Choosing Transportation Alternatives for Highly Perishable Goods

by

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Abstract

The selection of a transportation alternative to ship perishable goods is dependent on several interconnected factors, the most important usually being speed of delivery. This study focuses on the distribution operation of Tyco Healthcare's (THC's) nuclear medicine group in the continental United States. It studies the system constraints, service requirements and costs involved in shipping highly perishable radiopharmaceuticals.

The first stage of the study describes aspects of THC's radiopharmaceutical supply chain from order taking at the manufacturing plant to distribution of the prepared doses at the radiopharmacies. The second stage establishes the unit costs of shipping products to three sample regions via the four transportation alternatives currently used: ground courier, FedEx Express, commercial airline and chartered aircraft. The third and final stage of the study analyzes three hypothetical distribution scenarios. Its purpose was to challenge the restrictions and determine the opportunity cost of distributing the nuclear medicine under the current operating policies. Based on the results of all three stages, a set of cost savings recommendations is provided.

Thesis Supervisor: Dr. Chris Caplice
Title: Executive Director, MLOG Program

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Biographical Note

P. Louis Bourassa received his Masters of Logistics degree from MIT in 2006. Prior to his return to school, he had worked over five years as a Program Manager / Program Engineer for a software company involved in the flight simulator industry. Before then, he worked as a process engineer and project manager in the chemical process industry where he was involved in the start-up of a $350M plant based on an innovative process he had help developed. In 1992, Louis earned a Bachelor of Engineering from McGill University in metallurgy. He graduated with Great Distinction and received seven awards/scholarships including the Henry Birks Medal. In 1994 Louis completed a Masters of Engineering from McGill University in the discipline of metallurgy.

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1 Introduction

The selection of a transportation alternative to ship freight involves trade-offs between interdependent factors including cost, availability, reliability of on-time delivery and speed of delivery. Speed of delivery usually outweighs any other factor in importance when shipping highly perishable goods. This study focuses on the distribution operation of Tyco Healthcare's nuclear medicine group in the continental United States. It studies the system constraints, service requirements and costs involved in shipping highly perishable nuclear medicine from their point of manufacture.

1.1 Motivation

The constraints associated with distributing nuclear medicine (also called radiopharmaceuticals) include radioactive decay, production capacity, delivery time, transportation restrictions for hazardous goods, service level (availability and timely delivery) and transportation cost. Choosing a transportation alternative requires balancing these linked and often conflicting constraints to achieve the desired goal.

From a broader perspective, the interest of this study lies in the perishability of the products being distributed and the onus of providing same day delivery. It is hoped the framework used to determine the costs and the optimal transportation alternative under the different constraints can be applied to other goods such as food and blood products.

This study is sponsored in part by Tyco Healthcare (THC). Its motivation is to reduce operating costs. THC's division responsible for manufacturing nuclear medicine spends approximately $21.4 million (or 29%) of its annual transportation budget of $73.5 million to distribute the radiopharmaceuticals even though they only represent approximately 16% of its sales revenue (Tyco 2006). Furthermore, if the company can improve the way it serves its customers, it expects to capture more sales from its competition.

1.2 Nuclear Medicine

Nuclear medicines are radioactive drugs typically used for the diagnosis (e.g., anatomical imaging) and therapy of medical segments such as heart, oncology, renal, bone and lung.

All radioactive materials experience an uncontrollable, though predictable, decay (i.e., loss of radioactivity). Nuclear medicine producers must take this perishability into consideration in their distribution decisions. The medicine must be shipped with enough radioactivity so that it can serve its intended purpose. However, shipping radiopharmaceuticals with too much radioactivity is the equivalent of giving product away. Effectively, a balance must be reached between the cost of shipping speed and product decay. Because of these characteristics, shipping radiopharmaceuticals has been likened to shipping ice cubes without the benefit of refrigeration.

Timeliness of purchase or generation of the raw radioactive material is another factor that must be considered when manufacturing and distributing nuclear medicine. This is because the material begins decaying as soon as it is produced. Though the examination of the inbound shipments of raw materials is beyond the scope of this study, some attention is given to the coordination and planning of the raw materials generation conducted in-house by THC.

1.3 Business Overview

The market for nuclear medicine in the U.S. was estimated to be $2.1 billion in 2005 (Tyco 2006). Tyco Healthcare is one of the three major suppliers in this field; the other two being Bristol Myers Squibb and GE Healthcare (formerly Amersham Health).

THC's plant responsible for producing nuclear medicine is part of its Mallinckrodt operating unit. It is located in Maryland Heights, a suburb of St. Louis, MO situated near that city's international airport. The facilities employ approximately 400 people.

THC's manufactures over 125 different types of nuclear medicine. A product family consists of different radioactivity levels and doses of a same base radioisotope. For example the gallium 67 isotope is available as gallium citrate injections of 3.3 (1.65 mL), 6.6 (3.3 mL) or 13.2 mCi (6.6 mL) of radioactivity (volume).

In addition to producing nuclear medicine (also referred to as "hot products"), the Maryland Heights plant is responsible for producing and distributing "cold products". These are non-radioactive medicines used to direct the hot product towards the target organ. The hot and cold products are combined at radiopharmacies (pharmacies equipped and staffed to prepare radiopharmaceuticals) into doses that can be administered to patients.

The hot products manufactured by THC are domestically shipped to radiopharmacies via four transportation alternatives: ground courier, FedEx Express, commercial airlines and chartered aircraft. Figure 1.1 shows a diagram of the four alternatives. THC also ships its products internationally to Latin America and Canada, but those distribution networks are beyond the scope of this study.

In this study, the term transportation alternative is used to define any method employed to move products from one location to another. It is used in contrast to transportation mode which describes the use of trucks, trains, water vessels, aircrafts or pipeline transportation. For example, shipping a product using a commercial airline or a chartered aircraft service represents two transportation alternatives using a single transportation mode: aircraft.

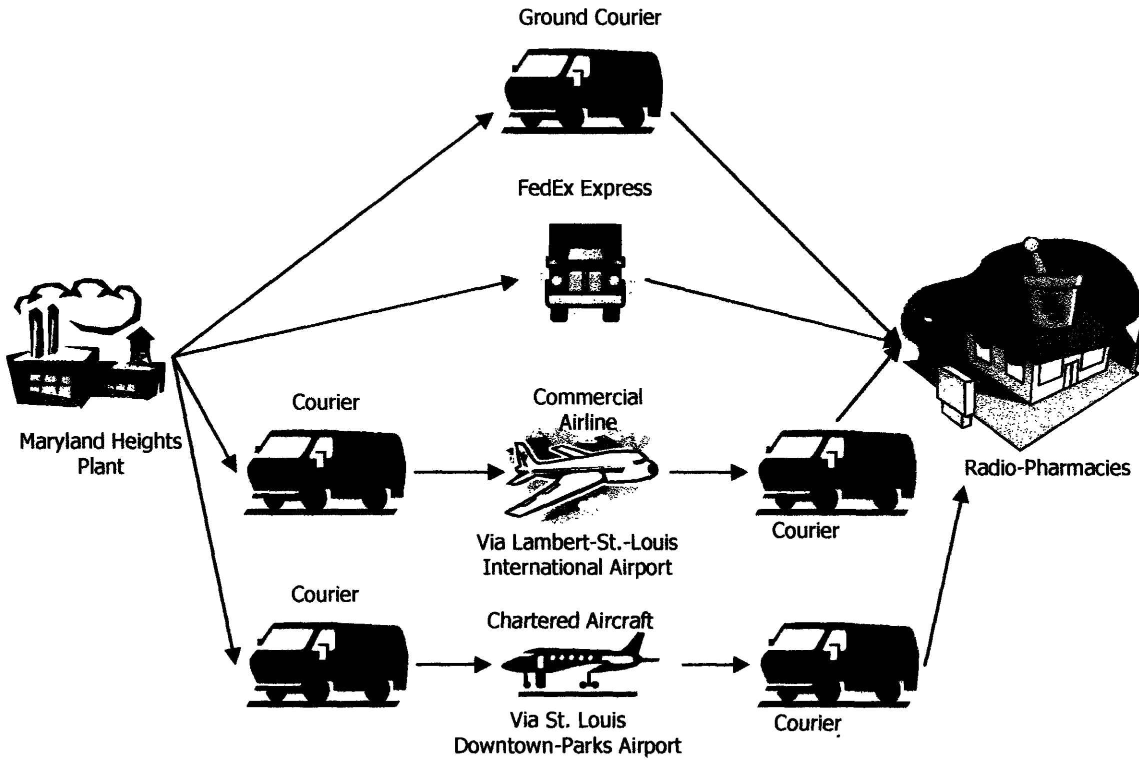

Figure 1.1 Diagram of transportation alternatives

1.4 Literature Review[1]

A review of the literature yielded little applicable information to distributing highly perishable goods. An effort was initially made to categorize nuclear medicine to find products that have similarities in perishability. Then, the literature was surveyed with an intent to find applicable criteria for selecting transportation alternatives for these types of products. Finally, the available literature on selecting transportation alternatives was examined. The following section considers the relevance of the findings.

How are perishable products categorized in the literature? Nahmias (1982) classifies them as either fixed lifetime or random lifetime. Products that have a fixed lifetime will decay at a fixed rate. The nuclear medicine under study has a fixed decay rate; therefore, random lifetime product assumptions are not a concern and are not considered in this study.

Federgruen, Prastacos and Zipkin (1986) present an allocation model for common perishable products (such as blood, food and drugs) shipped from one distribution center to many locations. Though this study does not examine inventory allocation, their model is relevant to this analysis because it considers transportation costs. Federgruen, Prastacos and Zipkin assume that shortages will be resolved by emergency delivery. In this study, low cost transportation alternatives will be replaced by high cost alternatives to meet the customer's delivery time constraints. This substitution achieves the same result as does emergency delivery in their model. It is expected the substitution will have similar effects on total cost.

Newspapers are another example of perishable goods. Hunter and Van Buer (1996) summarize the following features of the production and distribution of newspapers: narrow production and distribution time constraints, no existing inventory and highly connected production/distribution systems. To solve the newspaper delivery problem, Hunter and Van Buer divide locations into product zones, use vehicle routing methods to find the routes that satisfy the delivery time and transportation capacity requirements, and then track back to when the newspaper production run

[1] Yang 2006

must be completed. This study includes a consideration for customer distance from the distribution point, relationships between required delivery time, production capacity and production scheduling.

Cullinane and Toy (2000) apply content analysis methodology to transportation mode selection. Content analysis is a set of research tools used to determine key themes of written communications. Using content analysis methods, the authors conclude that the five factors most frequently used in mode selection are: freight cost, speed, transit time reliability, characteristics of the goods and service level. All of these factors are relevant and considered in this study.

Liberatore and Miller (1995) introduce the Analytic Hierarchy Process (AHP) methodology in carrier and mode selection. The AHP system incorporates quantitative factors and qualitative factors, both of which will be used in this study. The common quantitative factors are freight cost and inventory carrying cost. The common qualitative factors are perceived quality of customer service, cargo capacity limitation and shipment tracking capabilities and shipment tracing capabilities.

1.5 Approach

To analyze the distribution system and select suitable transportation alternatives, it is important to understand the context of the supply chain. The first stage of this study was to map the current radiopharmaceutical supply chain from order taking at the manufacturing plant to distribution of the prepared doses at the radiopharmacies. This work included documenting the current decision logic for the transportation alternative selection. Though some in-house literature was available from THC, most of the information came from interviewing key personnel including production planners, distribution managers, transportation analysts and a radiopharmacist. The results of this investigation are provided in Chapter 2, Aspects of the Supply Chain. They are an end in themselves in that documenting the supply chain was an objective of this study.

The second stage of the study consisted of mining the available data to gain additional insight into THC's operations. Here, the cost data were combined with the shipping data to establish the unit costs of shipping products to three sample regions (Dallas, Los Angeles and Orlando) via the four transportation alternatives. An analysis is also made to approximate the cost of an additional day of decay. The results and a discussion of these analyses are provided in Chapter 4, Base Costs.

The third and final stage of the study consisted of analyzing alternative distribution scenarios. This work challenged the restrictions to determine the opportunity cost of distributing the nuclear medicine under current operating policies. A spreadsheet model was built that calculates the distribution costs using the base freight data with as limited modification as possible. For example, if THC provided courier costs on a per-delivery basis, the model computed costs on a per-delivery basis instead of averaging the costs on a per-order basis. The objective of this approach was to provide as accurate a total cost as possible. The results and a discussion of this analysis are provided in Chapter 5, Alternative Distribution Scenarios.

The remainder of this document includes a description of the raw data provided by THC (Chapter 3), a discussion of ideas and possible avenues to investigate to further reduce THC's distribution costs (Chapter 6) and, a conclusion that summarizes the findings and recommendations of the study (Chapter 7).

2 Aspects of the Supply Chain

This chapter describes various aspects of THC's radiopharmaceuticals supply chain. The first section provides details on the products manufactured at the Maryland Heights (MH) plant. The following sections are arranged to follow the flow of an order from its arrival at the plant to the distribution of a prepared dose at a client's radiopharmacy. More specifically, an overview is provided on the types of orders and the order-taking process. Then, the manufacturing planning approach and production processes are summarized for the various hot products. This is followed by a description of the four transportation alternatives currently used and the considerations involved in their selection. Finally a summary of the operations at one of THC's radiopharmacy is provided.

2.1 Product Description

THC's nuclear medicine can be categorized in nine product families based on the radioisotope used in their manufacturing. They are chromium (Cr) 51, gallium (Ga) 67, indium (In) 111, iodine (I) 123 and 131, technetium (Tc) 99, phosphate (P) 32, thallium (Tl) 201 and xenon (Xe) 133. The product families are comprised of different concentrations and doses of a given isotope.

