Modeling the Logistics of FedEx International Express

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Abstract

The FedEx international express network ships 11.5 million pounds of packages per day through 15 international hub airports and local airports from which packages are locally collected and distributed. FedEx shipment data and estimation methods based on logistic theory provide for the development of a logistic cost function. To determine the lowest cost operating strategy for FedEx international express, logistic costs are estimated for the current network with and without transhipment points, which consolidate international shipments into fewer hub airports with higher volume. These estimation methods are then applied to a proposed network expansion and the related costs are estimated and compared. The potential to expand the network and increase overall revenue is explored, as the increase in costs is balanced by an increase in revenue. An alternate strategy is explored to reduce cost, including the introduction of a more diversified air fleet and the creation of a hybrid network with modified transshipment points. Through these alternate strategies, further cost savings for FedEx is realized through the use of larger aircraft and well as varying the number of transshipments due to demand between nodes. This study presents a method to estimate logistics costs and presents a repeatable methodology to evaluate the impact of new technologies, larger distribution areas, and innovating shipping schemes on shipping revenues.

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1 Problem Statement

FedEx is the world's largest provider of express shipments, with operations in more than 220 countries and territories (FedEx Annual Report, 2005). The company positioned itself as the leader in express shipping due to pioneering the hub and spoke network for package delivery. FedEx currently has a robust international shipment network, through which packages can be shipped internationally reliably and quickly (The Bureau of Transportation Statistics, 2006). The network used for these shipments, however, excludes portions of the world and favors others, and therefore expansion of international express services is a large part of this study. As FedEx's competitors are also gaining ground on the express shipping industry, it is important for FedEx to continue to expand and develop new markets.

This paper will investigate FedEx's international delivery network and investigate potential systems efficiencies that can be further exploited. To do this, a full discussion of the current logistics system, along with some service area expansion strategies, will be explored. This will be followed by a discussion of proposed system modifications which will be analyzed to determine cost savings potential. Networks that incorporate transshipments, which are intermediate locations visited between air hubs which further consolidate shipments with the same destination, will be explored in comparison to the current network. Finally, we will consider the effect of the upcoming Airbus A380 as well as innovative transshipment strategies on costs.

2 FedEx International Service Regions

2.1 Network Description

FedEx has a current service region which defines the areas eligible for international express shipments. This section will describe that service region, as well as a proposed expanded network.

2.1.1 Current Network Description

A total of 11.5 million lbs/day are delivered through the international express package network (FedEx Annual Report, 2005). FedEx delivers international packages through 15 international hubs (listed below) which are distributed throughout the world.

- Dubai, United Arab Emirates
- Fort Worth, Texas, USA
- Frankfurt, Germany
- Hong Kong, China
- Indianapolis, Indiana, USA
- London, England
- Memphis, Tennessee, USA
- Miami, Florida, USA
- Newark, NJ, USA
- Oakland, CA, USA
- Paris, France
- Seoul, Korea
- Subic Bay, Philippines
- Tokyo, Japan
- Toronto, Ontario

Each international hub resides in an international influence zone. These international zones are non-overlapping and delineate the entire service area served by that international hub. The "status quo," is described as shipping packages directly between international hubs. Two alternate logistic systems are estimated in this paper, one involving one transshipment and two transshipments.

Zero Transshipments

Each international hub ships packages directly to each other international hub under the zero transshipment model.[1] There are three levels in this international network for delivering a package. Each international influence zone (I) is further divided into several local delivery areas, each served by a local airport (II). These local airports have their own local influence zone. These local influence zones are non-overlapping, and together, all local influence zones cover an entire international influence zone. From the local airports, packages are distributed (III) through vehicle tours to the destination.

This model differs to the one and two transshipment models because it delivers packages in the shortest time as all flights are direct. However, the volume on each flight

[1] The clear restriction to the statement that all international hubs ship directly to every international hub is that those hubs within the same country do not ship to one another directly, as those shipments are considered domestic. This is only the case in the United States, where there are multiple international hubs in the same country.

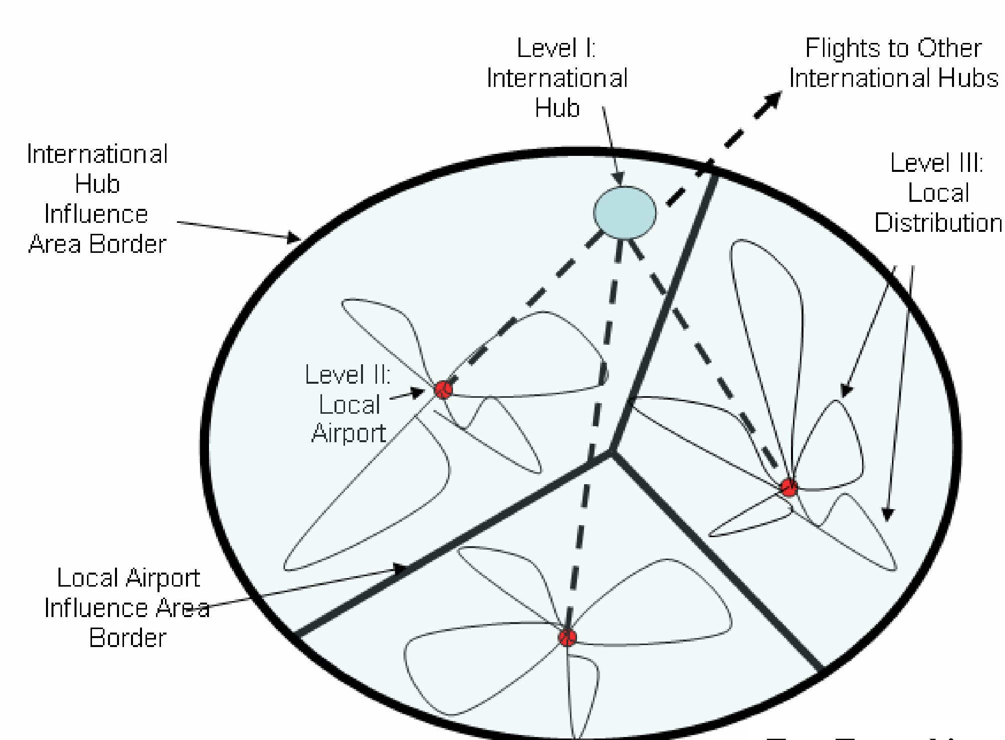
is lower than in other models, which indicates an opportunity to save money through economies of scale.

