Choosing Transportation Alternatives for Highly Perishable Goods: A Study of Nuclear Medicine

By Xiaowen Yang MLOG 2006

Introduction

Transportation requirements for perishable goods are stringent: the more perishable the goods, the more stringent the requirements. Fixed-lifetime products decay at a fixed rate, and when this rate is rapid, the choice of transportation becomes a primary consideration. Such is the case with nuclear medicines, radioactive isotopes used in the diagnosis and treatment of disease. High-speed delivery and minimization of transportation costs are considered the best transportation criteria. But should minimization of transportation cost alone be determinative or should total product cost be considered. For nuclear medicines the total cost is the cost of transportation and the cost of decay. The cost of decay largely depends on the hourly decay rate of medicine because the greater the radioactivity required at time of use, the more expensive to produce. And since radioactivity decays over time, the longer it takes to deliver the product, the greater the initial radioactivity must be. These are the considerations we study here with respect to the unique property of nuclear medicine, its rapid rate of decay.

The thesis researches the transportation alternatives used by Tyco Healthcare, Inc., one of four producers of radioactive pharmaceuticals in the United States. How to transport nuclear medicine? The findings of this research are threefold. First, it serves to develop a deeper understanding of the transport of nuclear medicine. Second, it serves to analyze whether current decision making processes can be adjusted to better reflect the total cost. Third, it recommends alternative criteria for making transportation decisions about nuclear medicine.

Nuclear medicine and its transportation alternatives

Nuclear medicine is widely used in diagnostic and therapeutic treatment throughout the world. Nuclear medicine is unique in two ways: it is hazardous, and it quickly decays. It
is hazardous, thus its transportation is subject to strict regulations by the US Department of Transportation, the US Environmental Protection Agency, the Occupational Safety and Health Administration and other state agencies. All carriers involved in the transportation process are trained in the safe handling of these materials from radiological and ergonomic standpoints. Nuclear medicine decays quickly and at a regular rate. The medicine studied here has diverse expiration dates based on different decay rates. As soon as medicine is manufactured, its radioactive decay begins. The radioactive decay is closely related to production costs. To guarantee that pharmacies receive medicine with a certain radioactivity levels, a tradeoff between transportation costs and decay costs has to be made. Manufacturers can either produce medicine with higher radioactivity levels or use quicker delivery alternatives.

Suppose that radioactivity is 100% at time of production. If hourly decay rate is 1%, then 48 hours later, the radioactivity will be 65%. But with 5% decay rate, it will be just 8%.

![Decay Rate Indicator](image1.png)

![Decay Cost Indicator](image2.png)

**Figure 1: Hourly Decay Rate and Decay Cost Analysis**

Four alternatives used in the transport of nuclear medicine are charter airlines, commercial airlines, ground couriers and FedEx Express. Out of four available alternatives, commercial airline carriers set a very strict limit on the transport index of a radioactive material to stipulate the maximum radioactivity each flight can carry. Ground courier service is used widely as local pickup and delivery service on weekdays and long haul services on weekends. Charter airline services offer flexible service: late pickups, early
arrival, and around the clock service. They also can transport larger-than-normal quantities of nuclear medicine. However, once charter airline service is used, there is a large fixed cost related to the charter usage. Comparing four alternatives available to the Tyco Healthcare, Inc. indicates that decision is a complex one because many tradeoffs are involved. The comparison is shown in below Figure 2.

<table>
<thead>
<tr>
<th>Cost Drivers</th>
<th>Fixed Cost</th>
<th>Fixed Cost per shipment</th>
<th>Fixed Cost per Lb</th>
<th>Origin Delivery Cost</th>
<th>Destination Pickup and Delivery Cost</th>
<th>Capacity Constraints</th>
<th>TI Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charter Airline</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Commercial Airline</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>FedEx Express</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Ground Courier</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

**Figure 2: Cost Drivers and Constraints of Four Alternatives**

Besides different cost drivers and capacity constraints, timing is another constraint. Customers require receiving the goods by a certain time, usually by 2 in the morning, adding the complexity to the selection process.