The different radiopharmaceuticals decay at different rates depending on the isotope they are based on. For instance, from their original radioactivity, Ga-based products decay at a rate of 0.95% per hour compounded hourly or 20.5% on the first day $(1-(1-0.0095)^{24})$. Likewise, for I-123-based products, the decay rate is 5.12% per hour compounded hourly; for Tc-based products it is 1.04% per hour compounded hourly and; for Tl-based products it is 0.88% per hour compounded hourly. Due to the differences in decay rates, some products start-off with a proportionally higher level of radioactivity compared to their nominal (or stated) value. Radioactive decay is exponential in nature; the decay rates, as presented above, are only representative of the first few days following manufacturing.

The radioactivity of a substance is measured in Curies (Ci) or Becquerels (Bq) with the latter being the SI standard unit. One Curie is equivalent to 1000 mCi, 3.7×10^{10} Bq and the amount of material that will produce 3.7×10^{10} nuclear decays per second.

Table 2.1 lists the calibration and expiration times of all the product families manufactured by THC. The calibration time is defined as the delay between the time a product has been manufactured to the time its radioactivity is measured to a meet its specification. At THC, for a product to meet quality specification, its measured radioactivity must be within 10% of its nominal value. For example, a 9.1 mCi (nominal value) capsule of sodium Iodide 131 must have a radioactivity between 8.2 and 10.0 mCi at calibration time.

If a product's radioactivity is below its nominal value, it does not mean it can no longer be used. The expiration time is defined as the length of time it takes for a product to no longer have the required effectiveness from the time it has been manufactured. Figure 2.1 shows the decay of a fictitious I-123 product with an initial radioactivity of 1.7 mCi, a nominal radioactivity of 0.5 mCi and a decay rate of 5.12% per hour.

Table 2.1 Product expiration times

Product Family	Calibration Time (days)	Expiration Time (days)
Chromium	Approximately 14	84
Gallium	3	14
Indium-111, OctreoScan®	6	7
Indium-111 Chloride	5	8
Iodine-123	1	2
Iodine-131	12 to 14 depending on product	17 to 60 depending on product
Phosphate	11 to 18 depending on product	24 to 60 depending on product
Technetium	0	14
Thallium	5 (Sunday through Wednesday) 7 (Thursday)	9
Xenon	9	21

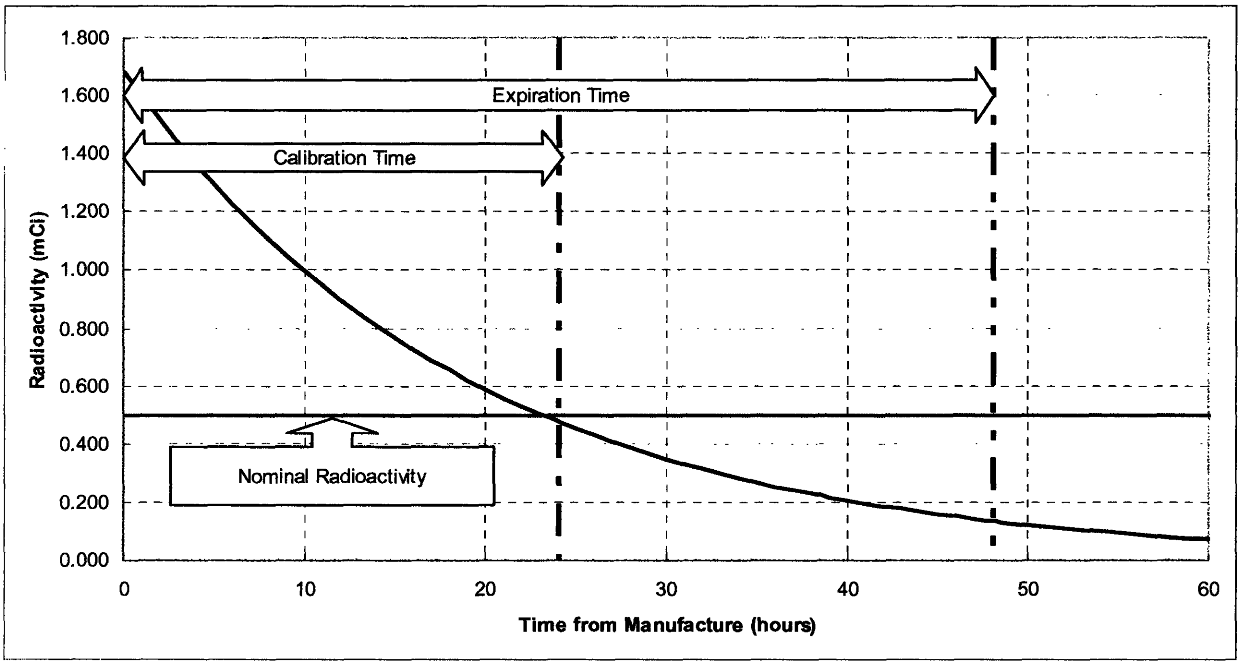

Figure 2.1 Radioactive decay of a fictitious 0.5 mCi I-123 product

Though all products are not manufactured daily (see section 2.3), most of them can be shipped daily due to the availability of stock. Of course, the caveat is that stocked items lose radioactivity. Customers know the manufacturing plant's production schedule and will typically order items when they are freshest, i.e., before their calibration time. This may allow the radiopharmacy to extract more doses from a given product.

2.2 Orders

Orders are classified as Standing or Demand. Standing orders are based on contracts established weeks to months in advance with customers. They call for regular shipments of product in previously agreed upon frequency, quantity and delivery times. For example, customer A has a Standing order that calls for the delivery of 20 vials of a Tl-based product every Monday. Adjustments to the quantities are typically allowed up to one day before the manufacturing is scheduled. It is common to have at least one customer make a change to its standing order on any given day (Tyco 2006). Demand orders are unplanned requests by customers that are received by EDI, fax or phone. Table 2.2 provides some statistics related to order types.

Table 2.2 Order type statistics

Order Type	Relative Quantity	Daily Quantity	Yearly Quantity
Demand	56%	359	130859
Standing	44%	286	104239
Total	100%	644	235097

Demand orders are normally fulfilled the same day (or before 3:00 AM the next day) they are received as long as they are placed prior to established deadlines. These cut-off times are given in Table 2.3. They are based on the transportation alternative (such as available commercial flights out of the St. Louis International Airport) used to fulfill same-day orders from customers. For example, the last suitable commercial flight out of St. Louis for Boston leaves at around 6:00 PM; so, an order for that region must be received by 3:00 PM to allow time for preparation and delivery to the airport.

As a last chance alternative, if an order is received after the city's Demand order deadline, but before 6:00 PM, the option of using FedEx Express is available. However, the customer has to decide whether he is willing to wait for later morning (possibly as late as 10:30 AM) delivery. Orders received after 6:00 PM are normally fulfilled the next day.

Table 2.3 Order deadlines for same day delivery

Cut-Off Time	Urban Region
10:00	Boise, ID Salt Lake City, UT
11:00	McAllen, TX
12:30	Denver, CO New Orleans, LA
13:00	Portland, OR
13:30	Minneapolis, MN
14:00	Raleigh, NC Richmond, VA
14:30	Albuquerque, NM Atlanta, GA Charlotte, NC Cleveland, OH Columbus, OH Detroit, MI Houston, TX Jacksonville, FL Miami, FL Orlando, FL Tampa, FL
15:00	Boston, MA Dallas, TX
15:30	New York, NY Newark, DE Oklahoma City, OK Phoenix, AZ San Antonio, TX San Francisco, CA
16:00	Baltimore, MD Chicago, IL Los Angeles, CA Philadelphia, PA Seattle, WA Syracuse, NY
16:30	Las Vegas, NV
17:00	All truck routes
18:00	Federal Express

Regardless of the type of order, they are all checked to ensure the customer is licensed to receive that particular radioactive product. The licenses are issued by regulatory bodies and copies must be supplied by the customer to THC to obtain service.

2.3 Production Planning and Production

Demand forecasting is done using an Excel-based system. It was developed in-house and uses historical data that may be adjusted, by an experienced production planner, for any foreseeable changes. The manufacturing is scheduled to meet the shipment drop-off times. These are based on the departure time of the transport used to service a particular region. For example, the chartered flight to Detroit, MI may leave at 10:30 AM on Sundays, so the orders going to the Detroit region must leave the MH plant by around 9:30 AM. The ordering deadlines (shown in Table 2.3) are different from the shipment drop-off times in that a Demand order might require the use of a transport that was not scheduled.

THC's production planners have characterized the demand for the Ga, Tc (the generators), Tl and Xe-based products to typically be level and straightforward to forecast. They observed the demand for In-based products is less level and thus harder to forecast. Similarly, they noted the demand for Cr, I-123, I-131, and P-based products tend to be based on Demand orders and are thus, the hardest to forecast. At an aggregate level, total orders by week are relatively constant over the period shown in Figure 2.2. For the given period, the average is 4501 orders per week with a standard deviation of 417 to make a coefficient of variation of 9.2%. The maximum quantity of orders in a week for the period is 5392; the minimum (due to holidays) is 3111.

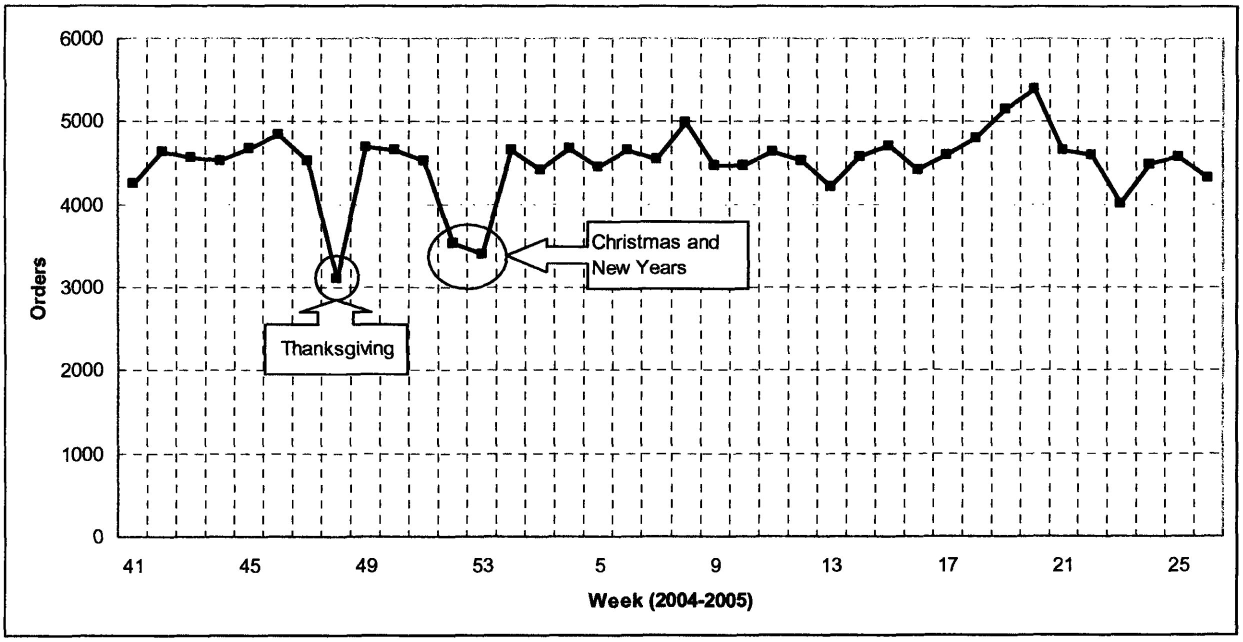

Figure 2.2 Orders by week (covering portions of 2004 and 2005)

The radiopharmaceutical manufacturing process depends on the source of the raw radioactive material, whether it is produced by the cyclotrons (device used to generate isotopes) located at the plant or it is purchased from outside vendors. In the first case, the isotope generation stage must be considered in the planning. In the second case, inbound shipments must reach the plant in a timely fashion. The raw material is constantly decaying, thus the production cycle also demands just in time processing and distribution. Relevant details of the production processes for each of the different product families are provided in the following sections. Table 2.4 summarizes their manufacturing frequency.

Table 2.4 Product manufacturing frequency

Product Family	Manufacturing Frequency
Chromium	6 / year
Gallium	2 / week
Indium-111, OctreoScan®	2 / week
Indium-111 Chloride	2 / week
Iodine-123	4 / week
Iodine-131	3 / week
Technetium	4 / week
Phosphate	26 / year
Thallium	6 / week
Xenon	1 / week

2.3.1 Chromium

Chromium-based products are manufactured every other month. The raw material arrives on the second weekend of the month. The production process takes approximately 2 days. The finished product is normally available for shipment by the third week of the production month. Inventory is kept in-house to respond to Demand orders; stock-outs are rare.

2.3.2 Gallium

Gallium-based products are manufactured on Tuesdays and Fridays. Production will either precede or follow the production of the Tl-based products depending on how it best fits the schedule. The generation of radioactive Ga also shares cyclotron capacity with the Tl production.

2.3.3 Indium

Indium chloride solutions are manufactured for shipping by Tuesdays and Fridays; OctreoScan® (based on In-111) is manufactured for shipping by Tuesdays and Sundays. Both their production processes follow an analogous path, with similar timings, to that of Tl-based products. The generation of radioactive In shares cyclotron capacity with the Tl production.

