ABSTRACT

CHIN-LING HO, Public Logistics Network Cost Analysis. (Under the direction of Dr.Michael G. Kay)

A public logistics network (PLN) was proposed as a means to allow multiple firms to cooperate in providing ground parcel transport. To support fast and flexible shipping, a PLN would require sorting in terminals. In this research, we address to find an upper bound on the terminal cost for a PLN system such that its total transport costs would be the same as that of the a private logistics network like UPS. The labor costs in current terminals are high because of lots of human handling [10]. In order to reduce high labor costs and provide efficient sorting capacity, we want to use automatic equipment in the PLN terminals.

Since the biggest parcel delivery company, UPS, is a hub-and-spoke (HUB) transportation system, the total logistics network cost in a PLN should be higher than UPS's. The total logistics network cost includes line-haul transportation cost, pick-up/delivery (P/D) routing cost, and terminal cost. By analyzing each cost in the logistics network, we define an upper bound terminal cost for a PLN based on a similar level of service with HUB. A hypothetical network of 36 terminals in the southeastern U.S. is used as an example PLN in the analysis.

In the example, we observed that transportation cost in a PLN is lower than in a HUB, and the saving transportation cost of PLN contributes to among that can be spent on sorting equipment at the terminals. The upper bound sorting cost for whole hypothetical network is around \$5–11 billion for 4–10 years. The average upper bound cost for each terminal is around \$163–318 million for 4–10 years. According to the number of sorts need in the hypothetical network, the upper bound sorting cost per truck stop, \$91,832–179,289, is offered to determine the size of terminals based on their sorting needs. All these upper bound costs can be used to provide a detailed terminal layout design in the future.

Public Logistics Network Cost Analysis

by

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BIOGRAPHY

Chin-Ling. Ho was born in Taipei, Taiwan. She received her B.S. degree in Civil Engineering from Chung Yuan Christian University (CYCU) and M.S. degree in Construction Management from National Taiwan University of Science and Technology (NTUST). In 2003 fall, she entered the graduate program of the department of Industrial engineering in North Carolina State University (NCSU) and was a teaching assistance of the class of engineering economic analysis. During her graduate study in NCSU, she majored in production management area, and minored in statistics. She is currently working on the cost analysis with her graduate advisor, Dr. Michael Kay, for a M.S. degree in Industrial Engineering.

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1. Introduction

With the increase of e-shopping and e-commerce business, companies or individual sellers need to provide short-transport-time and low-cost shipping services by outsourcing their logistics system [25]. The increase of competition in the transportation market requires the cooperation between third-party logistics [6]. They often use distribution centers, warehouses, or terminals to consolidate products or shipments. A distribution center is the place for receiving parts from suppliers, storing products, and distributing products to buyers. A warehouse is the place for a company to manage its inventory and to deliver products to its buyers. A terminal is the transshipment point for loading and unloading products.

A Public logistics network (PLN) is designed for the ground delivery to transport parcels [15]. In a PLN, public warehouses are used as terminals to operate ground parcel shipments, including sorting, loading/unloading, and consolidating packages. This research defines the logistics network cost for these public warehouses, including line-haul transportation cost, pick-up/delivery (P/D) routing cost, and terminal cost. However, it is difficult to evaluate the terminal cost due to unknown demand, the location of terminals, and technology expenses. We plan to use UPS experience to approximate the logistic network cost and then determine the terminal cost for a PLN.

The UPS transportation system is called the hub-and-spoke system (HUB). The HUB system uses a few large hubs to handle major transshipment needs. In contrast, a PLN is designed such that each terminal handles its own shipments. In order to maintain the same service level as a HUB system, a PLN would have more frequent sorting in terminals [15]. In addition, the terminal cost for a HUB system is high because lots of workers and cars are involved in the shipment handling, and workers must quickly sort packages with various sizes and weights [10]. If a PLN uses human handling, like a HUB system, it would have higher terminals cost than the HUB system. In order to reduce a PLN system cost, sorting and scanning packages should be operated automatically without any human handling.

It is a challenge to estimate cost for the automatic terminal when there is no such terminals in the current parcel industry. Therefore, this research tries to find an upper bound cost to invest PLN terminals without paying more costs than UPS. We address finding the upper bound of sorting asset cost for a PLN by assuming as the same total logistics network costs as a HUB system. The upper bound cost will be used to evaluate the investment plan for a PLN. Before delving further into the PLN cost analysis, the current parcel industry and the related research will be reviewed.

1.1 Parcel Industry

Parcel service, one of the services in the freight transportation, is a professional delivery service that primarily conveys parcels in accordance with a fixed, defined transportation program, by using logistics networks with fixed running times for their specific goods [31]. The size of a parcel is small enough to be handled by one person without aid, but normally larger than a single letter [3]. There are multiple transportation modes, which include air-cargo, railroad, water, pipeline, and truck in parcel service to cover wide regions and provide diverse services.

Mode Comparison

To choose a transportation mode for a particular shipment, the distributor must consider shipment sizes, feasible arrival dates for customers, and transportation costs [8]. The criteria of the mode selection include cost, service, and the type of packages. The advantage and disadvantage of transportation modes are presented in Table1.1.

Parcels requiring air service are routed to a nearby hub airport. Air freight is not a short travel mode and it is very expensive. It charges a high price for very high quality services, like emergency and national shipments. The operation of air cargo relies on trucks to support transportation from the airports to other ground transshipment points.

Water/Ocean shipping is widely used for international long-haul commodities. There are two kinds of commodities in ocean shipping, dry and wet. Wet commodity is mostly oil products and dry commodity can be anything else. Comparing with railroad freight car and trucks, these ships are enormous but slow. In contrast to air transportation, water mode tends to be relatively inexpensive per unit weight and per unit distance.

Railroads are used for low value freight, such as coal transport, that does not require high level-of-service shipments [30]. Due to economic considerations, companies need to gather enough traffic so that trains can be operated as a long train. Cost per freight car on a long train is much lower than on a short train, but the train operating costs increase with train length.

Trucking is the backbone of the freight system. If packages are moved over a short distance, truck mode is often used. Even goods carried by other modes often need trucking to provide access to air cargo, railroad, and seaport terminals. Truck shipping differs from other transportation modes in a number of fundamental aspects. Freight railroads run on right-of-way which they own and maintain. It is mostly a fixed cost. Alternatively, trucking industry uses public highways. They pay for a portion of their cost of using the highway on as-used basis and this is a variable cost. Unlike railroad and air cargo, truck industry tends to be primarily a variable-cost rather than a fixed-cost industry because trucks can ship less when business is down. On the other hand, time schedule for truck industry is more flexible than other modes; shippers could be asked to pick up and deliver packages at any time [30]. Overall, trucking is an efficient transportation mode in terms of time, location, and costs. For customers, delivering on time is the most important issue, regardless of which freight modes are chosen. Some shipping services named with Air, like UPS Next Day Air Saver and UPS Next Air Early, might also use rail or truck. Trucking is the most important modes in shipments. It is called ground delivery.