**Order profiling added complexity to the decision-making**

It is the current practice of manufacturers of nuclear medicine to produce and transport medicine on a daily basis. As a result, shipment volumes for most orders are rather small: the weight for 99.88% orders is less than 70lbs.

Orders are divided into two groups: standing orders and demand orders. Standing orders are orders placed by pharmacies far in advance, usually weeks or months in advance. Demand orders are placed with short notice; usually the next day delivery. Standing orders and demand orders exhibit different characteristics in quantity of order, specific stock keeping units (SKUs), and related weight of orders. Out of a total of 182770 orders shipped out by the Tyco Healthcare, Inc. within the nine month time period, 55% is demand orders and 45% is standing orders. By weight, 73% is standing orders and 27% demand orders. Standing orders are relatively stable on each day of the week (i.e. Monday has the same volume, Tuesday has the same volume, etc.), however, demand orders are quite volatile.
Tyco Healthcare, Inc. services a diverse group of customers. According to order frequency, all customers are divided into high frequency, medium frequency and low frequency users groups. High frequency users placed more than 22 orders per month; medium frequency customers placed 1 to 5 orders per week; and low frequency group placed one or none order per month. Clearly, focusing efforts on medium-to-high frequency users enables us to analyze the transportation alternative selection process in a more efficient way.

Tyco Healthcare, Inc. divides all “ship-to-city” destinations into two groups: cities within a radius of 500 miles and cities beyond 500 miles. For the first group, ground courier is the primary transport alternative on weekdays. For the 2nd group, ground courier is only used for weekend long haul delivery.

All pharmacies of Tyco Healthcare, Inc. are further divided into self-owned pharmacies and non-self-owned pharmacies. Self-owned pharmacies placed 63,313 orders; with the demand order to standing order ratio is 2 to 1. Compared to 1.2 to 1 ratio for regular pharmacies, self-owned pharmacies ordered a much higher demand orders.

When nuclear medicine is received by pharmacies, it is first assayed to determine its remaining radioactivity level. The expiration date, post calibration, varies from 24 hours to 2 months. For items that have a long expiration date, pharmacies will keep a certain level of inventory. For items with a rather short expiration date post calibration (i.e., I-123 expires 24 hours after calibration), pharmacies order from Tyco Healthcare Inc. only at the time of need.

**Current Alternative Selections**

There were 187220 orders shipped from Oct. 2004 to June 2005, with 45% of the total orders shipped by charter airline, 21% by commercial airline, 12% by FedEx and 25% by ground courier. If the orders are further broken down into standing orders and demand
orders, charter airline service carries 44% demand orders and 38% standing orders. Ground courier service carries a higher percentage of standing orders than demand orders (see Figure 3).

By weight, 63% of total orders were shipped by charter airline, 32% by commercial airline, 1% by FedEx and 4% by ground courier. If the orders are further broken down into standing order and demand orders, charter airline service carries 76% demand orders and 59% standing orders. Ground couriers carry 10% of demand orders and approximately 3% of standing orders.

Clearly, Charter airline service is the primary alternative used by Tyco Healthcare, Inc. It is also worth mentioning that ground courier service is widely used for origin airport delivery and destination airport pickup and delivery service. Next, we will look at analyze
whether current alternative selection is optimal or not by introducing an optimization model.

**Optimization Model and Sensitivity Analysis**

In an effort to optimize transportation alternative selections, mixed integer linear programming is introduced. Assumptions about rate structure and transit time are made and some constraints apply. Shipment data includes a stock keeping unit (hereafter abbreviated as SKU), quantities of each SKU, “ship-to-city” destinations, standard costs, and hourly decay rate. The transport index of radioactive materials for all orders is assumed to be on a radioactivity-scale of 5 or less.