2.3.4 Iodine

Products based on the I-123 isotope are manufactured for shipment on Sundays, Mondays, Tuesdays and Wednesdays. Products based on the I-131 isotope are manufactured three days a week: Monday, Wednesday and Thursday; raw material is also delivery three days a week. Inventory of I-131 products are kept in-house to respond to Demand orders.

2.3.5 Phosphate

Phosphate-based products are manufactured every other week. The raw material arrives the Saturday before the week of production. Two types of products are made. Both take a day to manufacture. One type becomes available for shipping on Tuesday, the other on Wednesday. Inventory is kept in-house to respond to Demand orders.

2.3.6 Technetium (Generators)

The radioactive molybdenum (Mo) used to manufacture the technetium generators arrives from Petten, Netherlands, at 8:00 PM on Saturdays, Sundays, Tuesdays and Thursdays. It is diluted to required concentrations all night. The first shipments start leaving the plant at 6:00 AM.

Some limited inventory of radioactive Mo is kept in-house to respond to Demand orders. It becomes useless within a couple of days.

2.3.7 Thallium

Thallium-based medicines are manufactured six days a week, Saturday through Thursday. On a production day, the high radioactivity Tl generated in the cyclotrons is typically available by 11:00 AM. The next stage of the process, after the generation, is to measure the intermediate product radioactivity to determine the amount available for further processing. Dilution and dispensing to order begins at 1:00 PM. After the individual solutions are sterilized by autoclave and packaged, they are sent to the Distribution department for final packaging and labeling. All orders must arrive there by midnight. They start leaving the plant at around 1:30 AM.

2.3.8 Xenon

The raw material for Xenon-based products arrives weekly on Tuesday morning. Manufacturing takes approximately a day. The finished product becomes available for shipping by 6:00 AM the following day on Wednesday. Inventory of this product is kept to satisfy demand when not in production.

2.4 Transportation Considerations

2.4.1 Planning

THC's transportation planning only depends on the required delivery times and the transportation alternative used to ship an order. It does not depend on the production schedule (recall that production is planned to meet the transportation drop-off times). Customers typically require their orders by 3:00 AM, sometimes earlier, for preparation and delivery to their customers by 8:00 AM the same day.

Order preparations are prioritized by drop-off times, not by customer volume, i.e., purchase volume. Due to Demand orders or other limitations (such as TI limits) some customers receive more than one delivery per day. The transportation planning must also consider such situations.

When using the ground courier alternative, planning involves providing enough time for the orders to get to their destination. The FedEx Express alternative requires that the packages be ready at the set pick-up time. The commercial airline alternative requires coordinating the delivery to the originating airport with the specific flights, and the pick-up from the gateway airports to the radiopharmacies. Finally, the chartered aircraft alternative requires the same coordination as the commercial airline, but the itinerary of the flights can also be customized to the specific needs of THC. For the commercial airline and chartered aircraft alternatives, the need for three service providers results in an increased potential for late delivery or other mishaps in addition to higher costs since three organizations must be paid.

Table 2.5 provides the average number of orders shipped per day (not including Saturday) during the period covering October1, 2004 to June 30, 2005. It gives an approximation of the breadth of the U.S. distribution network.

Table 2.5 Average daily shipments to each state in the continental U.S.

State	Daily Orders	State	Daily Orders	State	Daily Orders
FL	61.4	SC	14.6	NV	5.9
PA	60.0	MN	14.1	WI	5.7
CA	47.2	MA	13.6	AZ	5.0
TX	43.1	OR	12.2	ND	4.9
OH	37.0	WA	12.2	WY	3.7
NY	35.8	WV	11.9	NM	3.3
MO	33.7	IN	11.8	ID	3.1
TN	25.8	CO	11.8	NE	3.0
IL	24.8	KS	11.6	ME	2.8
MI	24.5	KY	11.1	UT	2.5
GA	22.1	OK	10.7	VT	1.3
NC	21.7	CT	10.7	DC	1.1
VA	19.3	IA	7.3	DE	0.9
MD	19.0	MT	7.1	RI	0.3
NJ	18.1	MS	6.7	NH	0.2
AL	18.0	AR	6.5		
LA	17.8	SD	6.4		
				Grand Total	753.3

2.4.2 Transportation Index

Nuclear medicine has an additional limiting characteristic in addition to the usual volume and weight capacities of a given transport. Transportation restrictions apply based on the radioactivity of a shipment. The Transportation Index (or TI) is used to categorize this attribute. The TI level represents the maximum radiation emission at 1 meter from the external surfaces of a given package and is equivalent to one tenth of a measurement in microsieverts. Regulations require that the measures must be taken on each face of each parcel shipped and must be listed on the parcel labeling. Different transportation rules apply depending on the TI level of a given shipment.

When selecting a transportation alternative, TI levels are a significant issue only for commercial airlines. Of the two companies used by THC, one has imposed a TI limit of 5 per plane (this was increased from a limit of 4 from less than two years ago) and the other has a limit of 3 per plane. As an indicator of the limit this represents, the lowest TI level for a Tc generator is 0.8, the highest is 5.2.

Though the other transportation alternatives must take extensive safety precautions when moving radioactive goods, the service providers have received exemptions from the U.S. Department of Transportation allowing unlimited TI levels.

2.4.3 Product Decay

As described in the introductory chapter, product decay is a major concern when shipping nuclear medicine and plays a key role when deciding on a transportation alternative. Most products decay by approximately 20% to 30% within a day of manufacturing and some even up to 72% (see section 2.1). Because of the added cost of this decay, the use of ground couriers has been limited to radiopharmacies reachable within a few hours of road travel (approximately within 500 miles of the Maryland Heights plant). The three other transportation alternatives used by THC include an airlift portion to minimize delivery delays.

2.4.4 Cost

Of course, as in any competitive environment, costs play an important role. The main objective of this study is to look at ways to reduce the transportation costs of the nuclear medicine. THC has ranked the cost of the four different transportation alternatives as follows (from least to most expensive): ground courier, FedEx Express, commercial airline and chartered aircraft. This order and other costs considerations are studied in greater details in the chapters that follow.

2.4.5 Customer Service Level

THC considers customer service level to be a key differentiator from its competitors and, as such, of up most importance. Given the choice, a customer would rather receive a fresher product. Therefore, the distribution network is arranged such that the customers receive product typically within 26 hours of manufacturing for their high volume radiopharmaceuticals (the Tl-based products and the Tc generators). Moreover, the company's policy is to provide same-day service for Demand orders whenever possible.

On-time delivery (when an order arrives at its destination before the agreed upon delivery time) is also an important consideration. Each of the transportation alternatives has a good record; results for October 2004 to October 2005 are shown in Table 2.6.

Table 2.6 On-time delivery records

MH plant to distribution	99.7%
Chartered aircraft	95.9%
Commercial airline 1	98.0%
Ground Courier 1*	99.9%
Ground Courier 2*	99.8%
Ground Courier 3*	99.8%
FedEx Express	97.0%
Average (by provider, not shipment)	98.6%

*Results are self-reported by the ground couriers.
They should be used for qualitative purposes only.

2.5 Transportation Alternatives

This section describes the usage, advantages, disadvantages and peculiarities of the four transportation alternatives. Table 2.7 shows the number of orders shipped tabulated by day and alternative. Table 2.8 shows the sum of the order weights tabulated by day and alternative. The data is reviewed in the following sub-sections.

Table 2.7 Order quantity by ship day and transportation alternative

	Chartered Aircraft	Commercial Airline	FedEx Express	Ground Courier	Total
Sunday	22654	4149		4972	31775
Monday	18353	7831	4254	6331	36769
Tuesday	12672	10721	3800	4894	32087
Wednesday	16948	7605	2520	5267	32340
Thursday	5240	5031	1386	2567	14224
Friday	1	735	4988	22590	28314
Total	75868	36072	16948	46621	175509
Relative to daily total					
Sunday	71%	13%	0%	16%	18%
Monday	50%	21%	12%	17%	21%
Tuesday	39%	33%	12%	15%	18%
Wednesday	52%	24%	8%	16%	18%
Thursday	37%	35%	10%	18%	8%
Friday	0%	3%	18%	80%	16%
Total	43%	21%	10%	27%	100%

Table 2.8 Shipped weight by ship day and transportation alternative

	Chartered Aircraft	Commercial Airline	FedEx Express	Ground Courier	Total
Sunday	636651	107535		147872	892058
Monday	427327	148316	71787	140614	788044
Tuesday	104548	126582	28283	47827	307240
Wednesday	318231	144120	29197	102113	593660
Thursday	52958	65735	12534	21338	152565
Friday	53	22180	108145	559435	689813
Total	1539766	614468	249946	1019199	3423379
Relative to daily total					
Sunday	71%	12%	0%	17%	26%
Monday	54%	19%	9%	18%	23%
Tuesday	34%	41%	9%	16%	9%
Wednesday	54%	24%	5%	17%	17%
Thursday	35%	43%	8%	14%	4%
Friday	0%	3%	16%	81%	20%
Total	45%	18%	7%	30%	100%

THC also uses a service called AirExpress which consists of shipping packages on a chartered aircraft that has been contracted out by another company. The service provider is the same as the one used for the regular chartered aircraft alternative, but the carrying capacity is shared with another customer. Because the AirExpress alternative has a fixed schedule, for the sake of this study, it has been grouped with the commercial airline alternative that shares this characteristic. This simplification was deemed acceptable considering that over the October 2004 to June 2005 period, less than 1% of orders and weight were shipped by the AirExpress service.

2.5.1 Ground Courier

By order quantity (27% of orders) and weight (30% of total weight), ground courier is the second most frequently used transportation alternative. Of the four, THC perceives it as being the least expensive given a fixed transportation lead time. However, over long distances, ground-based transportation alternatives are slower than air ones. This can result in situations where product decay costs are more important than the savings achieved by using a ground courier.

Considering its low cost, that TI issues are not a significant concern and that it is relatively simple to coordinate logistically, ground courier is used for all radiopharmacies within 500 miles of the Maryland Heights plant.

Ground courier is also used for shipping to most radiopharmacies on Fridays (see Table 2.7). Due to limited Saturday delivery requirements, two days of transport are available for the orders to reach the customers. Arguably two or more days of transportation lead time could be used every day. The reasons why this is not currently done are discussed in Chapter 5.

2.5.2 FedEx Express

Due to its perceived relative low cost compared to the other air mode alternatives, rapid service, convenience and capability of handling radioactive goods, FedEx Express could be considered an attractive transportation alternative. However, because it cannot promise deliveries before 10:30 AM, use of this alternative is constrained to shipments to more remote, sparsely populated regions where volume is low and customers are more willing to accept later deliveries. This limitation is reflected in its usage data: only 10% of orders (7% of weight) are shipped via FedEx Express. Again, Friday usage is pronounced due to the acceptability of two-day delivery.

2.5.3 Commercial Airline

Commercial airlines offer quick service and, as a general rule for THC, are used whenever possible to limit the quantity of chartered flights. The most restrictive factors of this alternative are the availability of timely flights out of the serving airport and the aforementioned airline-imposed TI limit of 5 or 3 per plane depending on the service provider. On average, only 6 orders (with a coefficient of variance of 0.9) are placed on any given flight.

Flight availability is further limited by the constraint of having to use wide body aircrafts where a significant physical separation can be established between the passengers and the radioactive goods. Other concerns include the occasional flight cancellations, delays, missed connections and the limited operating hours of the cargo facilities.

Usage of this alternative falls between that of the chartered aircraft and ground courier. The exceptions being Fridays, where most orders are shipped via ground courier, and Sundays, due to the limited amount of flights out of St. Louis.

When using this alternative, additional coordination is required. A ground courier must transport the packages from the manufacturing plant to the Lambert-St.-Louis International Airport and then from the destination airport to the radiopharmacies. A single service provider is used for the origin airport delivery, but various local couriers are used for the last leg of the itinerary. Only one company is contracted per region. In addition to complicating coordination, using three service providers to ship an order results in higher costs (three organizations to pay) and increased potential for late delivery or other mishaps.

The base rate for the commercial airline service is on a per-pound basis with a minimum charge threshold equivalent to a 100-pound package for the airports of interest in this study. Since THC rarely (if ever) ships radiopharmaceutical packages weighing more than 100 lbs by commercial airline, the base rate can be simplified to a per-package basis. Therefore, to reduce costs when using this alternative, it becomes advantageous to consolidate individual orders into a larger package, i.e., smaller boxes are placed in a bigger box to minimize costs. The larger packages are subsequently broken down into their smaller components by the ground couriers that are responsible for making the deliveries from the gateway airports to the individual radiopharmacies.

The technetium generators are never consolidated due their specialized packaging and weight, in addition to the U.S. Department of Transportation's restriction that only like products can be consolidated. Theoretically, consolidating two generators is allowable, but would result in an excessive package weight (above 100 lbs) and potentially excess TI. Consolidation is also used with the chartered aircraft service for the purpose of easing manipulation.

2.5.4 Chartered Aircraft

Perceived by THC as a high cost solution, the use of chartered aircraft service is limited to high volume regions. Tyco employs a single service provider. It is the only one currently qualified for TI exemption from the U.S. Department of Transportation thus allowing it to carry high volumes of radioactive goods. The main advantages to using this alternative are the absence of TI limitations, the flexible operating hours for early or late deliveries, the speed of service, and the ability for one charter to serve many gateway cities. Usage reflects these benefits: 43% of orders (or 45% by weight) are shipped by chartered aircraft.

One of the disadvantages of this alternative is that the relatively small planes occasionally max-out on volume (this occurs approximately twice per year - Tyco 2006). Furthermore, similarly to commercial airlines, a ground courier must be used to transport the packages from the manufacturing plant to the St. Louis Downtown Parks Airport and then another from the destination airport to the radiopharmacies. Again, this results in more involved coordination, higher costs since three organizations must be paid and an increased potential for late delivery or other mishaps.