Two Transshipments

The two transshipment model uses two transshipment points, termed super international hubs (or super hubs), which are chosen at three international hubs. The super hub at Memphis acts as a midway point for all packages originating in North and South America; the super hub at Paris serves Europe and the Middle East; and the super hub in the Philippines serves Asia and Australia. All packages travel from an international hub to the designated super hub, then on to the super hub which serves the destination international hub. From the international hub, local air and vehicle delivery occurs.

Using two transshipments, there are four levels in the international network for delivering a package. Each super international influence zone (I) is further divided into several smaller regional international zones (II). These regional international zones are similar to the international zones described in the zero transshipment model, except that now super international influence zones are comprised of multiple non-overlapping regional international influence zones. It is thought that this model provides benefits from concentrating volume; however, the reduced costs may be outweighed by the extra flights needed for two transshipments.

Zero Transshipments



Two Transshipments

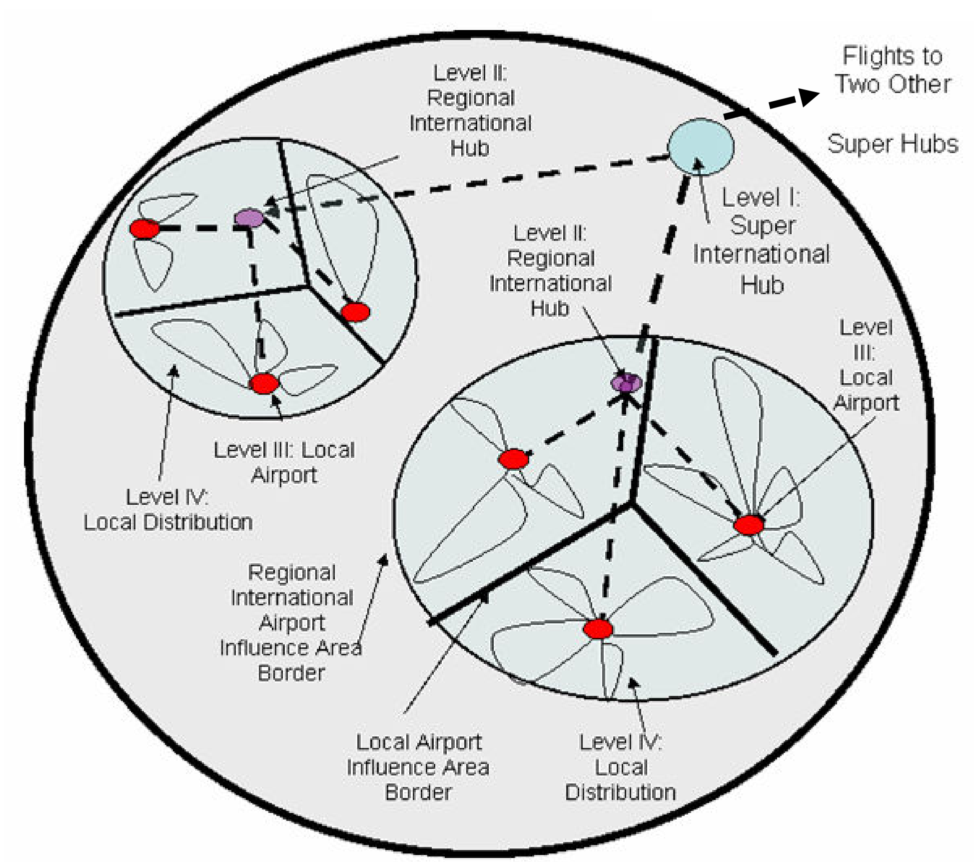


Figure 2.1.1-1. FedEx Network Hierarchy with Zero and Two Transshipments.

One Transshipment

This model adds one transshipment which will occur at the package origin. When a package is sent for international delivery, it will travel from the local airport, to the regional international airport, to the super hub designated for that region. From there, the package is shipped directly to the destination regional international airport. This design adds cost in terms of total distance traveled, but may reduce costs from concentrating volume. However, delivery time is increased as packages wait at the midway points.

2.1.2 Expanded Network

The expanded network model is built to determine if the costs from expanding the network to other areas of service can be outweighed by the revenue. The expanded network proposed in this study includes three regions which are un-served in the current networks. These regions include South America, Africa, and India. In the three areas, one new international hub will be placed, along with corresponding local airports from which local distribution can occur. Memphis will serve Rio De Janeiro, Paris will serve Johannesburg, and Philippines will serve Mumbai. As three new hubs will be placed, the total number of international hubs and zones will then increase from fifteen to eighteen. It is important to note that in moving from the current network to the expanded network, the size and shape of the 15 existing international zones does not change. Each hub is serving the same population that it served in the current network. Using demand estimation described below, we will show that daily volume on this expanded network increases from 11.5 million lbs/day to 14.6 million lbs/day.