Table 1.1 Comparison of different transportation modes

Mode	Advantages	Disadvantages
Air	Faster service International/national	Expensive price Truck support needed Schedule is not flexible
Rail	Low price	Slower service than trucks Truck support needed Schedule is not flexible
Water	Low price International/national	Truck support needed Slowest service Schedule is not flexible
Truck/Ground	Low price Schedule is flexible	More expensive than rail

Ground Delivery

Due to Motor Carrier Act of 1980, the deregulation of trucking industry, trucks can reduce empty-driving miles to improve trucking productivity. Trucking productivity depends on how many miles the transportation equipment operates empty or partially full load (Ton-Miles), but not on the quantity of material in the truck [30]. There are two main operations in truck carriers, truckload shipping (TL) and less-than-truckload (LTL) shipping. TL shipping is a straightforward operation, where a trucker delivers goods from point A to point B without stopping at any other terminals. LTL shipping uses terminals and feeder network to pick up the goods from the shipper in small trucks and deliver to other terminals. These terminals are used to provide temporary storage and consolidate shipping. Due to the different operations in TL and LTL, the prices charged from shippers are different as well. TL shipping is priced by truckers who ship goods such that they can get enough profit. LTL pricing is more complex because of its higher capital investment [30]. Therefore, LTL cost analysis is worth studying.

Nowadays, more and more LTL haulers are making headway among shippers that move large volumes of small packages to business consignees [29]. Some LTL haulers are associated with parcel and express specialists, such as delivery within specific time window, time-definite or day-definite. A trend of integrating public warehouses and LTL haulers is observed in the expansion of the small package delivery market. The PLN was proposed as a means of extending many features associated with public warehouses and LTL companies to enhance economical scales of shipping. This research will try to help LTL companies to analyze their investment costs on terminals.

Terminals in Parcel industry

The terminal operation is very important in the ground delivery. Plans about vehicle schedules, storing, sorting, consolidating, and customer service are managed in the terminals. In the parcel delivery industry, a terminal provides a transshipment point, which is different from a regular warehouse or a distribution center. Some ideas of parcel process system in transshipment center were presented by Mario [14]. He treated the parcel process system as a hierarchical system. The main tasks of parcel center are discharge, storage, sorting, and delivery as Figure 1.1. The parcel flow is composed of three parts: receiving, handling, and shipping. The locations of receiving and shipping in a terminal decide the different types of building layout such as cross-dock, L-shaped dock, and single dock. The design of building layout, which affects the response time of loading/unloading packages and traffic congestion, might cause the increase of indirect cost for terminal operation.

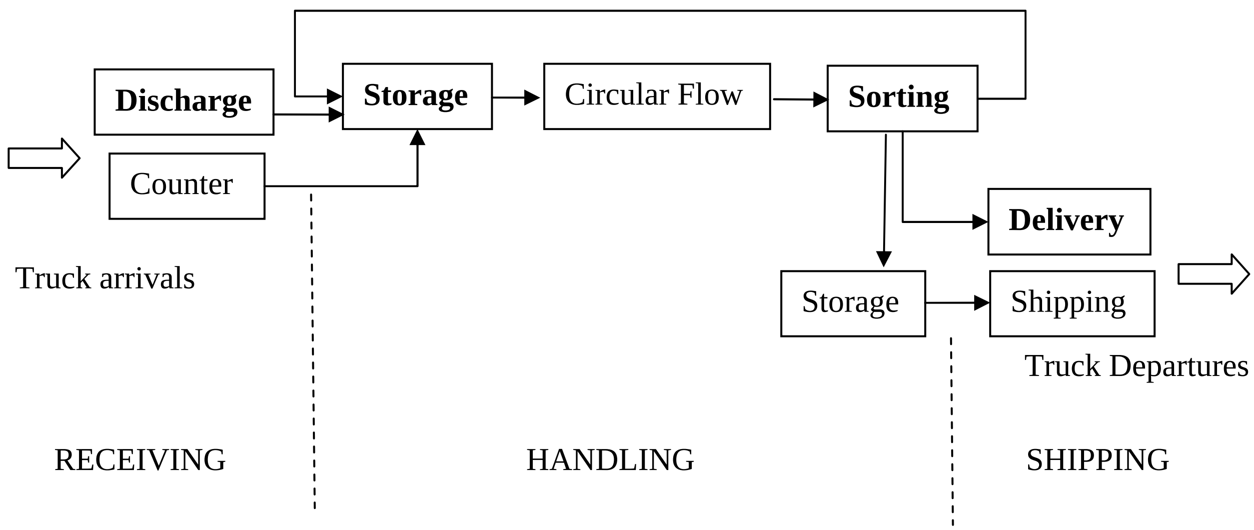

FIGURE 1.1 PARCEL FLOW IN POSTAL CENTER [14]

1.2 Logistics network related research

Logistics researches have been widely studied in business aspect and production aspect. This research classifies these related research topics into shippers, handlers, and carriers.

1. Shipper: delivery time and shipping cost

Nowadays, many manufacturers and retailers seek to outsource their logistics services to short lead-time or reduce cost. How to select motor carrier and service capability has been concerned in the carrier selection process, especially for the cost minimization [2]. The shipping cost with freight rate or lead time is examined in Economic Order Quality (EOQ) model for the inventory policy of supply chain companies [33].

2. Handlers: sorting technique and warehousing design

The use of terminals between plants/suppliers and customers allows the concentration of shipments to increase the flow on these links and to generate economies of scale by improving the vehicle load [21]. Two issues about sorting and warehouse layout design have been studied to improve the efficiency of terminals. First, sorting process is critical to reduce transportation time, save operating cost, and conserve resource [24]. Second, planning terminal layout is discussed to improve terminal efficiency and transportation time. Mathematical algorithms and heuristics were widely used for reducing operation cost of terminals and customer service cycle time [8] [18].

3. Carriers: vehicle routing and location of warehouse

Operations research has been used in finding optimal routing to deal with time-window and waiting cost [19]. In order to minimize overall cost, locations of warehouse and network modeling have also been studied [11]. Some researchers use simulation in the shipping system to describe network system [4].

Moreover, logistics cost have been investigated for various aspects. For example, the expected annual logistics cost is the summation of transportation cost, holding cost, ordering cost, and shortage costs in supply chain management [9]. For container, the operating costs for transportation are divided into three components: the routing costs, the resource assignment costs (driver/vehicle), and the container repositioning costs [17]. A cost function of LTL motor carrier, presented in the paper of Bruce [22], is the summation of labor cost, fuel cost, purchased transport cost as well as capital cost. Those studies help us to know which costs are important for different users, but they do not provide terminal cost for the parcel delivery. This research can expand logistics network studies to terminal area.