Currently, chartered aircraft service is used five days a week: Sunday through Thursday. In all there are 9 routes serving 12 different cities located East and South of St. Louis: Atlanta, Baltimore, Cleveland, Charlotte, Detroit, Fort Lauderdale, Columbus, Memphis, Orlando, Raleigh/Durham, Richmond and New York. The other regions are served by a mix of the remaining transportation alternatives.

The chartered airline currently uses two types of airplanes to service THC: Caravan and Lear. The first has more capacity (up to 51 generator, for example), but a slower rated speed of 200 mph. The second has a lower capacity (up to 39 generators, for example), but is much faster with a rated speed of 500 mph. Expectedly, the Lear jet is favored for longer routes.

2.6 Customer Use

When studying the production planning and distribution of the nuclear medicine, it is important to not only consider the manufacturing side of the supply chain, but also the customer side. This section provides an overview of relevant supply chain information at THC's radiopharmacy in North Attleboro, MA. For the sake of this study, the data is considered representative of all THC's customers.

Table 2.9 provides details of the inventory and delivery schedule of hot products at the facility. Any product not requiring "As needed" delivery is under a Standing order supply agreement.

Table 2.9 Inventory and deliveries at sample radiopharmacy

Product Family	Inventory on Hand	Deliveries
Chromium	None	As needed (very limited volume)
Gallium	Yes	Twice a week
Indium-111, OctreoScan®	None	As needed, but next day service required
Indium-111, Chloride	None	As needed
Iodine-123	None	Monday through Thursday
Iodine-131	None	As needed
Phosphate	None	As needed (very limited volume)
Technetium	Yes	3 to 4 per week
Thallium	Yes	Every day (except Saturday) Sometimes twice a day
Xenon	Yes	Once a week

Typically, radiopharmacies receive orders every day and sometimes even several times a day. Deliveries must be received before approximately 3:00 AM the following day to allow processing and distribution to the end clients. In the case of the sample radiopharmacy discussed above, it normally receives its orders by 12:30 AM (sometimes a second shipment may arrive between 2:00 AM to 3:00 AM). The prepared medicine leaves the radiopharmacy on one of three delivery runs to the end client:

1. Orders received the day before (those that were not fulfilled the day before) are delivered by 8:00 AM.

2. Orders in by 9:00 AM are delivered by noon the same day.
3. Orders in by 11:00 AM are delivered by 2:00 PM the same day. This run is not regularly scheduled.

3 Order and Cost Data

The analyses presented in this study are based on the order and cost data provided in this chapter. The data was made available by THC; some of it is masked due to its competitive sensitivity.

3.1 Order Dataset

Order information came in the form of a Microsoft Access database consisting of selected data for all orders shipped from October 1, 2004 to June 30, 2005. It originated from the order processing and distribution modules of THC's Oasis system (their own manufacturing resource planning software). The dataset contained 182,771 records with the information described in Table 3.1.

Table 3.1 Dataset field description (Tyco 2006)

Field	Description
Order	Unique internal code assigned by THC'S Customer Service. Used to differentiate orders.
Order type	Standing or Demand (described in section 2.2)
Weight	Order weight including its packaging
Shipment date	Date the order was shipped.
Shipment time	Time the order left the Maryland Heights plant.
Mode	Transportation alternative (with flight number if applicable)
FGCNID	Internal codes assigned on a day-by-day basis identifying gateway locations, and also taking into account product and time restrictions for certain deliveries (not used in analysis)
Gateway	Port of entry where a ground courier will pick-up a package to deliver it to a customer, i.e., a radiopharmacy.
Ground courier	Service provider that will deliver an order from a gateway to a customer.
Ship to name	Company name of the owner of the radiopharmacy delivered to.
Ship to city	City where the customer is located.
Ship to state	State where the customer is located.
MHMAN	Maryland Heights manifest number, assigned to each order as it is closed.
FGNMPK	Consolidation code and box number. Both these fields are used to determine when a shipment was consolidated with other shipments.
FGBXNO	

After removing the orders that were not shipped to continental U.S. locations and those that were listed as "HOLD" in the transportation alternative field, the dataset shrunk to 175,840 records. This subset was used to generate all the order data presented in this document.

3.2 Ground Courier Costs

The costs for the ground courier services are provided in Table 3.2. They are split into three categories. The first is for the delivery of packages from the Maryland Heights plant to the origin airports when using the commercial airline or chartered aircraft alternatives. The service provider has a team of drivers solely dedicated to the Maryland Heights plant. They shuttle back and forth to the airports to meet the flight departure times. The company chargers $50 per hour for this service and it has been estimated (Tyco 2006) that a trip to the St. Louis Downtown Airport requires 2 hours whereas the trip to the St. Louis International Airport requires 1.5 hours. Both these time estimates include the loading and unloading of the truck.

The second category of costs is for the delivery of packages from the destination gateway to a given radiopharmacy. This charge is for the linehaul/ground courier, commercial airline and chartered aircraft alternatives. It is on a per-stop basis, so if delivery to a given radiopharmacy involves multiple orders, the fee is charged once. Service provider 2 charges an additional $1.00 per mile when delivering to Mississippi.

The third category of costs is for the linehaul service currently used on Fridays for over the weekend deliveries. The charge is on a per-pound basis only; other than the difference for the Los Angeles region, there is no specific mileage fee.

Table 3.2 Ground courier costs

	Rate		Basis	Regions Served
Delivery from the Maryland Heights plant to the origin airport				
Ground Courier 1	$	100.00	per trip (2 h @ $50/h)	St. Louis Downtown Airport
	$	75.00	per trip (1.5 h @ $50/h)	St. Louis International Airport
Delivery from the destination gateway to a radiopharmacy				
Ground Courier 1	$	100.00	per stop	St-Louis, Chicago and Columbus
Ground Courier 2	$	100.00	per stop	Northeast, Florida, Louisana and Missouri
	$	1.00	per mile	Mississippi
Ground Courier 3	$	125.00	per stop	Northeast
Ground Courier 4	$	80.00	per stop	Colorado and Mountain
Ground Courier 5	$	100.00	per stop	California, Oregon and Washington
Linehaul service				
Ground Courier 1	$	1.35	per lb	Los Angeles
	$	0.10	per lb	All other cities

3.3 FedEx Express Costs

Samples costs for the FedEx Express service are provided in Table 3.3 (not all data is listed to limit space requirements). FedEx charges an additional $30.00 for all nuclear medicine packages due to the hazardous nature of the goods. Zones represent range buckets from a given origin. For example, shipping from St. Louis, MO to New York, NY represents a zone 5 range.

Table 3.3 Sample FedEx Express costs

Zone >	2	3	4	5	6	7	8
0.34 lbs	$ 5.00	$ 5.69	$ 5.98	$ 6.28	$ 6.53	$ 6.86	$ 7.06
1 lb	$ 5.50	$ 6.63	$ 7.94	$ 8.65	$ 9.35	$ 9.87	$ 10.05
2 lbs	$ 5.85	$ 7.15	$ 8.91	$ 9.69	$ 10.48	$ 10.82	$ 11.18
3 lbs	$ 6.47	$ 7.51	$ 9.87	$ 10.58	$ 11.61	$ 11.97	$ 12.22
4 lbs	$ 6.82	$ 7.94	$ 10.82	$ 11.79	$ 12.67	$ 13.11	$ 13.37
5 lbs	$ 7.26	$ 8.29	$ 11.71	$ 12.67	$ 13.71	$ 14.24	$ 14.68
6 lbs	$ 7.51	$ 8.72	$ 12.48	$ 13.54	$ 14.85	$ 15.38	$ 15.81
7 lbs	$ 7.78	$ 9.35	$ 13.37	$ 14.76	$ 16.07	$ 16.50	$ 16.77
8 lbs	$ 8.04	$ 9.87	$ 14.15	$ 15.54	$ 17.12	$ 17.47	$ 17.64
9 lbs	$ 8.29	$ 10.31	$ 15.20	$ 16.68	$ 18.34	$ 18.70	$ 18.96
...	...	...	...	...	...	...	...

3.4 Commercial Airline Costs

THC uses two commercial airlines to ship its packages. One of these companies transports 89.5% of all orders sent by this alternative. Its rates were considered to be representative of both service providers; they are listed in Table 3.4. Essentially, to ship a package to any city other than those listed in the table, it costs $154.60 if the package weights less than 5 lbs; $153.60 per package + $0.20 per lb if the package weights between 5 lbs and 67 lbs, inclusively; $149.60 per package + $0.26 per lb if the package weights between 68 lbs and 99 lbs, inclusively and; $91.25 per package + $0.79 per lb if the package weights more than 100 lbs.

Table 3.4 Commercial airline costs

Airport	Rate	Basis
All others not listed below	$ 58.35	per package < 100 lbs
	$ 0.53	average per lb for packages > 100 lbs
Honolulu, HI	$ 58.35	per package < 40 lbs
	$ 1.48	per lb for packages > 40 lbs
Albuquerque International, TX	$ 55.00	per package < 50 lbs
Columbus Regional, OH	$ 75.00	per package 50 - 70 lbs
Las Vegas, NV		
New York, LaGuardia, NY		
Oklahoma City, OK		
Omaha, NE		
Portlant, OR		
Richmond, VA		
Salt Lake City, UT		
Tampa, FL		
Washington, Dulles, DC		
Additional charges		
Hazardous goods surcharge	$ 85.00	per package
Fuel Surcharge	$ 0.20	per lb
Minimum	$ 1.00	per package
Security Charge	$ 0.06	per lb
minimum	$ 4.00	per package
Tax	$ 6.25	per package

For the sake of the analyses, the AirExpress service (service whereby orders are placed on a aircraft chartered by another company, see section 2.4) is considered a commercial airline alternative. Its costs were assumed to be the same as the commercial airline services.

3.5 Chartered Aircraft Costs

THC draws on a single provider of chartered aircraft (see section 2.5.4). Route details, as of May 2005, are provided in Table 3.5. Service costs (provider charges on a per-flight basis) are provided in Table 3.6.

Table 3.5 Charter route details

Route	Regions Served	Service Days*	Plane Type
102U	Mid Atlantic and Upper Mid Atlantic	7	Lear
102M	Mid Atlantic and Upper Mid Atlantic	1	Lear
102W	Mid Atlantic and Upper Mid Atlantic	3	Lear
244M	South-East	1	Caravan
110U & 110	North Central	71234	Caravan
244U/238U	Upper Mid Atlantic	7	Caravan/Lear
452U	South-East	7	Lear
452	South-East	1234	Lear
486U & 486	South-West	71234	Caravan

*Service days are numbered 1 through 7 starting on Monday.

Table 3.6 Charter unit costs

Route	Total Charge	Average Pkgs	Average Weight	Per Pkg Charge	Per lb Charge
102U	$ 6,750	63	1400	$ 107.14	$ 4.82
102M	$ 6,000	85	1800	$ 70.59	$ 3.33
102W	$ 6,000	90	1500	$ 66.67	$ 4.00
244M	$ 3,535	20	600	$ 176.75	$ 5.89
110U & 110	$ 2,550	61	1550	$ 41.80	$ 1.65
244U/238U	$ 2,970	79	1500	$ 37.59	$ 1.98
452U	$ 5,500	83	2400	$ 66.27	$ 2.29
452	$ 5,000	59	1445	$ 84.75	$ 3.46
486U & 486	$ 3,000	11	350	$ 272.73	$ 8.57

4 Base Costs

The cost of shipping all orders from October 1, 2004 to June 30, 2005 was calculated for three different regions: Dallas, Los Angeles and Orlando. The mix of transportation alternatives in the analysis represents the actual distribution operation employed by THC over the 39-week period (the date range of the provided dataset). The results of this analysis represent the base costs from which the costs of alternative distribution scenarios can be compared.

For the sake of the analysis, the Dallas region consists of the all the customers in the following cities: Abilene, Dallas, Fort Worth, Galveston, Houston, Lubbock, Lufkin, Nacogdoches, Sherman, Sugar Land, Tyler, Waco and Wichita Falls.

The Los Angeles region consists of the all the customers in the following cities: Anaheim, Bakersfield, Camp Pendleton, Colton, Commerce, Fullerton, La Jolla, Loma Linda, Lompoc, Long Beach, Los Angeles, Mission Hills, Oceanside, Palm Springs, Placenta, Ridgecrest, San Diego, San Luis Obispo, Santa Barbara, Torrance, Van Nuys and West Hills. This represents California customers located approximately south of Bakersfield.

The Orlando region consists of the all the customers in the following cities: Bay Pines, Daytona Beach, Fort Myers, Gainesville, Jacksonville, Jacksonville beach, Leesburg, Ocala, Orlando, Ormond Beach, Saint-Petersburg, Sanford, Sarasota, Tallahassee, Tampa, West Melbourne, Winter Park and Winter Haven. This region is essentially a quadrilateral with Tallahassee at the

NW corner, Jacksonville at the NE corner, Melbourne at the SE corner and Fort Myers at the SW corner.

4.1 Transportation Unit Costs

A complete list of the transportation unit costs for all three regions is provided in Table 4.1. Most of these values are taken from the data presented in Chapter 3 and are thus concealed. The origins of the other costs are discussed in the paragraphs that follow.