Using the increase in package volume per day, as well as the average revenue from a FedEx international package, $14 per package, it can be estimated that the earnings from expanding the network are 12.8 million ($/day). By this measure, FedEx could gain considerably by expanding its network to Africa, South America, and India.

2.1.2 Network Summary

When comparing the transshipment choices, it is clear that many of the component costs are constant across all models, while only selected costs vary. The bulk of the analysis will focus on these changing segments, while the segments that remain constant will receive less attention.

A discrimination strategy to transshipments is introduced as an extension to the three transshipment models discussed. This model is a variation of the one and zero transshipment models, in which super hubs only act as a transshipment point between international hub origin and destination if the volume shipped on that route is below a certain threshold volume. All routes between international hubs that are sufficiently busy deliver directly to the destination international hubs, without transshipments. This model preserves some benefits of the previous model by pooling packages from low-volume routes to take advantage of economies of scale.

2.2 Construction of FedEx Model

To calculate costs, the above models need to be expressed in terms of the appropriate input variables. First, the FedEx service area must be divided into international and local zones.

2.2.1 International zones

Recall that the current network service area includes 15 international airports and the expanded network includes 18 international airports. The distances between two airport hubs will influence the transportation cost in moving packages from origin to destination. In this analysis distance will be measured using the great-circle method; using the latitudes and longitudes of each point, the shortest arc between two points is calculated. Latitude and longitude coordinates of the international FedEx hubs in the model are available online at the Global Airport Database (2006).

2.2.2 Local Zones

The international zones are further divided into local zones. For each international zone, the number of local delivery zones and the distance from local airport to international hub must be determined. Both variables are determined by the land area of the international zone: the total land area determines the distance from local hubs to international hub, and the effective land area, or size of the service area, determines the number of local airports/zones. The number of local airports/zones within an international zone is determined by the size of FedEx's delivery area within the zone. To exclude unpopulated or isolated areas, we assume that FedEx only delivers to urban regions.

To simulate delivery regions scattered throughout an international zone it is assumed that the distance between each international airport and its local airports is equal. If an influence zone were circular with evenly distributed local zones and a central international hub, then the average distance from the international hub to a local zone would be two-thirds of the total radius of the international zone. This average distance is used as the distance traveled from each international hub to its local airports.

It is assumed that the size of a local zone is a square with 90 miles to a side. With this fixed, the number of local zones in an influence area equals the urban size of the area divided by the size of a local zone. The sizes of local zones are fixed and the number of zones is proportional to the service area of an international zone. Since there is no need for FedEx to deliver to unpopulated parts of the world, the service area of an international zone may be much smaller than its land area.

By aggregating the urban areas and urban population in each country within an international zone, we determine the total urban area and urban population (Center for International Earth Science Information Network, 2006). The total urban area is the effective area that FedEx serves, and the total urban population is the effective customer base.

2.2.3 Demand

The demand for shipping packages will vary greatly among international zones according to factors such as customer density and the wealth of those individuals. Customer density is determined similarly to service area; since the FedEx model only serves urban areas, the customers in an influence zone are the urban population of our zone. The total wealth in an influence zone is the product of its urban population and per capita GDP. It is assumed that a nation's shipping demand will scale with its wealth. By comparing the wealth in each international zone, we determine the relative wealth of each zone (World Bank GDP Tables, 2006). The total demand for FedEx international shipping is distributed to each international zone according to its relative wealth. Within an international zone, it is assumed that the demand from local zones is uniform.

In the expanded network, the estimated demand is 14.6 million lbs/day, found by calculating the total wealth of the new international zones. The additional demand from these additional zones is 2.1 million lbs/day.

3 Logistic Cost Function Estimation

The following section will estimate the costs for both the current service network and also the expanded network.

3.1 Terminal Costs

According to Smilowitz (2005), terminal costs include sorting costs and facility charges. The total terminal cost equation is as below.

$$z_{terminal} = z_{sorting} + z_{facilitychanges}$$

3.1.1 Sorting

The cost of sorting packages depends on the number of transshipments in the FedEx international network. Packages must be sorted at each node in the network. To estimate total sorting costs, the costs of sorting a package at each node in the network are determined and then summed together. It is assumed that at each node, each package is sorted based on its next destination in order to route the package to its final destination.

The factors that affect sorting cost at each hub include the volume that is handled at the hub, the complexity of the network, the efficiency of the sorting operations at the hub, and the labor costs in the country in which the hub resides. It is assumed that sorting costs are variable costs, and there are no fixed costs associated with sorting. This is valid because fixed costs are incorporated into the facility costs. As different network structures based on different number of transshipments are introduced, these costs will change because of the increase in volume of the packages that are handled at each international hub.

Volume

The sorting cost at a hub is proportional to the daily volume V, (lb/day) of packages that pass through.

Complexity

Sorting packages into routes takes more time than sorting into few routes and is more expensive. Complexity, C, is a unitless value that scales the sorting cost to reflect the number of routes, N, to which the packages are directed. The complexity of a sort at each hub is measured as the logarithm of the number of possible destinations from the hub. The logarithm is used because sorting costs are concave, as in they increase logarithmically with the number of sorting options. Flow charts of how complexity is measured for all transshipment cases follows.