1.3 Overview

This thesis introduces a PLN by comparing its routing with the line haulage of a HUB system in Chapter 2. Since UPS is a HUB system, its financial report will be studied to give a picture of terminal asset cost and parcel transport cost in a HUB system. For the basis cost understanding in the HUB system, we talk about how to generate costs for the PLN system. An analytical procedure is proposed to find the upper bound costs of sorting equipment for PLN in chapter 3. With a cost structure present, we provide formula to generate transportation cost and terminal cost for the needs of parcel industry. In chapter 4, an example of hypothetical network with 36 terminals is provided. In order to be close to real transportation cost, some trucking data are collected as well. The example will demonstrate all steps of our analytical procedures and provide a specific upper bound sorting cost range for PLN terminals.

2. Public Logistics Network

In this chapter, the difference of routing paths and sorting points between HUB and PLN is discussed. Also, a UPS financial report is used for managers to see asset values and average transport costs in parcel delivery companies.

2.1 Hub-and-Spoke (HUB) vs. Public Logistics Network (PLN)

The HUB transportation system is widely used in telecommunication, air transportation and parcel delivery networks. The line haulage of a HUB includes package shipping within hubs and from terminal to the origin of hub as well as from the hub to the destination of terminal. Each non-hub terminal is allocated to the closest and exactly one hub. Packages are only consolidated and sorted in the hub.

A HUB system is treated as a very cost-efficient system for global logistics by using multiple modes of transportation systems [17]. Most parcel companies use a HUB system to speed up both ground and air parcel service, but this kind of pure HUB networks is not the only network structure for trucking shipments. A hybrid HUB system was proposed to save more cost of line-haul than pure HUB system [6]. It shows that there exist other logistics network systems which may use lower cost by changing routing paths.

The purpose of a PLN is to provide a fast and flexible service by sorting packages in every terminal. Its routing paths between terminals are using Dijkstra's algorithm, which leads trucks to travel the shortest distance between terminals. Because every terminal is able to sort packages, packages will keep on loading and unloading in terminals until they arrive at their destination terminals.

Recent PLN research found that transport time of line haulage, including loading/unloading time, wait time, and transportation time is shorter in a PLN than in a HUB when the loading/unloading time is short [15]. Although both a HUB and a PLN are using Dijkstra's algorithm in line-haul routing, the routing paths would be changed with the sorting places that routing assigned. Using a network linking 18 terminals as an example, we illustrate the shortest routes in Figure 2.1(a) for the HUB system and in Figure 2.1 (b) for the PLN system.

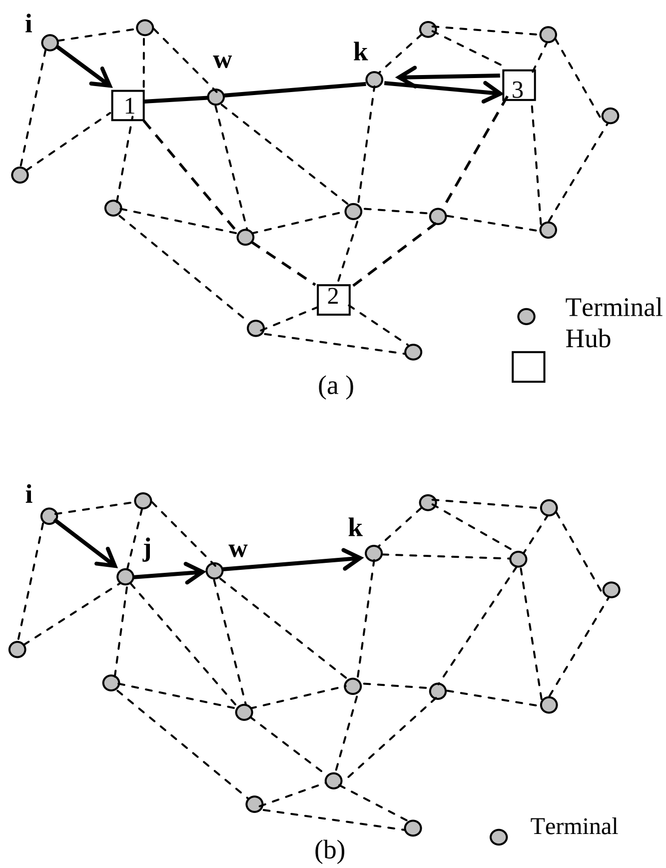

FIGURE 2.1 (A) HUB LINE-HAUL ROUTE; (B) PLN LINE-HAUL ROUTE

Line haulage of a HUB system or a PLN system can be denoted as shipping packages from terminal *i* to terminal *k*. For the HUB system, three terminals function as hubs to sort packages and the other terminals are used to collect local packages only. For PLN the system, all these 18 terminals operate as smaller hubs to sort passing packages. By using the Dijkstar's algorithm, both

HUB and PLN would pick the same routes for traveling a pair of terminals. Due to the sorting at different places, the trucks in the PLN could travel shorter but stop more terminals than in the HUB. The routes of the HUB and the PLN are described respectively:

HUB system:

Routing: Terminal *i* ⟶ hub 1 ⟶ Terminal *w* ⟶ Terminal *k* ⟶ hub 3 ⟶ Terminal *k*

Sorting: Packages are sorted in hub1 and hub3

PLN system:

Routing: Terminal *i* ⟶ Terminal *j* ⟶ Terminal *w* ⟶ Terminal *k*

Sorting: Package are sorted in terminal *i*, terminal *j*, terminal *w*, and terminal *k*

2.2 United Parcel Service (UPS)

UPS is the most successful parcel delivery among five large U.S. parcel industries: Airborne, DHL, FedEx, UPS and United State Postal [25]. To investigate current biggest parcel delivery company (UPS) will help us to define the logistics network cost in parcel industry. Their annual revenue the truck-based transportation represent that UPS is the largest domestic parcel carrier [31]. UPS uses a HUB system to deliver more than 14 million parcels per business day across the U.S. Its financial report would offer related logistics network costs for the HUB. Next we will discuss their transportation system, domestic service and service rate to provide a clear overview for ground delivery.

2.2.1 UPS transportation system

UPS is a hub-and-spoke system and has seven hubs in the U.S.: Louisville, Ky. (main U.S. Air Hub), Philadelphia, Pa., Dallas, Texas, Ontario, Calif., Rockford, Ill., Columbia, S.C., Hartford, Conn. All UPS goods-air and ground, domestic and international, commercial and residential services share the same network and infrastructure. Sharing infrastructure is very efficient and low-cost to use assets. A single network provides the flexibility to transport goods by using the most reliable and cost-effective transportation mode or combination of modes. Since UPS is one of the largest railroad customers in the United States [25], shipments are handled at a lower cost per package with fewer miles traveled between stops.