Table 4.1 Transportation unit costs

Region:	Dallas	Los Angeles	Orlando	Basis
Ground Courier (linehaul)				
Cost	$ 0.100	$ 1.350	$ 0.100	per lb
Delivery to radiopharmacy	$ 100.00	$ 100.00	$ 100.00	per stop
FedEx Express				
Base	$ 6.75	$ 7.75	$ 8.05	per package
Weight	$ 0.76	$ 0.90	$ 0.86	per lb
Hazardous goods surcharge	$ 30.00	$ 30.00	$ 30.00	per package
Commercial Airline				
Delivery to origin airport	$ 46.50	$ 46.50	$ 46.50	per trip (1.5 h @ $31/h)
Base	$ 58.35	$ 58.35	$ 58.35	per package
Hazardous goods surcharge	$ 85.00	$ 85.00	$ 85.00	per package
Tax	$ 6.25	$ 6.25	$ 6.25	per package
Fuel surcharge	$ 0.20	$ 0.20	$ 0.20	per lb
Security charge	$ 4.00	$ 4.00	$ 4.00	per package
Delivery to radiopharmacy	$ 100.00	$ 100.00	$ 100.00	per stop
Chartered Aircraft				
Delivery to origin airport	$ 62.00	$ 62.00	$ 62.00	per trip (2 h @ $31/h)
Base	$ 3.52	$ 3.52	$ 2.88	per lb
Base	$ 1,903	$ 1,903	$ 1,903	per charter
Delivery to radiopharmacy	$ 100.00	$ 100.00	$ 100.00	per stop

To facilitate the calculation of the aggregate cost to ship via the FedEx Express alternative, a regression analysis of weight versus cost was performed. This circumvented the problem of having to use the look-up table to determine the cost of each individual package. The analysis yielded a function that has a base per package cost and a variable per-pound cost. The function allows the precise calculation of the costs at an aggregate level using the total quantity and weight of packages sent. Partial results of the regressions are presented in Table 4.2. Figure 4.1 compares the actual FedEx Express costs to the calculated ones. The fit is accurate enough to provide a good estimate of costs.

Table 4.2 Results of regression analysis for the FedEx Express costs

Zone	Example	Base Cost (/package)	Variable Cost (/lb)	R^2
4	St. Louis to Dallas	$ 6.75	$ 0.76	0.995
6	St. Louis to Orlando	$ 8.05	$ 0.86	0.994
7	St. Louis to Los Angeles	$ 7.75	$ 0.90	0.993

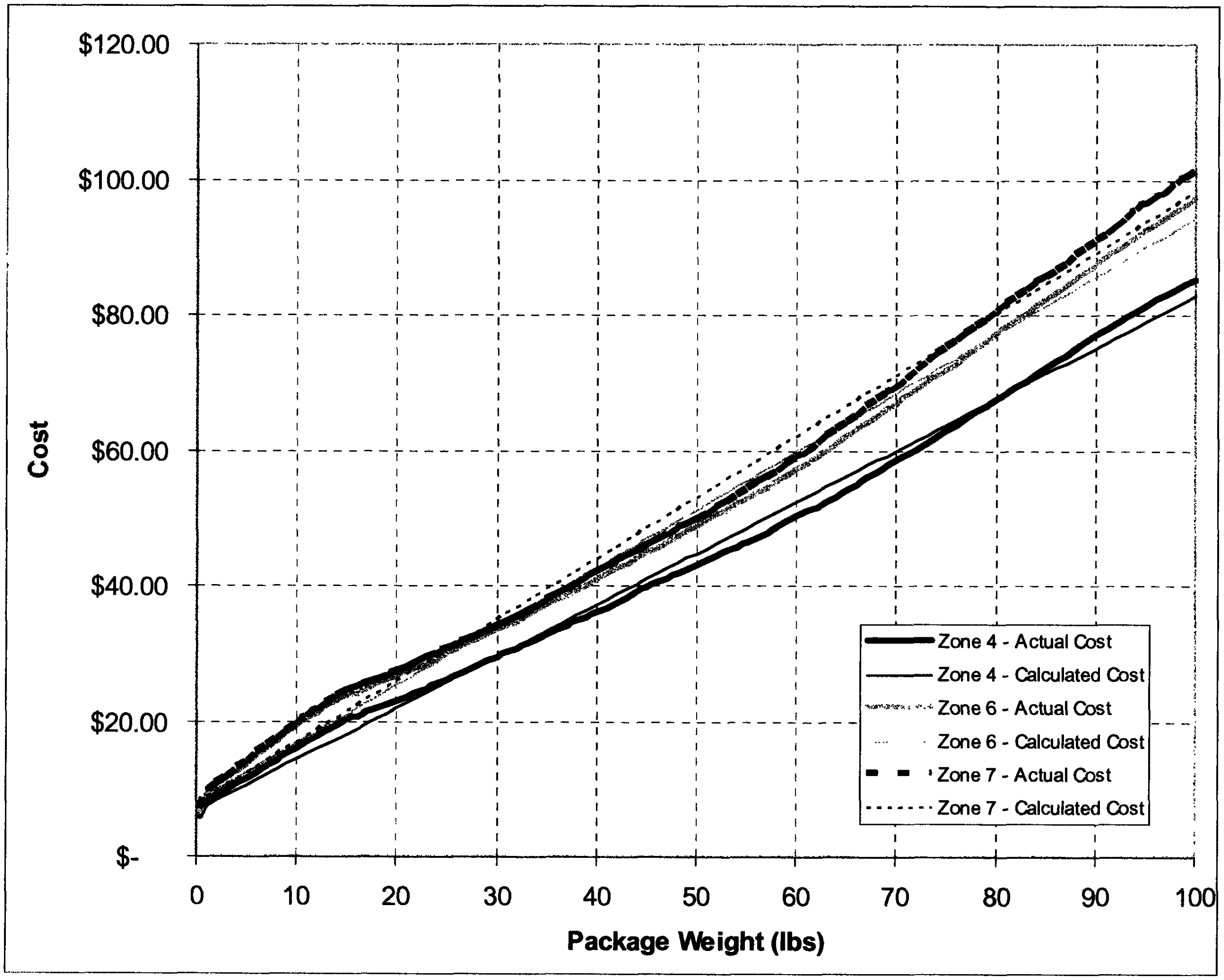

Figure 4.1 FedEx Express cost data, actual vs calculated

In determining the costs for the commercial airline alternative, all packages were assumed to weight less than 68 lbs and more than 5 lbs. In all three regions studied, there were a total of only five packages that weighed more then 100 lbs and they were all shipped by FedEx Express. Consequently, the base cost of $58.35 per package was correctly used since there were no packages that were charged a premium for weighing more than 100 lbs. Any weight above 67 lbs would have incurred and additional security charge of $0.06 per lb which was deemed insignificant. The calculations include the fuel surcharge of $0.20 per lb but not the floor charge of $1.00, this results in light packages (those weighting less than 5 lbs) being undercharged by as much as $0.80. This amount was also deemed insignificant.

Though further accuracy would have been achieved if the actual cost of the AirExpress service had been included in the analysis compared to using the commercial airline costs, it is estimated the results would not have changed significantly.

The cost per-charter was estimated to be the average of the per-city charge (see Table 4.3). The cost per-pound of shipping by chartered aircraft to a given city was estimated to be the average of the unit costs for the charters serving that city. In cases where a city is not currently being served by chartered aircraft, the average unit cost per city was used. Table 4.4 provides details of these calculations.

Table 4.3 Charter costs per city

Route	Total Charge	Qty of Cities	Charge per City
102U	$ 6,750	4	$ 1,688
102M	$ 6,000	4	$ 1,500
102W	$ 6,000	3	$ 2,000
244M	$ 3,535	1	$ 3,535
110U & 110	$ 2,550	3	$ 850
244U/238U	$ 2,970	1	$ 2,970
452U	$ 5,500	3	$ 1,833
452	$ 5,000	4	$ 1,250
486U & 486	$ 3,000	2	$ 1,500
		Average:	**$ 1,903**

Table 4.4 Charter unit costs per city

City	Average per Package Cost	Average per Lb Charge
Raleigh	$ 88.87	$ 4.08
Richmond	$ 88.87	$ 4.08
Baltimore	$ 81.47	$ 4.05
New York	$ 70.50	$ 3.53
Atlanta	$ 109.25	$ 3.88
Detroit	$ 41.80	$ 1.65
Cleveland	$ 41.80	$ 1.65
Columbus	$ 41.80	$ 1.65
Charlotte	$ 75.51	$ 2.88
Orlando	$ 75.51	$ 2.88
Miami	$ 84.75	$ 3.46
Memphis	$ 272.73	$ 3.46
New Orleans	$ 272.73	$ 8.57
Average:	**$ 103.51**	**$ 3.52**

4.2 Order Data

The order data for the three regions studied are presented in Table 4.5 (values were rounded to conceal the true per-unit costs). The total weight of shipments, quantity of orders, linehauls and flights were relatively straightforward to determine from the order dataset. For the commercial airline data, the quantity of packages represents the actual amount of consolidated packages shipped. The value was generated by counting the number of packages whose box number did not begin with a B and adding the count of packages whose box number begun with a given B value (e.g., B01, B02, etc.) for a given day and flight. The quantity of deliveries represents the quantities of radiopharmacies delivered to on a given day. The value was determined by counting each distinctive ship-to name and city (some customers have more than one radiopharmacy in a given region). In the case of commercial airline and chartered aircraft cargo, the delivery count also takes into consideration multiple daily deliveries to a radiopharmacy due to orders arriving on different flights.

Table 4.5 Order data

Region:	Dallas	Los Angeles	Orlando	Units
Ground Courier (linehaul)				
Total weight of orders	20000	4000	12600	lbs
Quantity of orders	900	300	700	
Quantity of linehauls	39	39	39	
Quantity of deliveries	300	150	300	
FedEx Express				
Total weight of orders	6000	22000	6000	lbs
Quantity of orders	700	1300	400	
Commercial Airline				
Total weight of orders	32000	33000	19000	lbs
Quantity of orders	2400	2100	600	
Quantity of flights	600	300	200	
Quantity of packages	1000	800	400	
Quantity of deliveries	800	800	200	
Chartered Aircraft				
Total weight of orders	64000	90000	150000	lbs
Quantity of orders	2600	3000	7400	
Quantity of flights	150	150	200	
Quantity of deliveries	700	1000	2400	
Total weight of all orders	122000	149000	187600	
Total orders	6600	6700	9100	

4.3 Base Costs

The calculated base costs are presented in Table 4.6 (these are the accurate values based on the true order and unit costs). For the chartered aircraft alternative two subtotals and per-order values were calculated. One uses the per-pound cost basis; the other uses the per-chartered-flight cost basis. The results of both calculation methods are also given for the grand total and per-order average.

Table 4.6 Base costs

Region:	Dallas	Los Angeles	Orlando
Ground Courier (linehaul)			
Weight	$ 1,892	$ 5,268	$ 1,218
Delivery to radiopharmacies	$ 22,680	$ 13,005	$ 27,285
Subtotal	$ 24,572	$ 18,273	$ 28,503
Per order	$ 27	$ 60	$ 38
FedEx Express			
Packages	$ 25,064	$ 49,191	$ 13,392
Weight	$ 4,673	$ 19,863	$ 4,884
Subtotal	$ 29,737	$ 69,054	$ 18,276
Per order	$ 44	$ 53	$ 52
Commercial Airline			
Delivery to origin airport	$ 27,296	$ 14,322	$ 8,882
Packages	$ 130,598	$ 101,050	$ 52,653
Weight	$ 6,442	$ 6,672	$ 3,705
Delivery to radiopharmacies	$ 68,709	$ 71,570	$ 20,060
Subtotal	$ 233,045	$ 193,614	$ 85,299
Per order	$ 102	$ 90	$ 141
Chartered Aircraft			
Delivery to origin airport	$ 9,362	$ 9,486	$ 12,090
Weight	$ 225,405	$ 316,023	$ 430,247
Charters	$ 287,325	$ 291,131	$ 371,049
Delivery to radiopharmacies	$ 57,830	$ 86,615	$ 198,815
Subtotal (weight basis)	$ 292,596	$ 412,124	$ 641,152
Subtotal (charter basis)	$ 354,517	$ 387,232	$ 581,954
Per order (weight basis)	$ 115	$ 144	$ 87
Per order (charter basis)	$ 139	$ 135	$ 79
Total (weight basis)	$ 579,951	$ 693,065	$ 773,230
Total (charter basis)	$ 641,871	$ 668,172	$ 714,032
Per order (weight basis)	$ 90	$ 104	$ 85
Per order (charter basis)	$ 100	$ 101	$ 79

From Table 4.6 it can be seen that the per-order costs of the different transportation alternatives for the Dallas region follow the supposed cost rank listed in section 2.4.4 (from least to most expensive): ground courier, FedEx Express, commercial airline and chartered aircraft.

For the Los Angeles region, FedEx Express is less expensive than ground courier because of the relatively high unit cost ($1.35/lb, masked) of shipping by the latter alternative. If the orders that are normally shipped by the Friday ground-courier transport can be ready for the Friday FedEx drop-off time and the customer is willing to accept (earlier) Saturday deliveries, it is worthwhile to further investigate the possibility of switching the transportation alternatives. The estimated cost saving is $7 per order.

For the Orlando region, the chartered aircraft alternative is less expensive than the commercial airline alternative. This difference is due to flight loading. In the case of the Dallas region, there were 2550 orders shipped on 151 chartered flights resulting in a loading of approximately 17 orders per charter. The Los Angeles region has a slightly higher load ratio at approximately 19 orders per charter (2867/153). The Orlando region has a loading factor of 38 orders per charter (7353/195). Considering that a chartered flight has a flat fee of approximately $1900 and that the air portion of the commercial airline alternative is a conservative $50 per order, it becomes advantageous to use a chartered aircraft when shipping more than 38 orders per day to a given region.