Efficiency

The efficiency, EF, of a hub measures the number of packages that one worker can sort in an hour (man*hour/lbs). Efficiency is based on how advanced the sorting machinery is at each local airport. It is assumed that the sophistication of the machinery is based upon the number of packages that the hub handles, the GDP of the nation, and the knowledge that a postal worker is able to sort 600,000 packages in a day with advanced machinery (Gonzales, 2006). Therefore, a unit of labor is able to process more pounds of packages at a higher GDP ranked hub. The labor rates for international air hubs are estimated to be “faster” than those at the local airport because it is assumed that there is more advanced machinery at the international hubs and less advanced machinery at the local airports.

Labor Cost

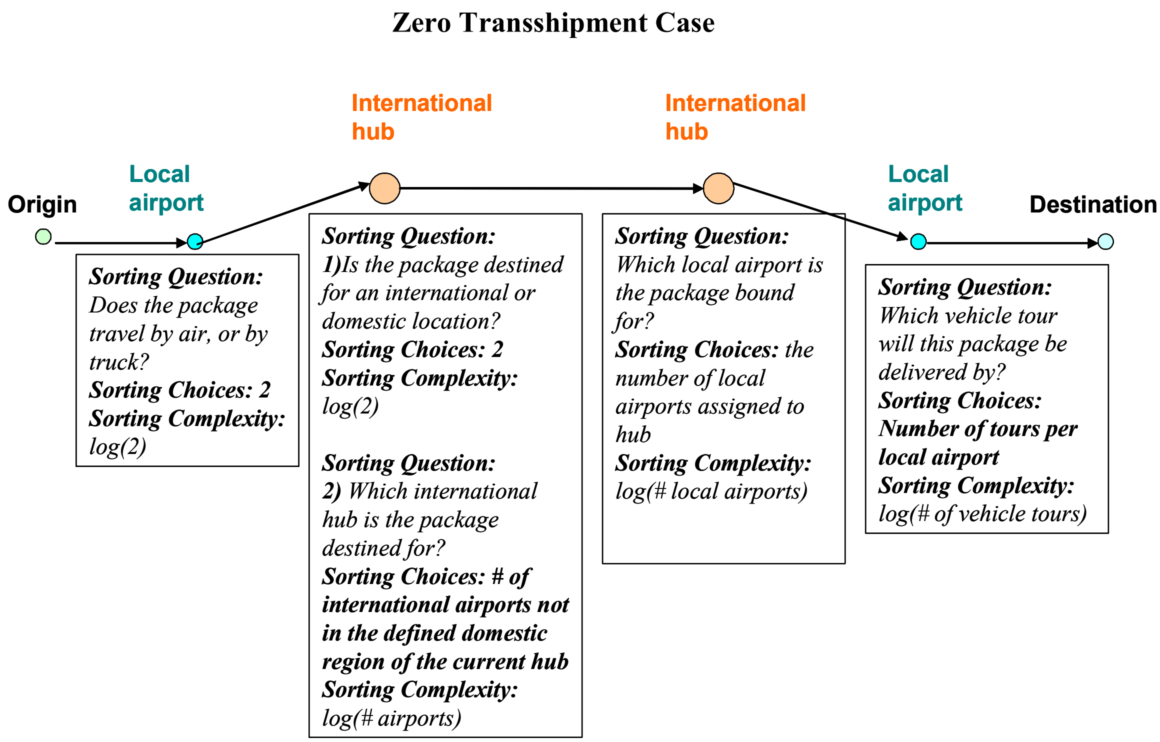
The wage rate ($/man*hour) for workers varies across the international FedEx network. Labor costs were determined as the average wage for each country in which an international hub resides (ILO October Inquiry database, 2006). It was then assumed that each local airport has the same wage rate of the international hub it serves.

Zero Transshipment Case

In the zero transshipment case, a package at an international hub will travel to any of the other eligible international hubs, which are the international hubs outside of the domestic area of the origin hub.

Two Transshipment Case

In the two transshipment case, a package at an international hub will only travel to the super hub, creating a simple sorting process. After arriving at the first super hub, the package can only travel to one of two other super hubs, creating another simple sort. This change does not increase sorting costs, but rather it decreases them. This is because the complexity at the hubs is decreased, as fewer questions are asked and the number of answers is reduced.