Four main UPS operations are pickup, sorting, line-haul feeder service, and delivery. The package pickup process is available for regular customers, drop boxes, and call-ins. Packages are aggregated in local operating centers and sorted according to ZIP codes, waiting for shipping to terminals. The inbound packages are delivered to customers during daytime, and outbound packages are collected in the evening after truck shipping is finished

2.2.2 UPS Domestic Service

UPS operates 185,000 trucks in its ground network and uses a fleet of larger vehicles to transport parcels between sorting hubs [25]. UPS provides every driver a specifically designed vehicle and all fuel, oil and maintenance. In the peak time, UPS leases additional trucks to support its transportation needs. All trucks, drivers, carriers, labors, and terminals are part of expenses in maintaining logistics network system.

UPS financial reports and price charts are very useful to estimate parcel transport costs and asset costs for a HUB system. Three segments are in UPS financial reports: U.S. domestic package operations, international package operations, and non-package operations. The domestic package operation is the most significant business for UPS. It includes service of “Next Day Air,” “Deferred,” and “Ground.” Comparing revenue of domestic package with other services, the revenue from domestic package is the highest, up to 72.7% of consolidated revenue. U.S. domestic package delivers more than 12 million packages with 88,000 vehicles [28]. The reason of this high percentage is the increase of shipping volume and price rate (Appendix D). U.S. domestic package financial data are organized in Table 2.1: revenue (R), operating profit (P), daily package and operating days.

Table 2.1 U.S. domestic package segment information, UPS 2004 Financial Report

U.S. domestic package	
Revenue	$26,610,000,000
Operating profit	$3,345,000,000
Long-lived asset	$15,971,000,000
Daily demand (units)	12,780,000
Operating day	254
Operating expense(R - P)	$23,265,000,000
Revenue per piece	$8.20
Operating cost per package	$7.17

Costs of “U.S. domestic package” are operating expenses and long-lived assets. The operating expense is related to the business operation without any asset investments. In the balance sheet the operating expense is composed of compensation and benefit and other expenses which are “repair and maintenance,” “fuel,” and “purchased transportation.” UPS operating expenses are listed in Table 2.2. The employee expense accounted for almost two-thirds of operating expense. It shows that employee expense is very heavy for UPS.

Table 2.2 UPS Operating Expenses, 2004, 2003

	2004 (in millions)	2003 (in millions)
Compensation and benefit	$20,916	$19,327
Repairs and maintenance	$1,005	$955
Depreciation and amortization	$1,543	$1,549
Purchased transportation	$2,059	$1,828
Fuel	$1,416	$1,050
Other occupancy	$751	$730
Restructuring charge and related expense	–	$9
Other expense	$3,902	$3,591
Total	$31,593	$29,040

On the other hand, assets in the financial report are composed of current assets, fixed assets, prepaid pension goodwill and etc. Long-lived asset information was provided in the "Geographic information" and divided into two parts: domestic and international. The long-live asset of "U.S. domestic package" is $15,971 million, which accounts for 80.7% of consolidated long-live assets in UPS. Detail of "property plant and equipment" from consolidated financial statements are provided in Table 2.3.

These values in Table 2.3 are depreciated by the straight-line method over the estimated useful lives of assets. The depreciation costs of these assets are listed as operating expenses. Interest incurred during the construction period of certain property, plant, and equipment is capitalized until the underlying assets are placed in service.

Table 2.3 UPS Property, Plant, and Equipment, 2004, 2003

	2004 (in millions)	2003 (in millions)
Vehicle	$3,784	$3,486
Aircraft	$11,590	$11,897
Land	$760	$721
Building	$2,164	$2,084
Leasehold Improvement	$2,347	$2,219
Plant Equipment	$4,641	$4,410
Technology Equipment	$1,596	$1,495
Equipment under operating lease	$57	$53
Construction-in-progress	$539	$450
Accumulated depreciation and amortization	($13,505)	($12,516)
Total	$13,973	$13,298

2.2.3 UPS parcel cost

In order to evaluate parcel delivery performance, the package cost per shipment can be a measurement for the efficiency of the HUB that UPS uses. This section aims to obtain the general package cost for different services of UPS in U.S. Dividing domestic revenue and operating expense by daily demands and operating day, the revenue and the operating expense per package is $8.20 and $7.17 which are shown in Table 2.1. These two costs explained the overall average cost per package in "U.S domestic package." However, since the parcel cost varies with shipping service and package weights, this average operating expense per package can not stand for the "Ground." It is incurred from a composite of three services: Next Day Air, Deferred and Ground (see Table 2.4).

Table 2.4 UPS domestic package with services

U.S. domestic package	Daily Package	Package %	Revenue per package
Next Day Air	1194000	9.34%	$19.92
Deferred	910000	7.12%	$13.68
Ground	10676000	83.54%	$6.42
Total/ Expected Value	12,780,000		$8.20

In Table 2.4, the overall revenue of “Next Day Air” services is $19.92. The delivery by Deferred usually needs 2–3 days and its revenue per package is $13.68. Generally, the delivery by Ground service needs 3–5 days and its average revenue per piece is $6.42. The average price of these services can be called as the revenue per piece, and the cost of these services should be lower than the revenue. Since the costs were not provided by UPS financial report, an approximate method is needed to obtain the specific operating expense for different services.

Next we use a simple method to approximate cost per package. First, we assume that the ratios of cost per piece are equal to that of revenue per piece for the three US domestic services. The ratio of a service revenue is computed as the revenue per piece for a service divided by domestic revenue per piece $8.20, and then we get 2.43 for “Next Day Air,” 1.67 for “Deferred,” and 0.78 for “Ground.” Multiplying these ratios with the U.S. domestic cost per packages, $7.17, the average cost per package for each of these three services are calculated and shown in Table 2.5.

Table 2.5 UPS “U.S. domestic” cost by services

U.S. domestic package	Revenue per package	Ratios	Operating Cost per package
Next Day Air	$19.92	2.43	$17.41
Deferred	$13.68	1.67	$11.96
Ground	$6.42	0.78	$5.61
Overall Expected Value	$8.20		$7.17

Since the price of UPS is always varied with weight of package and traveling distance, the cost of UPS must be also varied with the weight of package and traveling distance. The price charts may be able to provide a basis of package costs for different weights and distances.

UPS processes the price rates of shipments by determining the size and weight of package and then determining the rate of service and the price zone. We organized the ground residential chart as an example in Table 2.6. Weights were ranked from 5 to 70 pounds by the increment of 5, and zones were provided from zone 2 to zone 8. We observed that the price per package is higher if the weight of package is heavier or the traveling distance is longer. Furthermore, we represent the pricing relationship between zone and weight in Figure 2.2. In Figure 2.2, each line represents prices in one zone.

The price is positively related to the package weight and the zone. Packages shipped in smaller zones are always charged less than in larger zones for traveling less distance. We observed that the price changes significantly at the weight of about 70 lbs. When the weight of package is less than 70 lbs, the slopes of smaller zone are less than the slopes of larger zones. These trends show that prices are affected by traveling distance more than by weight when weight of package is less than 70 lb. In contrast, when the weight of package is over 70 lbs, prices increase with a same slope. That shows prices are affected by the weight of human's moving limitation.