Comparing the transportation alternatives on a regional basis also yields some interesting insights. In the case of the ground courier alternative, shipping to the Los Angeles region is significantly more expensive due to the aforementioned high unit costs ($1.35/lb versus $0.10/lb for the Dallas and Orlando regions). Considering the relative high cost of the deliveries to the radiopharmacies, the differences in per-order costs are also partially explained by the number of orders per delivery. Dallas has an attractive ratio of 3.4 orders per delivery compared to 2.0 and 2.3 for the Los Angeles and Orlando regions, respectively.

Predictably, the difference in per-order costs of the FedEx Express alternative is reflective of the travel distance to the various regions.

The difference in per-order costs of the commercial airline alternative is mostly due to the order to package ratio. The Los Angeles region has a relatively high 2.6 orders compared to 2.1 and 1.4 for the Dallas and Orlando regions, respectively. This result highlights the benefit of consolidating packages. Based on discussions with personnel at the Maryland Heights plant, consolidation has already been maximized to the extent allowable by law.

The difference in per order costs of the chartered aircraft alternative is mostly due to the aforementioned flight loading.

Comparing the results obtained by using the weight or charter cost basis, there is no clear advantage to either method. For the Dallas region, the weight basis yields a lower cost, but for the Los Angeles and Orlando regions the charter basis yields a lower cost. The service provider charges on a per-flight basis. So, if a more accurate charter cost could be obtained, it would be best to use this value compared to a potentially unrepresentative per-pound value that is based on an average.

Overall, the Orlando region has the lowest per-order cost. This result is a consequence of the high volume of packages shipped by chartered aircraft.

4.4 Decay Costs

Table 4.7 shows the weekly costs to add one day of radioactivity for an assortment of THC products. More explicitly, the costs are for an additional day of radioactivity, not for an additional week of radioactivity. The sales data represent the totals for a sample week in November 2005. The unit cost of activity for the Ga, Tc and Tl-based products has been rounded to \$0.25/mCi and that of I-123-based products to \$5.00/mCi. The weekly decay costs by product family are shown in Table 4.8. Due to the competitive sensitivity of this information, the true data has been concealed; nevertheless, the aggregate values shown in Table 4.8 are equivalent to those that were calculated using the actual data.

Table 4.7 Decay costs

Description	Nominal Activity (mCi)	Initial Activity (mCi)	Rate of Decay (per hour)	Over 24 Hours: Decay	Over 24 Hours: Cost of Decay (per unit)	Sample Week: Sales (units)	Sample Week: Total Cost for Week
Thallous Chloride (Tl-201)	2.2	10.0	0.95%	20%	$ 0.64	3	$ 2
Thallous Chloride (Tl-201)	2.8	12.0	0.95%	20%	$ 0.77	4	$ 3
Thallous Chloride (Tl-201)	5.0	15.0	0.95%	20%	$ 0.97	12	$ 12
Thallous Chloride (Tl-201)	6.3	35.0	0.95%	20%	$ 2.25	422	$ 951
Thallous Chloride (Tl-201)	9.9	40.0	0.95%	20%	$ 2.57	2,800	$ 7,209
Gallium Citrate Injection (Ga-67)	3.3	30.0	0.88%	19%	$ 1.77	2	$ 4
Gallium Citrate Injection (Ga-67)	3.3	25.0	0.88%	19%	$ 1.48	2	$ 3
Gallium Citrate Injection (Ga-67)	6.6	35.0	0.88%	19%	$ 2.07	6	$ 12
Gallium Citrate Injection (Ga-67)	6.6	35.0	0.88%	19%	$ 2.07	7	$ 14
Gallium Citrate Injection (Ga-67)	13.2	55.0	0.88%	19%	$ 3.25	45	$ 146
Gallium Citrate Injection (Ga-67)	13.2	55.0	0.88%	19%	$ 3.25	49	$ 159
I-123 Capsules, Diagnostic	0.100	2.000	5.12%	72%	$ 25.30	498	$ 12,601
I-123 Capsules, Diagnostic	0.200	4.000	5.12%	72%	$ 50.61	1,975	$ 99,946
M0-99 DTE Generator (Tc-99)	1000.0	1000.0	1.04%	22%	$ 71.30	3	$ 214
M0-99 DTE Generator (Tc-99)	1000.0	1000.0	1.04%	22%	$ 71.30	3	$ 214
M0-99 DTE Generator (Tc-99)	1500.0	1500.0	1.04%	22%	$ 106.95	5	$ 535
M0-99 DTE Generator (Tc-99)	2000.0	2000.0	1.04%	22%	$ 142.60	25	$ 3,565
M0-99 DTE Generator (Tc-99)	2500.0	2500.0	1.04%	22%	$ 178.24	35	$ 6,239
M0-99 DTE Generator (Tc-99)	3000.0	3000.0	1.04%	22%	$ 213.89	39	$ 8,342
M0-99 DTE Generator (Tc-99)	3500.0	3500.0	1.04%	22%	$ 249.54	34	$ 8,484
M0-99 DTE Generator (Tc-99)	5000.0	5000.0	1.04%	22%	$ 356.49	40	$ 14,260
M0-99 DTE Generator (Tc-99)	5000.0	5000.0	1.04%	22%	$ 356.49	5	$ 1,782
M0-99 DTE Generator (Tc-99)	5000.0	5000.0	1.04%	22%	$ 356.49	25	$ 8,912
M0-99 DTE Generator (Tc-99)	5000.0	5000.0	1.04%	22%	$ 356.49	15	$ 5,347
M0-99 DTE Generator (Tc-99)	6000.0	6000.0	1.04%	22%	$ 427.79	40	$ 17,111
M0-99 DTE Generator (Tc-99)	7500.0	7500.0	1.04%	22%	$ 534.73	100	$ 53,473
M0-99 DTE Generator (Tc-99)	11000.0	11000.0	1.04%	22%	$ 784.27	80	$ 62,742
M0-99 DTE Generator (Tc-99)	14000.0	14000.0	1.04%	22%	$ 998.17	150	$ 149,725
M0-99 DTE Generator (Tc-99)	16000.0	16000.0	1.04%	22%	$ 1,140.76	100	$ 114,076
M0-99 DTE Generator (Tc-99)	19000.0	19000.0	1.04%	22%	$ 1,354.66	60	$ 81,279
M0-99 DTE Generator (Tc-99)	19000.0	19000.0	1.04%	22%	$ 1,354.66	50	$ 67,733
					Totals for week	6,634	$ 725,095

Table 4.8 Weekly decay costs by product family

Product Family	Cost	Fractional Cost
Tl	$ 8,176	1%
Ga	$ 339	0%
I-123	$ 112,546	16%
Tc	$ 604,034	83%
Total	$ 725,095	100%

The cost of Tc decay represents a large portion of the total (83%) due to the relatively high sales volume and initial activity. Compared to the other product families, they lose a significant and thus expensive amount of radioactivity in a short period of time. For example, a generator with an original radioactivity of 19.0 Ci will lose 4.2 Ci of radioactivity or $1054 of value (at $0.25/mCi) over a period of 24 hours. The decay costs of I-123 are also relatively high due to the high decay rate (5.12% per hour) and the high raw material cost ($5.00 per mCi).

From what is known of Bristol-Myers Squibb's (BMS's) strategy, their policy is to ship their orders by FedEx Express for delivery by 10:30 AM the next day (Tyco 2006). As seen in section 2.6, for the radiopharmacies, this can represent an additional day of decay compared to a delivery in the early AM (before 3:00). For the Tc-based products only, it is also BMS's policy not to compensate for this extra day of decay. If this policy was applied by THC, the total cost of an additional day of decay (as calculated above) would drop from $725k to $121k.

The analysis assumes that the sales data for the sample week is representative of the sales data for all weeks. This assumption can be deemed reasonable considering the relatively constant demand shown in Figure 2.2. Moreover, the analysis does not cover the sales for all product families. Therefore, the results in Table 4.7 and Table 4.8 are meant to provide an idea of the order of magnitude of the decay cost. They will be used in the next chapters when discussing distribution alternatives and recommendations.

5 Alternative Distribution Scenarios

This chapter studies three alternatives to the distribution operation of THC presented in Chapter 4. The first describes a situation where all orders are shipped by ground courier. The second alternative describes a situation where all orders originally shipped by commercial airline are shipped by chartered aircraft. Finally, the third describes a situation where all orders are shipped by FedEx Express. The period covered is the same as for Chapter 4, that is, from October 1, 2004 to June 30, 2005.

5.1 Shipping All Orders by Ground Courier

The modified order data representing a situation where all orders are shipped by a single daily linehaul service to a given region are presented in Table 5.1 (values were rounded to conceal the true per-unit costs). The resulting transportation costs are presented in Table 5.2 (these are the accurate values based on the true order and unit costs). The analysis assumes that the unit costs presented in Chapter 3 would remain the same; however, increased usage could result in additional savings to those presented below.

Table 5.1 Order data for shipping all orders by ground courier

Region:	Dallas	Los Angeles	Orlando	Units
Ground Courier (linehaul)				
Total weight of orders	122000	150000	190000	lbs
Quantity of orders	6400	6600	9000	
Quantity of linehauls	233	233	233	
Quantity of deliveries	1500	2000	3000	
FedEx Express				
Total weight of orders	0	0	0	lbs
Quantity of orders	0	0	0	
Commercial Airline				
Total weight of orders	0	0	0	lbs
Quantity of orders	0	0	0	
Quantity of flights	0	0	0	
Quantity of packages	0	0	0	
Quantity of deliveries	0	0	0	
Chartered Aircraft				
Total weight of orders	0	0	0	lbs
Quantity of orders	0	0	0	
Quantity of flights	0	0	0	
Quantity of deliveries	0	0	0	
Total weight of all orders	122000	150000	190000	
Total orders	6400	6600	9000	

Table 5.2 Costs of shipping all orders by ground courier

Region:	Dallas	Los Angeles	Orlando
Ground Courier (linehaul)			
Weight	$ 11,824	$ 186,672	$ 18,055
Delivery to radiopharmacies	$ 127,962	$ 171,785	$ 244,460
Subtotal	$ 139,786	$ 358,457	$ 262,515
Per order	$ 22	$ 54	$ 29
FedEx Express			
Packages	$ -	$ -	$ -
Weight	$ -	$ -	$ -
Subtotal	$ -	$ -	$ -
Per order	N.A.	N.A.	N.A.
Commercial Airline			
Delivery to origin airport	$ -	$ -	$ -
Packages	$ -	$ -	$ -
Weight	$ -	$ -	$ -
Delivery to radiopharmacies	$ -	$ -	$ -
Subtotal	$ -	$ -	$ -
Per order	N.A.	N.A.	N.A.
Chartered Aircraft			
Delivery to origin airport	$ -	$ -	$ -
Weight	$ -	$ -	$ -
Charters	$ -	$ -	$ -
Delivery to radiopharmacies	$ -	$ -	$ -
Subtotal (weight basis)	$ -	$ -	$ -
Subtotal (charter basis)	$ -	$ -	$ -
Per order (weight basis)	N.A.	N.A.	N.A.
Per order (charter basis)	N.A.	N.A.	N.A.
Total (weight basis)	$ 139,786	$ 358,457	$ 262,515
Total (charter basis)	$ 139,786	$ 358,457	$ 262,515
Per order (weight basis)	$ 22	$ 54	$ 29
Per order (charter basis)	$ 22	$ 54	$ 29

Considering service provider costs alone, ground courier is the least expensive transportation alternative to distribute nuclear medicine. Furthermore, additional cost reduction is achieved in this scenario by limiting the deliveries to a given radiopharmacy to one per day. Actual savings compared to the base scenario are considerable as can be seen in Table 5.3. Savings for the Dallas region are more substantial due to a decrease in the total number of deliveries.

Table 5.3 Savings compared to the base scenario

Region:	Dallas	Los Angeles	Orlando
Total (weight basis)	$ 440,165	$ 334,609	$ 510,715
Total (charter basis)	$ 502,085	$ 309,716	$ 451,517
Per order (weight basis)	$ 68	$ 50	$ 56
Per order (charter basis)	$ 78	$ 47	$ 50

Implementing this distribution strategy implies that same-day or even next-day service could not be offered for all but those regions that can be reached within a few hours ground travel from the manufacturing plant. Furthermore, additional raw material costs would be incurred to compensate for decay since not all regions could be reached within a day's travel. Considering only the Dallas, Los Angeles and Orlando regions (that represent 12.6% (22,215/175,509) of orders) and the date range of the study (39 weeks), the total cost of decay becomes greater than $3.5M (at $725k per week, see section 4.4). Compared to the savings achieved by switching to ground courier only (less than $1.3M total), it does not make sense to implement this distribution strategy.

If the decay cost of the Tc-based products are not included in the analysis (the customers are asked to absorb it), the total cost of decay drops to approximately $600k (39 weeks x $121k per week x 12.6%) and it becomes economically advantageous to pursue this distribution alternative. Average savings of 33% could be achieved for the three regions.

5.2 Shipping All Commercial Airline Orders by Chartered Aircraft

Shipping orders that were originally transported via commercial airline by chartered aircraft represents a situation where there is limited same-day service and extensive chartered aircraft coverage. Because it is assumed there would be no change in the transportation lead time, decay costs are not considered a factor. Table 5.4 presents the modified order data for this scenario (values were rounded to conceal the true per-unit costs). The updated transportation costs are presented in Table 5.5 (these are the accurate values based on the true order and unit costs). The analysis assumes that the unit costs presented in Chapter 3 would remain the same, which is not necessarily true considering the increased usage.