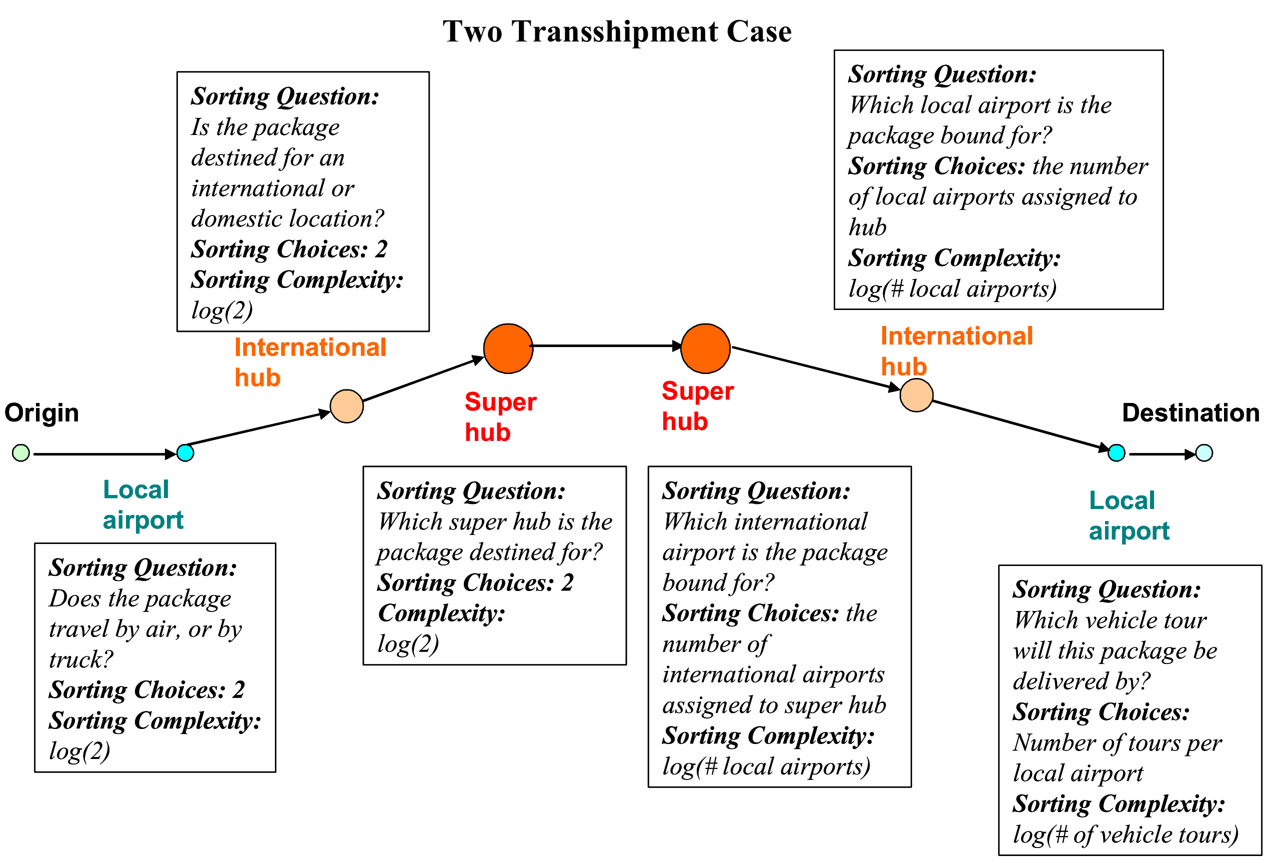


Figure 3.1-1. Sorting steps: Zero Transshipment Case and Two Transshipment Case.

One Transshipment Case

The one transshipment network is similar to the two transshipment network as all outbound packages are received at the designated international hub. However, these packages are then routed directly to the appropriate international airport, which could be a regional international airport or super hub, skipping the transshipment at the destination super hub.

The sorting costs are estimated by summing the total sorting costs for each hub, and then summing the costs for the individual hubs. The following equation finds the total sorting cost across all hubs for each sorting step i:

$$z_{sorting\ i} = \Sigma_i V_i * \log(C_i) * LR_i * EF_i$$

It will be shown that the sorting costs decreased when transshipments were introduced, as the sorting options decreased in complexity and more packages were routed through hubs with advanced machinery. The costs increased overall for the expanded network simply because more packages are sorted.

3.1.2 Facility Charges

The cost of fixed facilities differs between the current level of service and the expanded network, and they will both be described below.

Current Network

The facility charges are written as a function of flow. The cost of fixed facilities, such as terminals and the technology used to run them, was calculated to be $9.702*10^9$ (\$/year) in 2006. This value is scaled by 14.3%, which is the percent of express service which is international, for a total of $5.441*10^6$ (\$/day) for international shipments (FedEx Annual Report, 2005). This value does not change with the number of transshipments.

Expanded Network

To determine this cost, a scaling factor is used on the current network facility charge cost. If all hubs are of equal cost, then each hub for the current network would cost 362,733 (\$/day). However, since the super hubs are larger and have more local airports than the three new regional hubs, it is estimated that the cost of fixed facilities is

200,000 ($/day) for the three new regional hubs. This brings the total facility charges to a total of $6.529*10^6$ ($/day).

3.2 Transportation Costs

Transportation costs account for local distribution of packages from the local airports to the destinations on trucks, the line haul costs, which is the air freight movement between the international hubs and the local airport, and long haul transportation air flights between international hubs.

$$z_{transportation} = z_{localdistribution} + z_{linehauldistribution} + z_{longhaultransportation}$$

The variables used are below in Table 3.2-1.

Variables & Constants	
N	number of hubs
TU	number of tours
δ	the density of the region
A	Area (πxradius²)
V	Total weight handled (lbs) at each hub
r_{bar}	average distance that an international hub sits from its local airports
$P_{B, A, M}$	Number of Aircraft of type B-727 (B), A310 (A), MD-11 (M)
$F_{B, A, M}$	Fixed Cost of Aircraft of type B-727 (B), A310 (A), MD-11 (M)
R_{ij}	Distance between hubs i and j
C_{p1}	$3.4*10^{-5}$ gallons/lb*mile, the fixed cost of fuel consumption for long haul flights
C_{tr}	$1/mile, the cost of operating a truck
C_p	$4*10^{-5}$ gallons/lb*mile, the fixed cost of fuel consumption for line haul flights
C_f	2 $/gallon (cost of fuel)
10,000	Vm (lbs) of local transportation vehicles
5,000	number of packages per local distribution tour

Table 3.2-1. Values for Long Haul Transportation Cost Equation.

3.2.1 Local Distribution

Local costs account for pick up and delivery costs between origins and local airport consolidation terminals (Smilowitz, 2005).