Pricing decision might also be affected by the company strategy such as the profit policy, which is unseen in this figure. From the average cost per package in Table 2.5 and the price trend in Table 2.6, the cost for shipping one package by trucks may be from $5 to $40 when the weight of package is less than 70 lbs. UPS prices can be used as indexes for evaluating average transport cost in trucking.

Table 2.6 2005 UPS Ground Residential price and zone, in dollar

lb \ zone	2	3	4	5	6	7	8
5	5.56	5.79	6.47	6.67	7.02	7.25	7.85
10	6.35	6.45	7.08	7.47	8.05	8.87	9.88
15	7.08	7.39	7.64	8.24	9.82	11.53	13.07
20	7.61	8.38	8.68	9.8	11.96	14.07	16.28
25	8.36	9.42	9.94	11.39	14.14	16.62	19.52
30	9.17	10.37	11.24	12.96	16.33	19.12	22.68
35	9.84	11.38	12.54	14.57	18.47	21.79	25.9
40	10.53	12.41	13.81	16.19	20.48	24.45	28.99
45	11.15	13.39	15.02	17.81	22.33	27.08	32.02
50	11.62	14.23	16.05	19.26	23.84	29.36	34.57
55	12.1	14.83	16.96	20.47	25.19	30.9	36.35
60	12.58	15.42	17.73	21.45	26.44	31.73	37.55
65	13.06	15.95	18.35	22.13	27.34	32.62	38.75
70	13.5	16.48	18.93	22.81	28.15	33.5	39.94

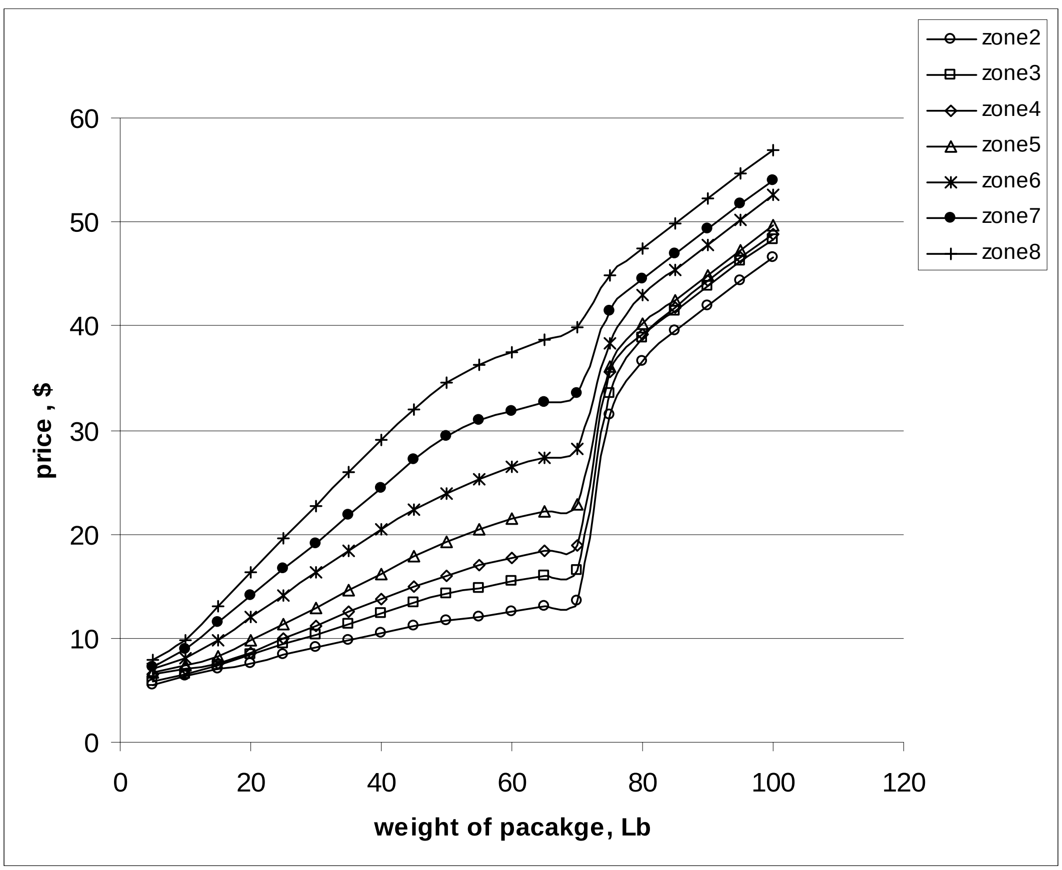

FIGURE 2.2 UPS RESIDENTIAL PRICE TREND

3. Cost Analysis

This section proposes an analytical procedure to calculate costs in parcel industry. The procedure is to define the upper bound on sorting equipment cost that a PLN might spend. The assumption is that the total logistics networks cost of a PLN is as low as that of a HUB system. In the previous chapter, operating expense, asset cost, and package costs are discussed for a HUB system. In this chapter, the logistics network cost structure, cost formula for line-haul transportation and local pick-up/delivery (P/D) routing, economical transformation between operating cost and asset cost will be discussed. These discussions help managers equally to measure logistics network costs for both HUB and PLN system.

3.1 Defining Logistics Network Cost of Parcel Delivery

The logistics network in the parcel industry is a network in which terminals are linked to transport parcels. The logistics cost for a carrier is computed as a composition of the cost for drivers and vehicles to make pickups and deliveries (Pick-up/Delivery routing), the line haul cost for transporting freights between terminals (Line-haul transportation) and the handling cost for sorting and consolidating freight (Terminals) [10]. Other related researches considered logistics operations as line-haul operations, local P/D operations and terminal operations. In this research, we also consider these three operations in the evaluation of the logistic network cost.

As an example for a parcel delivery, a two-stage network system is shown in Figure 3.1. The shipment movement can mainly be divided into the line haulage and the local P/D routing, both of which are independent [11]. The line haulage is the first stage that covers the long-distance transportation. The P/D routing is the second stage where shipments are delivered to and from customers by smaller trucks (vans) within the local area. For most delivery companies, in order to decrease shipping cost, packages are aggregated into one large unit in the line-haulage and increase the economic scale in terminals. When packages arrive at the destination terminal, they wait until being delivered to individual customers. However, resources (vehicles, handlers and drivers) of the line haulage and the P/D routing are separated. Cost of the logistic network is the summation of line haulage cost and pick-up/delivery routing cost.