Table 5.4 Order data for shipping all commercial airline orders by chartered aircraft

Region:	Dallas	Los Angeles	Orlando	Units
Ground Courier (linehaul)				
Total weight of orders	19500	4200	13000	lbs
Quantity of orders	900	300	750	
Quantity of linehauls	39	39	39	
Quantity of deliveries	300	150	200	
FedEx Express				
Total weight of orders	6100	22000	6000	lbs
Quantity of orders	700	1300	350	
Commercial Airline				
Total weight of orders	0	0	0	lbs
Quantity of orders	0	0	0	
Quantity of flights	0	0	0	
Quantity of packages	0	0	0	
Quantity of deliveries	0	0	0	
Chartered Aircraft				
Total weight of orders	96000	125000	168000	lbs
Quantity of orders	4800	5000	8000	
Quantity of flights	200	200	200	
Quantity of deliveries	1000	1300	2400	
Total weight of all orders	121600	151200	187000	
Total orders	6400	6600	9100	

Table 5.5 Costs of shipping all commercial airline orders by chartered aircraft

Region:	Dallas	Los Angeles	Orlando
Ground Courier (linehaul)			
Weight	$ 1,892	$ 5,268	$ 1,218
Delivery to radiopharmacies	$ 22,680	$ 13,005	$ 27,285
Subtotal	$ 24,572	$ 18,273	$ 28,503
Per order	$ 27	$ 60	$ 38
FedEx Express			
Packages	$ 25,064	$ 49,191	$ 13,392
Weight	$ 4,673	$ 19,863	$ 4,884
Subtotal	$ 29,737	$ 69,054	$ 18,276
Per order	$ 44	$ 53	$ 52
Commercial Airline			
Delivery to origin airport	$ -	$ -	$ -
Packages	$ -	$ -	$ -
Weight	$ -	$ -	$ -
Delivery to radiopharmacies	$ -	$ -	$ -
Subtotal	$ -	$ -	$ -
Per order	N.A.	N.A.	N.A.
Chartered Aircraft			
Delivery to origin airport	$ 12,028	$ 12,152	$ 14,384
Weight	$ 338,785	$ 433,453	$ 483,598
Charters	$ 369,146	$ 372,952	$ 441,453
Delivery to radiopharmacies	$ 81,012	$ 110,925	$ 202,555
Subtotal (weight basis)	$ 431,825	$ 556,530	$ 700,537
Subtotal (charter basis)	$ 462,186	$ 496,029	$ 658,392
Per order (weight basis)	$ 89	$ 111	$ 88
Per order (charter basis)	$ 96	$ 99	$ 83
Total (weight basis)	$ 486,134	$ 643,857	$ 747,316
Total (charter basis)	$ 516,495	$ 583,356	$ 705,171
Per order (weight basis)	$ 76	$ 97	$ 83
Per order (charter basis)	$ 80	$ 88	$ 78

The transportation cost savings of this alternative compared to the base scenario are presented in Table 5.6. Though they are not as substantial as the scenario involving ground courier service only (where savings ranging from $47 to $78 per order were calculated), the savings would amount to a significant amount when considering all regions and a period of a year. Further savings could potentially be negotiated with the charter service due to increased usage.

Table 5.6 Savings compared to the base scenario

Region:	Dallas	Los Angeles	Orlando
Total (weight basis)	$ 93,817	$ 49,208	$ 25,914
Total (charter basis)	$ 125,376	$ 84,817	$ 8,861
Per order (weight basis)	$ 15	$ 7	$ 3
Per order (charter basis)	$ 19	$ 13	$ 1

A large part of the cost reduction can be attributed to the increase in flight loading. For the Dallas region, the quantity of orders per flight increased from 17 to 25 (47% more). The Los Angeles region saw its quantity of orders per flight jump from 19 to 26 (37% more). The Orlando region actually saw its quantity of orders per flight drop from 38 to 34 (the increase in the number of flights from 5 per week to 6 per week was not compensated by a proportional increase in orders). Additional savings were achieved by assuming that a single delivery per day would be required to supply the radiopharmacies.

5.3 Shipping All Orders by FedEx Express

Shipping all orders by the FedEx Express alternative represents a similar distribution system to that of Bristol-Myers Squibb (BMS), one of THC's major competitors (Tyco 2006). The modified order data for this scenario are presented in Table 5.7 (values were rounded to conceal the true per-unit costs). The resulting transportation costs are presented in Table 5.8 (these are the accurate values based on the true order and unit costs).

Table 5.7 Order data for shipping all orders by FedEx Express

Region:	Dallas	Los Angeles	Orlando	Units
Ground Courier (linehaul)				
Total weight of orders	0	0	0	lbs
Quantity of orders	0	0	0	
Quantity of linehauls	0	0	0	
Quantity of deliveries	0	0	0	
FedEx Express				
Total weight of orders	122000	150000	190000	lbs
Quantity of orders	6400	6600	9000	
Commercial Airline				
Total weight of orders	0	0	0	lbs
Quantity of orders	0	0	0	
Quantity of flights	0	0	0	
Quantity of packages	0	0	0	
Quantity of deliveries	0	0	0	
Chartered Aircraft				
Total weight of orders	0	0	0	lbs
Quantity of orders	0	0	0	
Quantity of flights	0	0	0	
Quantity of deliveries	0	0	0	
Total weight of all orders	122000	150000	190000	
Total orders	6400	6600	9000	

Table 5.8 Costs of shipping all orders by FedEx Express

Region:	Dallas	Los Angeles	Orlando
Ground Courier (linehaul)			
Weight	$ -	$ -	$ -
Delivery to radiopharmacies	$ -	$ -	$ -
Subtotal	$ -	$ -	$ -
Per order	N.A.	N.A.	N.A.
FedEx Express			
Packages	$ 236,455	$ 250,523	$ 344,501
Weight	$ 92,684	$ 134,937	$ 160,566
Subtotal	$ 329,139	$ 385,460	$ 505,067
Per order	$ 51	$ 58	$ 56
Commercial Airline			
Delivery to origin airport	$ -	$ -	$ -
Packages	$ -	$ -	$ -
Weight	$ -	$ -	$ -
Delivery to radiopharmacies	$ -	$ -	$ -
Subtotal	$ -	$ -	$ -
Per order	N.A.	N.A.	N.A.
Chartered Aircraft			
Delivery to origin airport	$ -	$ -	$ -
Weight	$ -	$ -	$ -
Charters	$ -	$ -	$ -
Delivery to radiopharmacies	$ -	$ -	$ -
Subtotal (weight basis)	$ -	$ -	$ -
Subtotal (charter basis)	$ -	$ -	$ -
Per order (weight basis)	N.A.	N.A.	N.A.
Per order (charter basis)	N.A.	N.A.	N.A.
Total (weight basis)	$ 329,139	$ 385,460	$ 505,067
Total (charter basis)	$ 329,139	$ 385,460	$ 505,067
Per order (weight basis)	$ 51	$ 58	$ 56
Per order (charter basis)	$ 51	$ 58	$ 56

The cost savings of this scenario compared to the base case are presented in Table 5.9. Switching to the same distribution system as BMS and foregoing same-day delivery service would reduce the transportation costs by approximately 40% when not factoring in decay. As with the all-ground-courier scenario, switching to FedEx Express only would save about $800k which is not sufficient to cover the expected $3.5M cost of decay. If the decay costs of the Tc-based products are not included in the analysis, average savings of 10% could be achieved for the three regions.

Table 5.9 Savings compared to the base scenario

Region:	Dallas	Los Angeles	Orlando
Total (weight basis)	$ 250,812	$ 307,605	$ 268,163
Total (charter basis)	$ 312,732	$ 282,712	$ 208,966
Per order (weight basis)	$ 39	$ 46	$ 30
Per order (charter basis)	$ 49	$ 43	$ 23

5.4 Same-Day Service Constraint

The problem with these three distribution alternatives is that they do not consider THC's policy of providing same-day service for Demand orders. In the first case, a ground mode is too slow to be able to serve a country-wide range on short notice (with less than 16 hours lead time). In the second case, it may be possible to delay the chartered flights (this is discussed in section 6.3). However, a trade-off is required between costs and how long THC is willing to wait for last minute orders; the later a chartered flight leaves St. Louis, the fewer cities it can serve and the more flights are needed. Finally, shipping by FedEx Express necessarily implies that the package will arrive the next day.

In reality, the distribution system would be greatly simplified if same-day service was not provided since multiple last-minute daily deliveries to radiopharmacies could be eliminated. Therefore, the purpose of studying these distribution alternatives is to provide an idea of the savings that could be achieved and to potentially serve as motivation for change (or not to change). Comparing the results provides an estimate of the opportunity costs of transportation to offer same-day service. The next chapter discusses strategies to reduce distribution costs based on the findings of the analyses.

6 Discussion

From Table 2.1 it can be seen that not all product families of nuclear medicine are highly perishable and required same day or next day delivery to remain usable. For the sake of this discussion, the product families will be categorized as either Short Fulfillment Lead Times (SFLT) or Long Fulfillment Lead Times (LFLT) items. The SFLT products are those based on I-123, Tc and Tl. The medicines based on iodine-123 have a high decay rate, 5.12% per hour and a high raw material cost, $5.00 per mCi. These characteristics are reflected in their relatively short shelf life (less than 2 days). They require expedited service for timely delivery to the end client. The products based on technetium are considered SFLT items because of their high level of radioactivity. In absolute terms, they lose a significant and thus expensive amount of radioactivity in a short period of time Of the approximate $725,000 weekly cost to extend all product life by a day, 83% of the total is for Tc-based products (see section 4.4). Finally, thallium-based products are considered SFLT because of their high sales volume and the limited production capacity. Longer transportation lead times would require higher initial activities which would further limit production capacity.

The LFLT products are based on chromium, gallium, indium, iodine-131, phosphate and xenon. Because they have a more limited sales volumes and shelf-lives ranging from 7 to 84 days (see Table 2.1), they are considered to have longer fulfillment lead times than their SFLT counterparts. Next day delivery service is an imperative only if customer service is considered a constraint.

6.1 Products with Short Fulfillment Lead Times

Providing next day service for the SFLT products appears to be the most viable option given the aforementioned constraints. What is interesting to investigate further regarding these medicines is the range of the radiopharmacies supplied exclusively via ground courier. In the case of the thallium-based products, completed orders begin to arrive at the Distribution department by 1:30 AM and are required at the radiopharmacy by 2:00 AM the next day. Theoretically, this leaves a 24.5-hour window for transportation. These timings are presented in Figure 6.1 with those of the commercial flights normally used to supply the THC radiopharmacy in North Attleboro, MA.

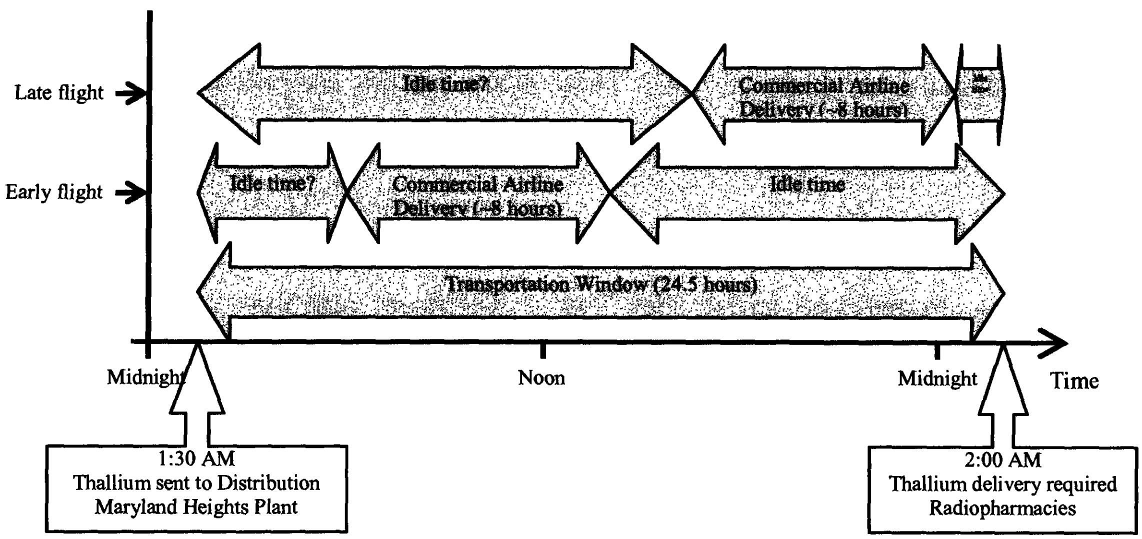

Figure 6.1 Diagram of the transportation timings for thallium-based products leaving the MH plant and going to the THC radiopharmacy in North Attleboro

The situation shown in Figure 6.1 highlights the speed of delivery of the commercial airline alternative, but also shows that the products spend significant idle time (approximately 67%) decaying, to no ones advantage. Considering that this specific radiopharmacy is located approximately 1000 miles away (Google® Maps quotes a road distance of 1200 miles and approximately 21.25 hours of travel), it may be possible to provide daily delivery service using a ground courier.

THC currently limits the radiopharmacies that are exclusively served by ground courier to those within a 500-mile range from the Maryland Heights plant. It is recommended that THC investigate extending this range to 750 miles and possibly 1000 miles. Figure 6.2 shows the coverage area for various ranges from the originating location.