The model of the Vehicle Routing Problem (VRP) is used for this local distribution cost (Daganzo, 2006). The unknown in the local distribution equation is the density of each region. This is determined using the percent of urbanized land, discussed earlier in the study. The total distance of each tour is then determined by multiplying the area with the density and a given constant ($2/(6^{.5})$). However, to consider the assumption that tours are separated based on a geographical basis, the radius in the area equation is divided by the total number of local airports per hub. Because these trips are done two times in one day, a morning drop-off and an afternoon pickup the one way cost are estimated, and the total sum is multiplied two to reflect this. The equations used to estimate the local distribution cost is below.

$$z_{localdistribution} = 2C_{tr}*TU*2*A*(\delta/6)^{.5}$$

3.2.2 Line Haul Transportation

The line haul distribution is calculated based on flights traveling between an international hub and its local airports. These values are easily calculated using the average distance that an international hub sits from its local airports, the number of local airports (N), the volume handled at each local airport, the type of aircraft allocated to each route, the fixed cost of aircraft, and the fuel consumption for each flight.

Flight Allocation

Given the composition of the FedEx air fleet, it is assumed that three representative aircrafts are used to fly between international hubs and their local airports. These three aircraft are the B-727, the A310, and the MD-11, with respective capacities of 40,000, 70,000 and 150,000 lbs. The fixed cost of flying each aircraft from one origin to destination can then be determined. These fixed costs will be added to the overall cost of operating a flight to obtain the total cost of a flight.

Fixed Aircraft Cost

Using known features of operating costs for air freight, fixed costs in the long haul case would represent about two-thirds of the total cost of a flight. Using the fuel price of $2 per gallon, the fuel costs for the maximum flying range of each of the representative aircraft was calculated, which enabled the estimation of the total cost of a flight at maximum range. The fixed cost for a flight is then two times the fuel expenses at maximum range. Because the B-727 is considered a shorter haul aircraft, the fixed cost was three times the fuel expenses at maximum range.

Estimates of the fixed costs to operate the different categories of aircrafts are then obtained. However, the results were adjusted to give more realistic results, especially for the bigger aircrafts (the first approximation was effectively high, and did not reflect that using bigger aircraft allows for economies of scale on the fixed costs). This approach resulted in estimating a B-727 to have a capacity of 40,000 lbs and a fixed cost of 25,000

\$/flight, the A310 to have a capacity of 70,000 lbs and a fixed cost of 45,000 \$/flight, and the MD-11 to have a capacity of 150,000 lbs and a fixed cost of 85,000 \$/flight.

Using the known volume handled at each hub and the demand on each link, the optimal set of aircraft are assigned to each route, which will minimize the fixed costs on each link. For example, for a link with a demand of 128,000 lbs, flying one MD-11 will be more profitable (fixed cost= 85,000 (\$/flight)) than using two A310 (fixed cost= 2*45,000=90,000 (\$/flight)).

Consumption

Each aircraft in the FedEx fleet has a level of fuel consumption, which is the ratio of number of gallons used in flight, per distance traveled and load moved. According to an Air France environmental report (2006, p.22), typical aircraft fuel consumption is 200 grams of fuel per ton-kilometer traveled for medium haul flights (line haul flights in this case), which is equivalent to $4*10^{-5}$ gallons/lb*mile.

The final equation used to estimate the line haul transportation is below.

$$z_{linehauldistribution} = 2*C_p* r_{bar}*N*V + F_B*P_B + F_A*P_A + F_M*P_M$$

3.2.3 Long Haul Transportation Costs

Long haul transportation costs consist of flying packages between the international hubs. It is presumed that there is enough demand for (at least) one flight to connect each hub pairs every day as discussed in the demand section. The approach then involves determining the type, or capacity of the aircraft that connect each of the hubs, based on the demands between the hubs. This method is similar to the line haul estimation, with the only change being that the consumption is estimated at $3.4*10^{-5}$ (gallons/pound*mile). This consumption value changes because line haul flights are typically shorter than the long haul flights, and it is therefore estimated that line haul flights consume more because the take off and descent are the most fuel intensive operations.

We apply then a similar formula as for the line haul transportation cost:

$$Z_{longhauldistribution} = C_f*C_{p1}* R_{ij} *N*V + F_B*P_B + F_A*P_A + F_M*P_M$$

The distance traveled by aircraft will necessarily increase with the introduction of transshipments, because most international shipments no longer fly directly to their destination international airport. A package flying from an origin regional international hub to a destination regional international hub would be shipped only once and directly in the network without transshipments, whereas in the case with two transshipments, the package would travel on a flight between origin hub to origin super hub, a flight between two super hubs, and then another flight between the destination super hub and the destination hub. The long haul transportation costs will therefore be significantly increased. Through the data analysis, the conjecture that the costs will increase with the number of transshipments was confirmed.

4 Logistic Cost Function Results

4.1 Cost Comparison

Below is the full comparison of cost breakdowns for the component costs.

Terminal Cost Comparison		
	Current network ($/day)	Expanded network ($/day)
0 trans	5,609,000	6,728,000
1 trans	5,577,000	6,685,000
2 trans	5,577,000	6,685,000
Sorting Cost Comparison		
	Current network ($/day)	Expanded network ($/day)
0 trans	168,000	199,000
1 trans	136,000	156,000
2 trans	136,000	156,000
Transportation Cost Comparison		
	Current Network ($/day)	Expanded Network ($/day)
0 trans	16,574,000	21,922,000
1 trans	18,390,000	24,367,000
2 trans	21,438,000	28,440,000
Long Haul Cost Comparison		
	Current Network ($/day)	Expanded Network ($/day)
0 trans	13,213,000	17,944,000
1 trans	15,029,000	20,388,000
2 trans	18,077,000	24,461,000

Table 4.1-1. Cost Comparison of Component Costs.

