities as the movement of returned products, facilities to accommodate returned items, and overall remedy process for returned items.

Over the last two decades reports on the reverse logistics, discussing all different topics, are abundant inside the academic boundary. Nonetheless, it is rare to find a study discussing 3PL logistics operations. To fill this gap this dissertation models UPS, a representative of 3PLs. In chapter one, we present the research question and research background, along with an overview of reverse logistics. The chapter also provides seven hypothesis statements, developed by considering all three new decision variables in the full model, and they are as follows.

H1: The profit of the full model, incorporating optimal price of items that UPS carries, will be significantly larger than that of the reduced model.

H2: The profit of the full model, incorporating optimal transportation modes of moving items that UPS carries, will be significantly larger than that of the reduced model.

H3: The profit of the full model, incorporating optimal outsourcing costs of items that UPS carries for remanufacturing, will be significantly larger than that of the reduced model.

H4: The profit of the full model, incorporating optimal transportation modes of moving items that UPS carries and outsourcing costs of items that UPS carries for remanufacturing, will be significantly larger than that of the reduced model.

H5: The profit of the full model, incorporating optimal price of items that UPS carries and optimal transportation modes of moving items that UPS carries, will be significantly larger than that of the reduced model.

H6: The profit of the full model, incorporating optimal price of items that UPS carries and outsourcing costs of items that UPS carries for remanufacturing, will be significantly larger than that of the reduced model.

H7: The profit of the full model, incorporating optimal pricing of items that UPS carries, the optimal transportation modes of moving items that UPS carries, and outsourcing costs of items that UPS carries for remanufacturing, will be significantly larger than that of the reduced model.

In chapter two of this dissertation the relevant literature was extensively reviewed and classified as survey papers, strategic papers, and tactical papers. Important survey papers include Zhang et al (1997) discussing the designing issues of environmentally conscious manufacturing systems, Fleischmann et al(2000) reviewing network design for product recovery systems, and Guide & Van Wassenhove (2006) proposing future directions for research in reverse logistics. We also observe a large body of literature handling the issues pertaining to the strategic decisions of firms about reverse logistics.

One of the strategic papers reviewed in this dissertation is a network design for facilities concerned with deciding on the locations for return flow to manufacturing firms, divided into general design and specific functional design.

Another topic relevant to strategic issues for product returns is the channel design for return flows, including coordination, competition, and pricing. Channel coordination and competition have been paid a large amount of attention in supply chain management and marketing journals. Hence, in this dissertation the papers associated with the channel coordination and competition under a reverse logistics environment were reviewed in a way to contrast with those found in other disciplines.

Tactical papers are mainly concerned with the treatment of returned products and inventory. Under the treatment of returned products we discussed production planning, encompassing disassembly and remanufacturing. Many authors have studied disassembly processes, separating a product into its constituent parts, components, and subassemblies. A major concern with respect to disassembly lies in retrieving optimal components and designing disassembly processes. The research stream on retrieving optimal components is an investigation based on the quality or time value of the returned products, which was initiated by Krikke et al (1998), who distinguished five product recovery options for returned product or components. Even though uncertainty in the disassembly process is prevalent, authors on the topic assumed certainty. Hence, the reports in the area are divided into those assuming certainty and uncertainty. For example, under certainty assumption, Brander & Forsberg (2005) assumed a deterministic and constant disassembly rate.

Many articles in the literature propose disassembly methodology and algorithms, such as Gungor & Gupta (1998), who developed three steps to handle disassembly efficiently, and Kongar & Gupta (2006), who implemented fuzzy goal programming to circumvent the uncertainty under the section of uncertainty.

Remanufacturing papers discuss mainly the scheduling issues of remanufacturing process, whose representative study can be Guide (1996), who examined a Drum-Buffer-Rope (DBR) scheduling method combined with priority dispatching rules. Another important category, comprising tactical papers, was mentioned in the inventory management in reverse settings.

The management of inventory in a sustainable supply environment is more complex due to the uncertainty associated with return times, return volume, and return items. In this section a traditional approach of classifying a deterministic and stochastic inventory model was taken. Representative literature, assuming a deterministic model, includes Richter (1996) and Dobos & Richter (2004). The stochastic model is further divided into periodic review and continuous review systems. Simpson (1977) is considered a first paper studying inventory that takes the stochastic environment into the model, assuming no lead times in remanufacturing and purchasing.

Chapter three overviews the research design. A major service that UPS's logistics business offers to its customers is the movement of products in both forward and reverse flows. The firm currently has four warehouses and one hub operation in the United States, which was implemented in the model. Even though UPS handles more than three products, the model only treats three important items, namely, cellular phones, laptops, and printers, in order to avoid unnecessary complexity in the analysis.

The model is not only concerned with the expansion of current facilities, it also considers opening new warehouses in the country. New candidate locations for possible opening were selected by UPS. The primary objective of this study is to evaluate the superiority of the full model to the reduced model. Hence, a statistical method was implemented for confirmatory analysis.

Along with confirmatory analysis an exploratory analysis was also conducted to enrich the detailed information valuable for UPS's business. Due to the complexity arising from ranged parameters obtained through UPS and our intention to differentiate the set of parameters, a Monte Carlo simulation was applied, differentiating each set of parameters by scenarios. The chapter also includes a profit calculator.

Another important portion of chapter three is the presentation of two mathematical models, namely, a full and reduced model. The reduced model was formulated by integrating previous frameworks, found mainly in a large body of literature pertaining to the topic. Since UPS, a 3PL, is involved in both the forward and reverse movement of product flows, Ko & Evans (2007), which is a uniquely up- to- date article studying both forward and reverse flow in UPS, was the foundation for the development of the reduced model. The full model proposed in this dissertation supersedes the reduced model by adding such decision variables as price, transportation modes, and outsourcing costs for remanufacturing. Among others, price is a highlighting factor to add in the full model, leading the model to a maximization of profit.

Among papers on reverse logistics we realize that all of them are aimed to minimization of cost but Realff et al (2004). However, the approach of Realff et al (2004) is completely different from ours in that the price in their study is given in the reverse setting only, whereas we are probing to find an optimal price in the process of both forward and return flow. Cost minimization as an objective function in a model is not ideal and the reason is clearly indicated by Guide et al (2006) who asserted that managers in companies are concerned with profit maximization instead of the minimization of costs to the firm. Hence, adding price to the model distinguishes this dissertation from previous works.

Chapter four presents data describing the UPS logistics environment for the analysis of this dissertation. We would like to express our sincere appreciation to Brian Vowels, an operations manager in UPS, who sacrificed his time and effort to provide us with data, a very crucial thing for the successful completion of this dissertation. The data are arranged by parameters and decision variables.

The analysis and results portion in chapter five is committed to the analysis of the hypotheses by varying price elasticity, a combination of transportation modes, and outsourcing costs. Major findings through exploratory analysis of each hypothesis are well described in the conclusion section of the analysis and result chapter.

Chapter six discusses the heuristic algorithm to circumvent the complexity of an exact solution based on Simulated Annealing (SA).

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