The original database given by Tyco Healthcare, Inc. contains only order-level data. Therefore, basing the optimization analysis on the whole database is difficult. To make the analysis representative, we choose one city located within a radius of 500 miles and one beyond that. We also selection cities that have enough order quantity and utilize all four alternatives in current operations. Based on the above consideration, Orlando and Memphis are chosen and May 2005 is chosen randomly as the analysis basis.

The results show transportation alternative selections under current operations and optimization models are different. Using the optimization model, the total cost reduces by 10% and transportation alternative mix changes a lot. Optimization one focuses on minimizing transportation cost and optimization two focuses on minimizing total cost. For two optimization scenarios, the transportation alternative selections are obviously different, but the total costs are within 1% difference. It is obvious that the decrease of transportation cost is cancelled out by increase of decay cost based on the data selected.

The sensitivity of the model outputs to changes or estimation errors in three particular inputs are conducted. The three particular inputs are delivery deadline,
acceptable radioactivity level and transit time. The results reveal transportation alternative and total costs are rather sensitive to model inputs.

**Recommendations**

Should the transportation alternative decision be made on total costs? Our answer is that it depends. At this stage, Tyco Healthcare, Inc. doesn’t establish a practice that considers tradeoffs between transport costs and decay costs. This thesis shows that a carefully designed policy that considering the above tradeoffs brings down total costs to a certain level.

This thesis also studies the customer order frequency, “ship to city” statistics and customer geographical segmentation. If efforts to improve the alternative selection process can be concentrated on customers who order at a regular basis, in other words, customers that are more valuable to Tyco Healthcare, Inc. cost savings can be achieved in a more effective way.

Whether all nuclear medicine needs to be delivered on a daily basis? Our answer is no. Inventory practice adopted by one representative pharmacy indicates that keeping a certain level of inventory on medicine with a long expiration date and restrict daily delivery practice to medicine with short expiration dates is feasible. The thesis further indicates that certain products are suitable to be shipped via preferred alternatives. For example, charter airline service, which has a fixed outlay for each flight, is more suitable to carry high decay rate and high density goods.

Even if transportation alternatives can’t be changed, shortening transit time can achieve cost reductions. By better coordinating product flows between the manufacturing and shipment departments, the ABC Company can achieve certain level of cost reductions, a practice comparable to JIT management.
The optimization model allows transportation alternative decisions to be made automatically, thus removing the burden from human being. Although the optimization model doesn’t take consolidation shipments into consideration, the consolidation practice applies to the model. By inputting orders to the same “ship to city” destination under one virtual order number, the model can make decision on consolidated shipments.

**Future Research**

This work is by no means complete. Further research should focus on the application of the model presented in this thesis. The SKU level data intensive requirement to develop the detailed model did not permit the application on the whole database, let alone application in the real world setting. The following areas are some thoughts about the model and selection problem:

1. Minimum data requirement to test the model. Order level data for nine months are available to do the general analysis. However, only May 2005 Orlando and May 2005 Memphis data are available to extract SKU level information. A big database is absolutely helpful in evaluating the model.

2. The optimization model can be used to make decision on each order or each shipment level. It only deals with discrete orders. The model can’t make optimal decision if the transportation decisions are highly interdependent. More work should be done in this regard.

3. Validation of assumptions in designing the model. Both the transit time and transportation alternative rate structure are based on our best estimates of actual value. In real world, the assumptions or inputs are more complicated. Therefore, the assumptions should always be updated.

4. The constraints of each alternative should be considered. For example, charter airline has a fixed expenditure no matter how many pieces of goods or how many pounds of goods are shipped. There should be enough orders, packages or weights to justify the usage of charter airline. Another example is the ground courier delivery. As shipments of nuclear medicine tend to be of low volume, carriers need
to consolidate the shipments with shipments from other shippers. The complexity of consolidation process should be considered.