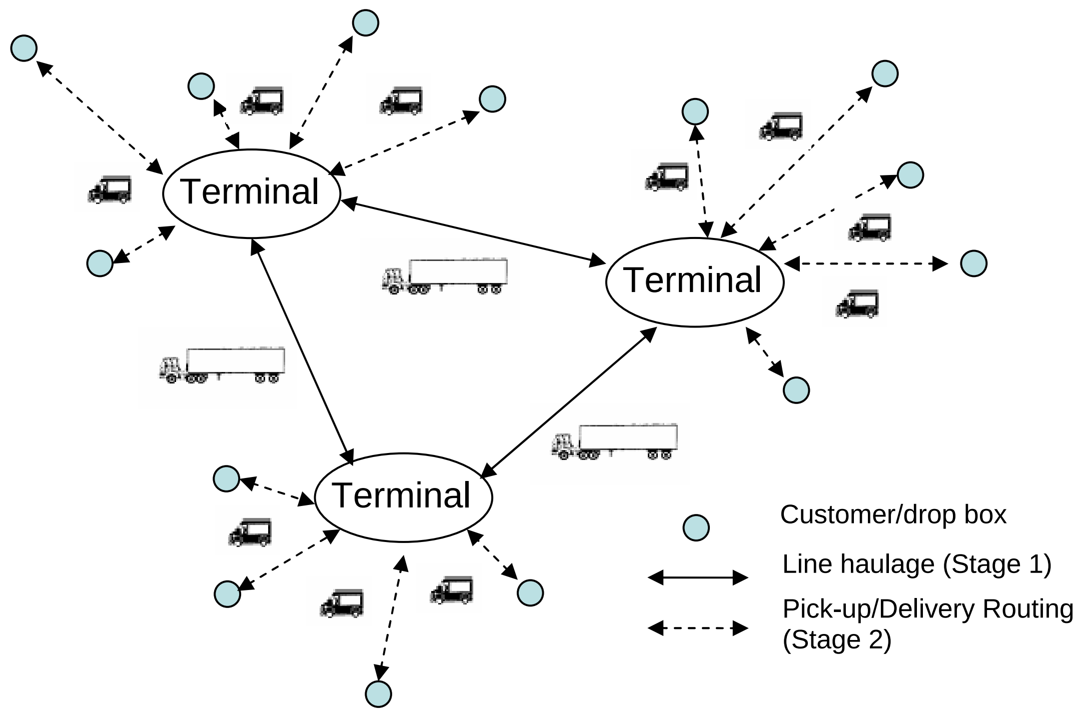

FIGURE 3.1 LINE HAULAGE AND PICK-UP/DELIVERY ROUTING

From the financial point of view, the logistics network cost for a parcel delivery company is associated with operating expense and asset costs. Before starting business, companies need to invest asset cost such as lands, buildings, equipment or machines to support their business operations. Operating expense in the company's income statement is a catchall for every expense in that accounting year. Hence, total logistics network cost for a parcel deliver company should include the initial asset cost and daily operating cost. Based on parcel movements and financial needs, all the costs in the logistics network are listed and organized in Figure 3.2.

	Line haulage	Pick-up/Delivery
Operating Expenses	♦ Line-haul Transportation ♦ Terminal Operating cost	♦ P/D Routing
Assets	♦ Terminal Equipment ♦ Vehicles	♦ Vans

FIGURE 3.2 COSTS OF LOGISTICS NETWORK SYSTEM FOR PARCEL DELIVERY

Based on the movement of parcel, the logistics network cost can be separated as line-haulage and P/D routing. From a financial point of view, the logistics network cost is divided into operations and assets. For example, the terminal equipment cost can be defined as a part of line haulage cost or a part of asset cost.

For the convenience of calculation, the logistics network cost structure is reorganized as shown in Figure 3.3. The movements of a parcel delivery are in the top of the structure. Also, terminal operating cost and terminal asset cost are condensed into a terminal cost. We calculate the logistics network cost as the summation of line-haul transportation cost (1), P/D routing cost (2) and terminal cost (3).

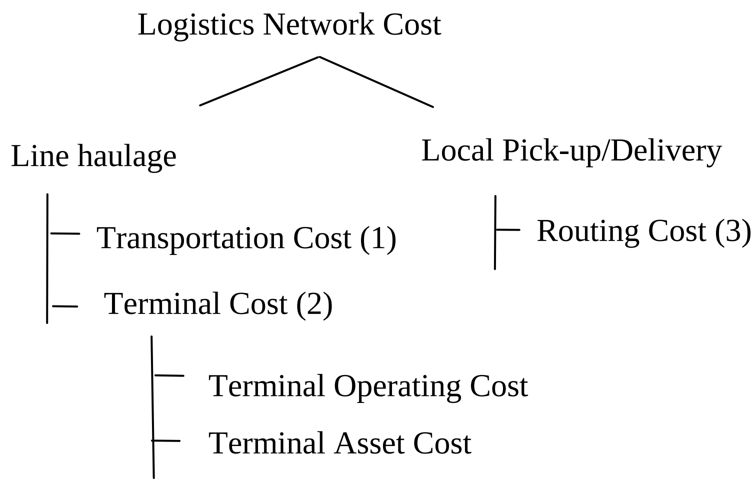

FIGURE 3.3 LOGISTICS NETWORK COST STRUCTURE

3.2 Analytical Procedure

After illustrating the structure of logistics network cost, we propose a procedure to explain the relationships among individual costs. The analytical procedure has three steps: input constraints, compute costs, and approximate a PLN upper bound sorting costs (Figure 3.4). Specifically, step 1 allows a company to input its constraints, step 2 computes all individual costs in logistics network cost, and step 3 uses the results from step 2 to provide the possible upper bound of sorting equipment costs for the PLN system and the transportation cost for each parcel. Since having different units between operating cost and asset cost, defining present value of logistics network cost can lead us find the upper bound asset cost for PLN. Since they are not consistence in units, a cost transformation with economic formula will be applied to solve the problem.