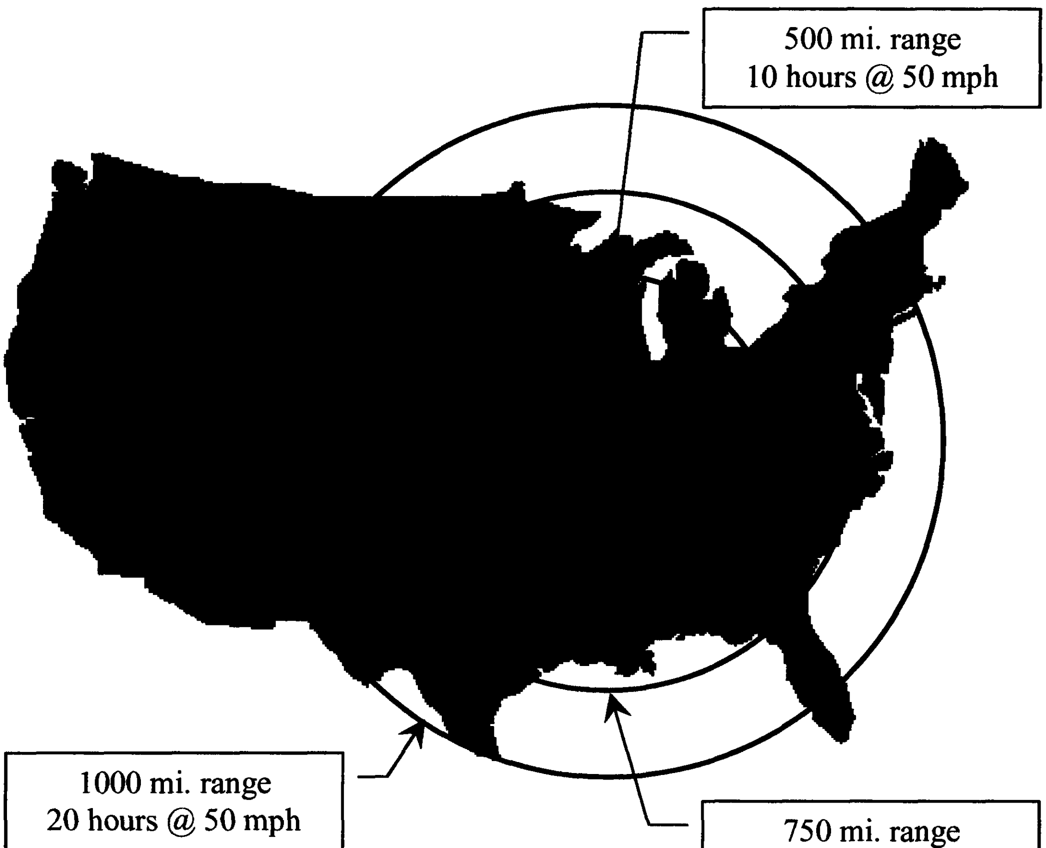

Figure 6.2 Coverage areas for various ranges from the St. Louis, MO area

The idea is to use a linehaul ground service to transport the orders to the dispatch centers of the ground couriers that currently provide the local delivery service (the linehaul would not be for each radiopharmacy). Of course, not all regions are conducive to this arrangement. Many of them are located beyond the 1000-mile range and would still need to be serviced by air-mode alternatives (FedEx Express, commercial airline or chartered aircraft). Other issues including whether daily ground transportation service is available or not and rules for driver hour of service would still need to be resolved. The production schedule of the other SFLT products would also have to be adjusted to suit the transport departure times. Furthermore, to respond to same day Demand orders, a late-afternoon flight on a commercial airline could be used.

From the analysis presented in Chapter 5, it is estimated that approximately $50 per order could be saved when shipping to Dallas, TX (650 miles, 11.5 hours away (Google® Maps)). Likewise, it is estimated that approximately $40 per order could be saved when shipping to Orlando, FL (1000 miles, 19.5 hours away (Google® Maps)). These estimates include an allowance of approximately $10-28 dollars for the Demand orders.

6.2 Products with Long Fulfillment Lead Times

For LFLT products, using a combination of optimized inventory levels, demand forecasting from the radiopharmacies and an increased initial radioactivity of the medicines, it may be possible for the radiopharmacies to only require replenishment via the weekly ground courier delivery.

Increasing the initial radioactivity of the LFLT products may be another strategy to reduce THC's transportation costs especially for those product families with a shorter shelf-life, i.e., those based on gallium and indium. For example, consider the gallium citrate injection with a nominal radioactivity of 13.2 mCi. Increasing the shelf life by 4 days incurs a cost of $18.37 per injection (considering an initial radioactivity of 55.0 mCi, a decay rate of 0.88% and a raw material cost of $0.25/mCi). Therefore, for a cost differential of approximately $100 per package between shipping via commercial airline or ground courier, an order would have to be larger than 5 injections for the commercial airline alternative to be more economical.

Another option to reduce transportation costs of the LFLT nuclear medicines would be to use THC's own radiopharmacies as regional distribution centers. This way, Demand orders could be fulfilled not by expensive air freight from the Maryland Heights plant, but by using the quick and relatively inexpensive in-house delivery service of THC's radiopharmacies (note that some of the Demand orders for SFLT products could also be fulfilled in this manner).

Convincing THC's customers to optimize their inventory levels and improve their forecasts is probably not an easy task considering they have little to gain from it. These objectives could also be performed by THC if the radiopharmacies were willing to share sales data. This may be difficult to achieve as well considering the customer is often also the competitor. Convincing THC's own radiopharmacies would probably by an easier task. This change would be especially beneficial if the radiopharmacies were used as regional distribution centers since it would then become possible to aggregate demand for an entire region. This would make forecasting more accurate, resulting in lower safety stock levels and thus lower inventory costs.

6.3 Optimal Use of Chartered Aircrafts

Compared to the commercial airline alternative, chartered flights have the advantage of a flexible schedule that can be adjusted by THC. An analysis could be made to determine the optimal departure times. On one hand, it appears advantageous to delay the flights as much as possible to increase the probability of placing late Demand orders on them. On the other hand, if the flights left earlier, the delivery range for the ground couriers could be extended.

For example, a single charter may be able to serve both the San Francisco and Los Angeles regions if it landed early enough and somewhere in between; San Diego is approximately a 7 to 9 hour drive away from San Jose. Holding delivery costs to the radiopharmacies constant, the daily savings would be approximately \$1900, the cost of a chartered flight. The cost of shipping an order by commercial airline to the Los Angeles region is approximately \$57 (see Table 4.6), not including the radiopharmacy delivery fee. Therefore, as long as there are fewer than 34 Demand orders (\$1900/\$57) that can be included in a later departure flight, it is advantageous to have the charter leave sooner. While these calculations provide an estimate of the potential daily savings for a single region, other factors have to be considered, including whether the aircraft would have enough capacity for all the orders.

6.4 Radiopharmacy Deliveries

The fee to deliver orders from a region's gateway to a radiopharmacy is a significant contributor to the total cost of transportation (see Table 4.6). Though the cost data did not clearly reflect this fact, one can intuitively surmise it is best to maximize the order-to-delivery ratio. Unfortunately, the quantity of orders is not something easily controllable by a Distribution department. However, in THC's case, the quantity of deliveries is something that can potentially be adjusted.

It is recommended THC investigate the possibility of limiting the amount of deliveries to once per day per radiopharmacy. For all but expedited delivery cases, the ground courier could be asked to hold orders until they have all been received for the day (i.e., after the arrival of the last flight in). For example, in the case of the THC radiopharmacy in North Attleboro, it receives orders from commercial airline flights in the afternoon and in late night (around 12:30 AM). Savings could be achieved if the orders were only delivery once, when the late shipment arrives.

Of course, this would only be feasible if the nuclear medicine was only required by the radiopharmacy in the early AM.

7 Conclusion

7.1 Constraints

Of the many constraints Tyco Healthcare faces when choosing transportation alternatives for the distribution of its nuclear medicine, five stand out as most critical: product decay must be minimized; an alternative must be available to provide same-day order fulfillment; orders must be delivered early, typically before 3:00 AM; hazardous good restrictions (i.e., the Transportation Index) limit the quantity of orders that can be placed on a commercial flight and; total costs must be minimized.

Products based on the iodine 123, technetium and thallium isotopes require delivery within approximately one day of manufacturing to minimize costly decay. Products based on the chromium, gallium, indium, iodine 131, phosphate and xenon isotopes are less time sensitive and may be delivered within a few days of manufacturing, some within a few weeks. However, THC's customers typically prefer to receive the freshest possible product because it allows them to extract more doses from a unit.

THC's customers (radiopharmacies), need their orders in the early AM in order to meet their delivery requirements to their customers (hospitals, clinics, ...).

7.2 Transportation Costs

An analysis of the transportation costs from the manufacturing plant in MH to the Dallas, Los Angeles and Orlando regions showed that the ranking of the transportation alternatives by cost was dependent on the region served. For the Dallas region, the order (from least to most expensive) was: ground courier, FedEx Express, commercial airline and chartered aircraft. Comparatively, when shipping to the Los Angeles region, FedEx Express is less expensive than ground courier due to the relative high per-pound charge of the latter alternative (hypothetically $1.35/lb compared to $0.10/lb for all other regions - true costs have been masked). For the Orlando region, the chartered aircraft alternative is less expensive than the commercial airline, on average, by approximately $60 per order. This difference is due to the loading factor of the airplane. Since the charter service provider charges on a per-flight basis regardless of loading, it becomes advantageous to use this alternative when shipping approximately more than 38 orders per day to a given region.

The cost analysis also confirmed the benefit of consolidating orders when shipping by commercial airline. This practice should be maximized to the extent allowable by regulations.

7.3 Distribution Alternatives

When analyzing the possibility of using the ground courier or FedEx Express alternatives to ship all goods, it was found that the additional raw radioactive material costs incurred to compensate for even a single day of decay (approximately $38M per year in additional raw material) far outweighed the savings associated with these scenarios. However, if THC were to follow Bristol-Myers Squibb's policy of not compensating for the extra day of decay of the Tc-based products, saving of approximately 33% or 10%, respectively, could be achieved. Studying a scenario involving the shifting of all commercial airline service to chartered aircraft service revealed that significant savings could be achieved (up to $19 per order for the Dallas region) due to the increased loading of the chartered aircrafts. The caveat with these strategies is that they curtail same-day order fulfillment in some, if not all, regions.

7.4 Recommendations

Under the current manufacturing schedule, there exists a relatively long delay (in terms of perishable goods) between the time a product is ready for distribution and the time an order is needed at a customer's facility. In the case of Tl-based products, this window is up to 24.5 hours long. It is recommended that the possibility of extending the range of pharmacies served by a ground courier service from 500 to 750 miles or even 1000 miles be further investigated. The savings are estimated to be in the order of $50 per order to the Dallas region and $40 per order to the Orlando region even if the cost of using the commercial airline alternative to fulfill same-day order requests is factored in.

Shifting the production of the I-123, Tc and Tl-based products to a few hours earlier, thus increasing the time available for distribution, would further support the usage of ground transportation. A trade-off analysis would have to be made to compare the cost of decay and the increase in range of the ground courier alternative.

Products based on Cr, Ga, In, I-131, P and Xe have a lower sales volume and a longer shelf-life (ranging from 7 to 85 days) than those based on I-123, Tc and Tl. Using optimized inventory levels, demand forecasting from the radiopharmacies and minimal increase in initial radioactivity of the medicines, it could be possible for the radiopharmacies to only require replenishment via a weekly ground courier delivery. Optionally, to further reduce transportation costs of these products, it is recommended THC investigate using its own radiopharmacies as regional distribution centers. Demand orders could then be fulfilled not by expensive air freight from the Maryland Heights plant, but by using the quick and relatively inexpensive in-house delivery service of the radiopharmacies. This option has the added advantage of aggregating demand for the entire region, thus improving the forecast accuracy which results in lower safety stock levels and lower inventory costs.

Under a weekly delivery system, inventory levels would only have to be checked once per week (periodic review). The "order up-to" inventory level would be calculated using the Base Stock model. The costs for such a policy would have to be compared to a policy where the longer shelf-life products are shipped with the shorter shelf-life products, i.e., more frequently. It may turn out that conducting a daily check of inventory (continuous review) with its associated economic order quantity and lower safety stock levels may be less expensive particularly if decay costs are taken into consideration.

Determining an appropriate inventory policy (continuous review vs. weekly shipments) would have to be made by region and should consider all transportation alternatives available. For example, if a region is served by chartered flights, the cost of adding packages to shipments is minimal compared to a region only served by commercial airline. In this case, continuous inventory review would probably be advantageous.

Chartered flights have the added advantage of an adjustable schedule. It is recommended that the departure time of each route be attentively studied. Within the constraints of this transportation alternative, there exists a time that maximizes the savings associated with having a flight leave later or earlier. Delaying has the advantage of increasing the probability of placing same-day orders on the flight whereas having a flight leave earlier allows for a larger region to be served by the ground courier that delivers orders from the gateway airport to the radiopharmacies.

Another possible cost saving measure would be to limit the deliveries to radiopharmacies to one per day (currently, multiple deliveries per day to a given radiopharmacy are a common occurrence). For all but expedited delivery cases, the ground courier contracted to provide the service could be asked to hold orders until they have all been received for the day (i.e., after the arrival of the last flight in).

Finally, as a last cost saving consideration, it is recommended THC investigate shifting the Thursday production to Friday. Currently, the Maryland Heights plant shuts down production every Friday. The Thursday production is shipped, by ground courier/linehaul, on Friday for Sunday delivery to most radiopharmacies since there is little demand for Saturday deliveries. If the plant shut down on Thursday, produced on Friday and shipped via the regular distribution network on Saturday, it would be possible to save on the decay costs incurred when shipping over two days.

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