After calculating the cost of each segment of shipping, the total costs of the network can be determined. The final equation is:

$$z_{totalcost} = z_{terminal} + z_{transportation}$$

For both the current network and the expanded network, the model with zero transshipments produces more savings than the models with one or two transshipments.

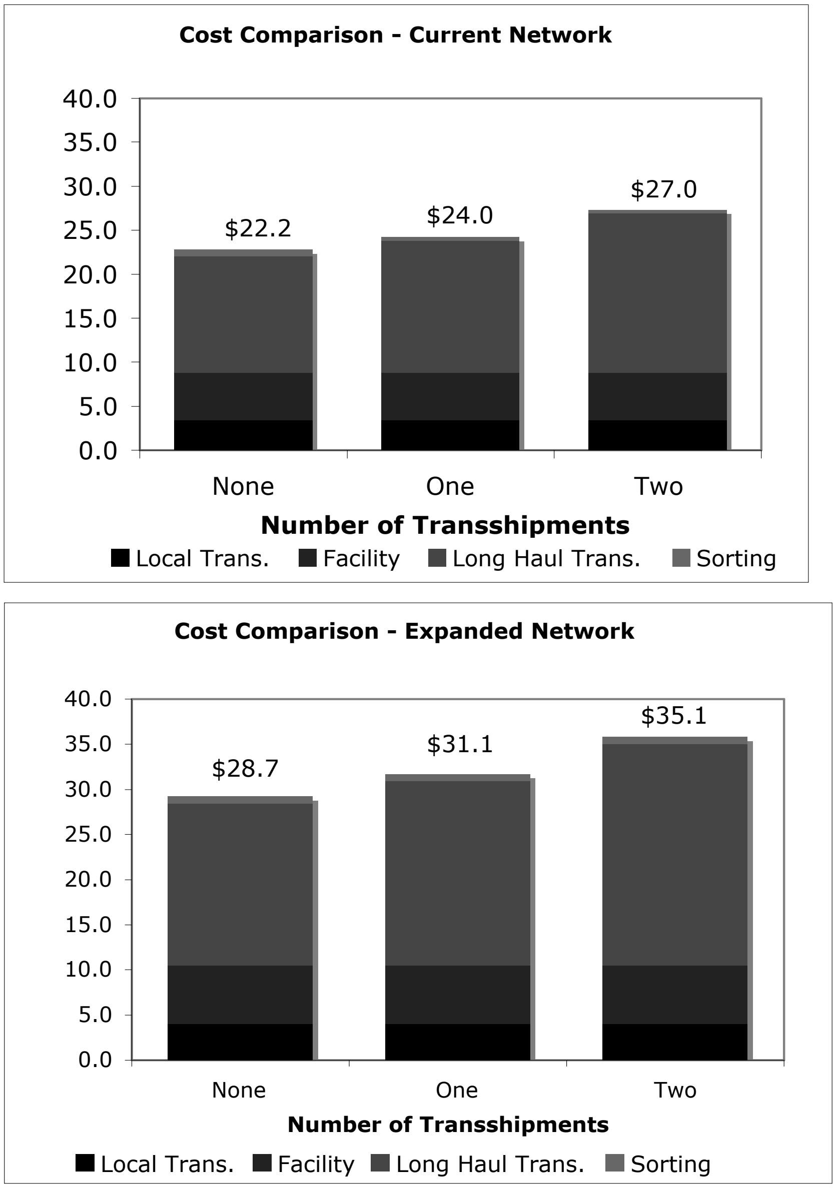


Figure 4.1-1. Cost Comparison for the Current and Expanded Network.

The main driver of the cost increase is the long haul transportation cost. While most other costs are constant, the long haul segment accounts for nearly all the increased costs when transshipment points are added. It is logical that long haul would have such a great effect, since it reflects the cost of shipping packages worldwide.

As transshipment points are added to the network, the long haul costs tend to increase because the total distance that packages travel increases. However, the unit cost of transportation ($/lb*mile) decreases because larger, more efficient aircraft can be used in place of smaller aircraft. In the one transshipment and two transshipment models above, the cost from added distance overwhelms the savings from economies of scale, causing total costs to rise.

In contrast to the long haul costs, the sorting costs decreased as transshipment points were added. Since the sorting costs grow logarithmically with complexity (number of possible destinations), the simpler sorting at transshipment points reduced the cost. The decrease in sorting costs are, however, not enough to account for the increase in transportation costs, and the reduction in sorting costs had little effect on overall costs.

When FedEx ships international packages using no transshipment points, it achieves the lowest shipping costs, at 22.2 million $/day in the current network, and 28.7 million $/day in the expanded network. These estimated results are close to FedEx's actual costs.

4.2 Network Comparison

When comparing the expected revenue from the expanded network with the increase cost from the expanded network, it can be seen that FedEx has the potential to increase revenue by expanding to the three new service areas. The cost increase compared to the current network for each transshipment level is less than 12.8 million ($/day), the revenue from the expanded network. FedEx would therefore gain considerably by expanding its network to Africa, South America, and India. The conclusion from this section is therefore the FedEx should continue to use zero transshipments, however, they should look into expanding their service areas.

4.3 FedEx Actual Costs

The actual cost of the FedEx international shipping network could be estimated from its most recent annual statement. For the most recent year, FedEx reported annual revenues of 21.5 billion dollars on its shipping division, with a profit of 1.8 billion dollars. Operating costs, the difference between revenue and profit, are 19.7 billion $/year, or 77.4 million $/day.