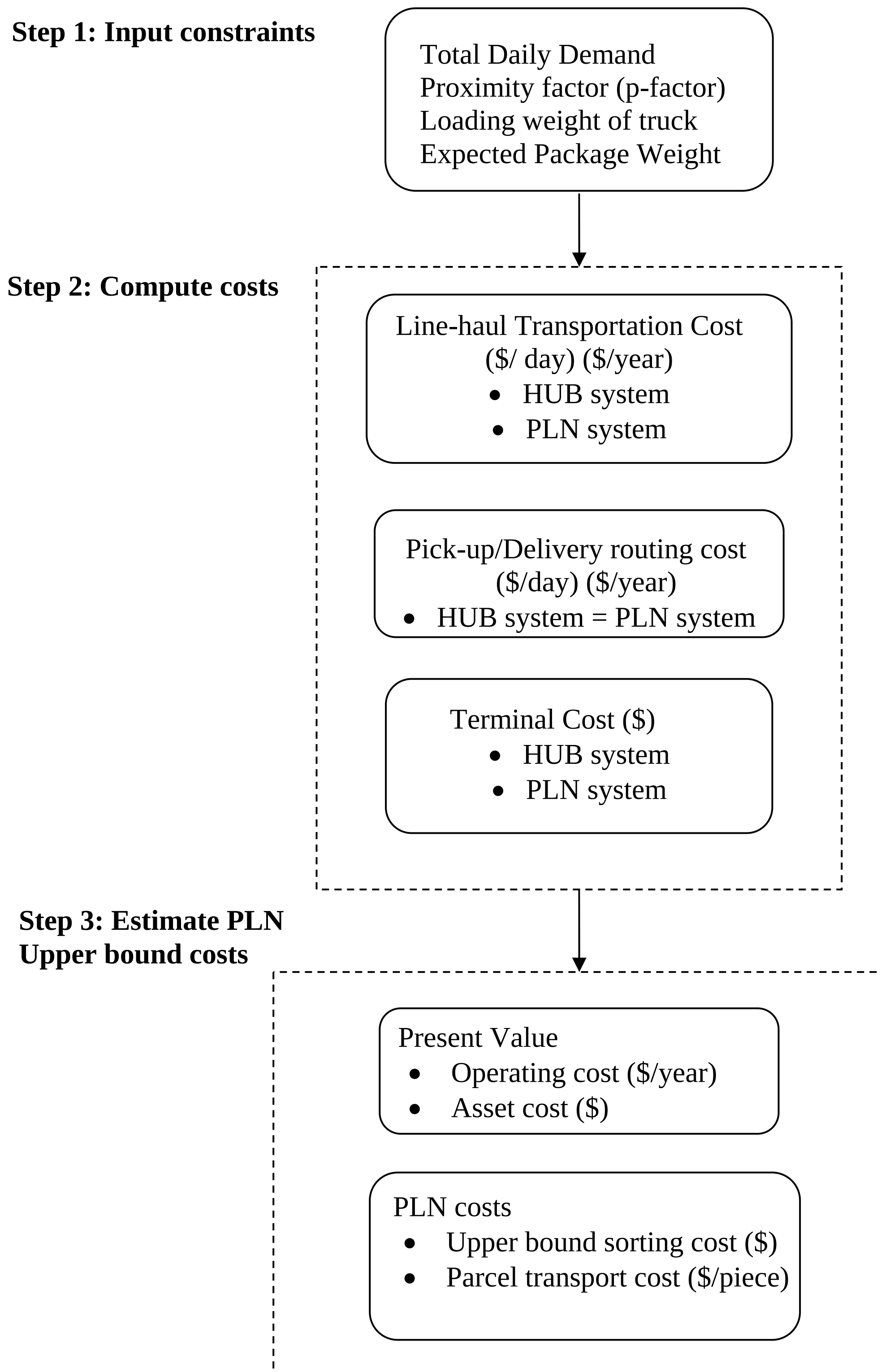

FIGURE 3.4 COST ANALYTICAL PROCEDURE

The details of the analytical procedure are described as follows.

Step 1: Input Constraints

Before a company starts evaluating its logistics network cost, constraints are required for the transportation demand and number of trips for truck schedules. From demand and the number of trips, we can generate the number of trucks, the number of carriers, the gallons of gasoline, and the number of sort needs in the line-haul transportation.

- **Proximity factors:** The proximity factor controls the extent to which a terminal is more likely to transport packages to nearby terminals as opposed to terminals located further away. The demand weight between each pair of terminals is estimated by using the population percentage of each terminal together with a proximity factor, w_{ij}. When the proximity factor is bigger, there are more nearby shipments and shorter traveling distances [15].
- **Total daily demand:** The total number of packages delivered in a day.
- **Expected Package Weight**: An expected weight for all delivered packages in the network system.
- **Loading weight of trucks:** The maximum capability of a line-haul deliver truck.

Step 2: Compute costs

The logistics network cost, including line-haul cost, P/D routing cost and terminals cost, for both a HUB and a PLN, is computed in the step 2. First, line-haul transportation cost is computed by following the different path for both a HUB and a PLN. Then, by letting the HUB and the PLN system use the same P/D routes, we simplify the calculation of the P/D routing cost. For computing terminal cost, we respectively consider terminal operating cost and terminal asset cost for HUB and PLN. The detail of cost calculations will be provided in the next cost sections.

Step 3: Estimate PLN Upper bound costs

To estimate the PLN upper bound cost, operating cost and asset cost are needed. However, the calculated costs are not consistent in units. The operating cost usually is represented as dollars per year ($/year), and asset costs are represented as dollars ($). In order to operate these costs, finding present value for the operating cost is needed. This research uses an economical formula to recalculated the value of operating cost according to the useful life of used assets.

The way to estimate the PLN terminal cost is based on the assumption that total logistics network cost in PLN is equal to the logistics network cost in HUB. We evaluate the difference between operating cost of the HUB and the PLN system. Summing the difference of operating cost and origin asset cost of HUB, the upper bound of PLN terminal cost can be found. Transportation cost, including line-haul transportation cost and P/D routing cost, will be used to calculate the average parcel transportation cost. The purpose of calculating average parcel transportation cost is to validate logistics network cost in a HUB by comparing it with UPS prices.

3.3 Transportation Cost

As we mentioned above, line-haul transportation and P/D routing are two independent transportation resources. Their costs should be computed separately. Here, the concepts of computing line-haul transportation costs in a HUB and in a PLN are the same. Dijkstra's algorithm is used to find the shortest path for both systems. Because of the difference of sorting terminals, the shortest paths are not the same, which lead to two different line-haul routes and costs. The shortest paths in the HUB are based on the assigned hubs but the shortest paths in the PLN are based on the location of destination terminals. Since we assumed that the HUB and the PLN use the same P/D routes, P/D routing cost of HUB is equal to that of PLN. The advantage of same P/D routing allows us to focus on the difference of line-haulage between the HUB system and PLN system. The details of how to calculate line-haul transportation cost and P/D routing cost are discussed in the next section.

3.3.1 Line-haul Transportation Cost

Line-haul transportation cost depends on line-haul truck operations such as truck rental/purchased fee, fuel cost, and driver cost. These costs are incurred according to the number of trucks, the number of carriers, and the gallon of gasoline, and vary with truck capacities and proximity factors. Some notations are defined:

TC: Average truck rental /purchased cost per day

FP: Fuel price per gallon

CS: Daily carrier salary

NT: Total number of trucks

NG: Total gallon of gasoline

NC: Total number of carriers

Line-haul Transpiration Cost Model, CL

$$CL = TC \times NT + FP \times NG + CS \times NC \tag{3.1}$$

Assuming truck schedules are based on finished daily demands, and all packages are shipped. Figure 3.5 shows an example of 1000 units of 10 lb packages in terminal *i* waiting for shipping to terminal *j* by a truck that can carry 5000 lb weight of products. The total distance between terminal *i* and terminal *j* is 600 miles. By passing an intermediate terminal *f*, these packages are shipped 250 miles plus another 350 miles from terminal *i* to terminal *j*. Assuming one truck can operate 8 hours a day and travel between two fixed terminals at the speed of 60 mph. First, compute the number of trip, by dividing total weight of packages by the loading weight of truck, i.e., (1000 × 10)/5000 = 2 trips. Second, the number of trucks per trip is computed as shipping distance divided by daily truck operating hours and shipping speed. The number of truck is rounded up to an integer. When a truck arrives at terminal *f*, all packages are unloaded, and another truck comes to ship the packages to terminal *j*. Therefore, the number of truck required in one trip is 2 trucks, i.e., 250 / (60 × 8) = 1 plus 350 / (60 × 8) = 1. The number of trucks is computed as the number of trips multiplied by the number of trucks required for a trip. In this example 4 trucks are required since 2 trips × 2 trucks/ trip = 4 trucks.