Throughout this analysis the fact that FedEx's international shipping is 14.3% of the total shipping by volume has been used. If we assume that an international package costs the same as a domestic package, then the daily international cost is equal to the total cost prorated by this percentage. Through this logic, the daily cost for shipping international packages is 11.0 million $/day. This value is much lower than the estimated cost of 22.2 million $/day for the current network.

However, it is reasonable to think that the cost of shipping an international package is more expensive than the cost of shipping a domestic package. Using this paradigm to analyze the final result of the logistic cost function, the result of the estimated logistics cost function potentially falls in the range of values for the actual FedEx shipping cost.

5 Strategies for Expanded Network

Now that we have determined baseline costs for the current network, new strategies can be tested to gain further improvements. These strategies should be implemented when the network is expanded, achieving even greater savings as determined above. The addition of a new, larger capacity aircraft, as well as a discriminating strategy involving transshipment points will make the expanded network even more profitable than currently projected. After describing the proposed improvements, the cost savings to the expanded network will be calculated.

5.1 Impact of a Diversified Fleet

FedEx has ordered nine Airbus A380 aircraft, capable of handling 300,000 lbs of freight (FedEx Annual Report, 2005). These aircraft are expected to arrive between 2009 and 2011. When delivered, the A380 will reduce costs by providing even greater economies of scale for high-volume shipments. Currently, FedEx's largest aircraft model, the MD-11, has a capacity of 150,000 pounds of cargo.

Using costs estimates of the A380, we recalculated shipping costs for the expanded network. This high-capacity aircraft has the most cost savings when the FedEx network includes transshipments. The transshipment points concentrate the flows of packages, and allow the A380's massive cargo capacity to be best utilized. The aircraft will have less effect when there are no transshipment points, because there will be less need for the capacity. The savings in the two transshipment model, at 3.5 million $/day, were over seven times greater than the savings with no transshipment points.

However, with the expanded network, using the A380 does not decrease long haul cost enough to make using transhipments the lowest cost method. Using no transhipments remains the best choice, however, by a much smaller margin over the one transhipment case than found before.

This estimation justifies FedEx's order for the upcoming aircraft. However, delays in development may have led to the decision in late 2006 to cancel the order. While it is possible that FedEx will continue with its current fleet, it is likely that once the A380 is in full production, FedEx will renew its order.

In addition to technological improvements, there may be ways to adjust the use of transhipment points in the expanded network to reduce costs further. These are explored in the next section.

5.2 Impact of a Hybrid Transshipment Model

Since the lowest costs result from the models with zero or one transshipments, it makes sense to explore a hybrid transshipment model: if the demand is high enough on one link between two international hubs, the packages will fly directly; otherwise they will be shipped with one transshipment.

Given the demand on each link, the optimal cut off point of package volume between those shipments needing transshipments and those shipments not needing transshipments to minimize the total cost was found. The local cost will be the same as with zero or one transshipment, whereas the sorting and the long haul transportation will be modified. The most significant changes in cost will be in the long haul transportation cost, so therefore, the cut off point is optimized so that the long haul transportation cost will be minimum.

The minimum cost was determined to be when the cutoff point for shipment volume is 20,000 lbs. It is clear that the cut off point to ship directly between two international hubs will be set at 20,000 lbs on a link, which is the optimal value for both cases.

We can then compute the total global cost to operate the network with a hybrid transshipment model. It is found that the total cost for the hybrid transshipment model (with the expanded network) is 27,934,000 ($/year) without the A380 and 27,494,000 ($/year) with the A380.

5.3 Results Revisited

After including cost savings from the A380 aircraft and the hybrid transshipment model, we can reconsider the best options for the expanded network. As expected, the A380 has the most impact when flying to/from transshipment points, because the volume on these flights is greatest. There is little savings in the zero transshipment model, because the flows do not justify such a large aircraft.

The hybrid transshipment model reduces cost further than any other option. It uses the most cost effective parts of the other models. Long haul costs are reduced to the minimum because there is no longer a trade-off between extra distance and volume efficiencies. High-volume, high efficiency flights travel directly to the destination, because nothing is gained by consolidating these packages. Low-volume links travel through a transshipment point which enables economies of scale to be gained from the use of larger aircraft.

The lowest possible cost for the expanded network is 27.5 million $/day, using the hybrid transshipment model and the A380 aircraft. This is a 1.2 million $/day improvement over the lowest cost found before considering both the A380 and the hybrid transshipment strategies.

6 Conclusions

Overall it was found that expanding the network to new service areas was profitable from a cost and revenue perspective. Furthermore, using zero transshipments was the lowest cost method for the networks, compared with using either one or two transshipments. When innovative strategies were introduced, it was found that costs could be further decreased by using the A380, a high capacity aircraft potentially being delivered to FedEx in the next 5-10 years. Lastly, using a hybrid transshipment model which discriminates based upon origin/destination pair demand produced the overall greatest cost reduction as a strategy; these costs could even further be reduced by introducing the A380.

At this point we can also consider the effects of route choice on delivery time. As discussed earlier, it is faster to deliver packages directly than through a transshipment point. In the expanded network the results are less clear because the cheapest choice of hybrid transshipments does incur a time delay. All packages that travel through a transshipment point will be delayed 12 to 24 hours as they are sorted and sent on the next leg. Fortunately, only a small percentage of packages are delayed, because the majority of packages from the busiest airports still travel directly. So while we do not calculate the time delay explicitly, we can be sure it will be small compared to the total shipping time. Furthermore, it is assumed that those routes needing a transshipment would be the less popular links; FedEx could introduce a strategy to compensate their customers because of the increased time of package delivery.

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