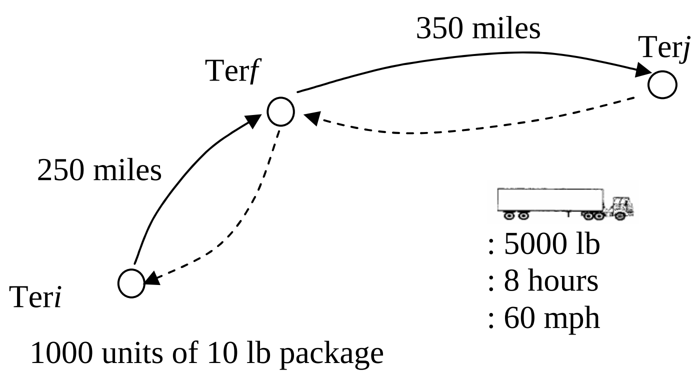

FIGURE 3.5: NUMBER OF TRUCK INTERPRETATION

Similarly, the number of carriers is calculated as the number of trips multiplied by the number of carriers in one trip. Assuming that a carrier drives 8 hours a day with the speed of 60 mph, then the number of carriers is 4 as well. The gallon of gasoline used is calculated as total travel distance divide by the average miles traveled per gallon.

3.3.2 Pick-up/Delivery (P/D) routing cost

Since the same demand and P/D routes are assumed, P/D routing cost would be the same in both a HUB and a PLN. Two actions in P/D routing are delivering packages to customers and picking up packages at the stops by local vans. We believe that the cost of vans for picking up packages could be omitted because no matter how far a van travels, the van should pick up all of packages when driving back to the terminal at the end of the day. Cost of vans is used to determine the P/D routing cost in the whole logistics network. Just like line-haul truck, cost of vans is spent on the rental/purchased truck, gasoline, and one driver payment.

Some notations are defined:

VC: Van rental/purchased cost per day

FC: Fuel cost per van per day

TD: Total daily demand in the logistics network

D: Average-handling packages per van per day

P/D routing cost model, CPD:

$$CPD = (VC + FC + CS) \times \frac{TD}{D} \tag{3.2}$$

The total P/D routing cost is the number of vans multiplied by the cost of one van. The number of vans is determined as the daily demand divided by the average delivering packages per van. From equation 3.2, the larger the handling packages can be, the less the P/D routing costs would be.

3.4 Terminal cost

In Figure 3.3, terminal operating cost and terminal asset cost are put into terminal cost. Terminal operating cost is used to represent the cost for the daily operation in terminal such as labor and handled cars. Terminal asset cost represents buildings, technology equipment, and plant equipment based on the present values of assets after deduction. As has been mentioned, the total logistics network cost of the HUB system, including transportation cost and terminal cost, is what is to be set for the PLN system. Terminal cost of the HUB should be computed first.

3.4.1 HUB system

The way of generating terminal operating cost of HUB is based on the operation in line-haul. There exists a strong relation between line-haul transportation and terminal operation. So setting a percentage of line-haul transportation, we can approximate the terminal operating cost. The operations in hub (or terminal) mostly are proportional to the needs of transfer. When line-haul transportation is heavy, the operations in terminals are even heavier due to the need to cooperate with truck schedules. On the report of Wanser and Zapfel [16], he presented the parcel delivery service with complete geographic coverage for a HUB system:

- Line-haul transportation: 15–25%
- Pickup and delivery costs 35–60%
- Depot (terminal) Operating cost: 25–45%

These percentages show that terminal operating cost is higher than line-haul transportation cost. We know that, in a HUB, the terminal operating cost could be greater or equal to line-haul transportation cost. For a highly efficient HUB system, the terminal operating cost may be closer to line-haul transportation cost. Therefore, this research set 100% of line-haul transportation cost for determining terminal operating cost in a HUB. On the other hand, terminal asset cost of a HUB is referred to UPS long-life asset in financial report which is provided in chapter 2. The process to find the terminal cost is shown in Figure 3.6. However, terminal operating cost and terminal asset cost are using different units. A cost transformation is required to calculate terminal cost by taking the present value of operating costs. A method for the cost transformation will be discussed in following sections.

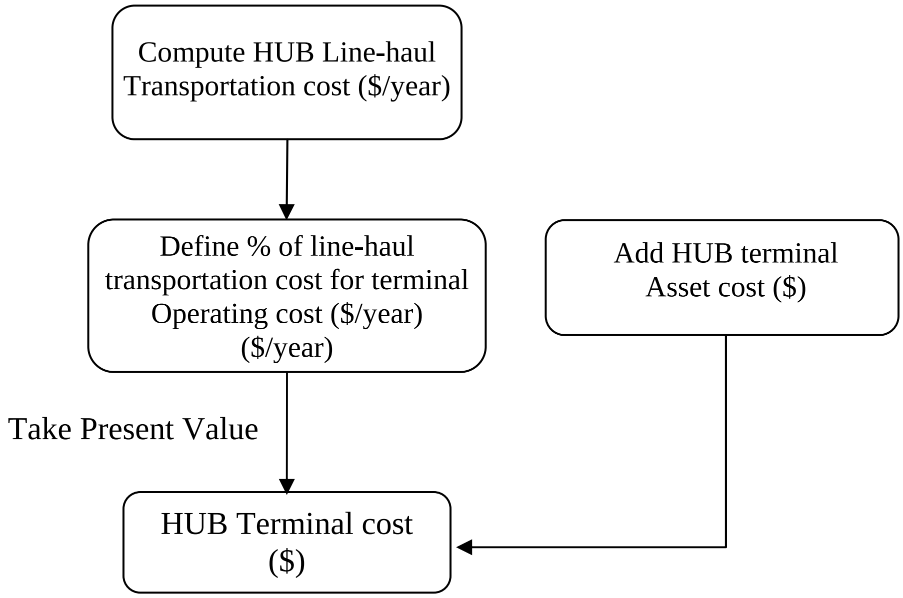

FIGURE 3.6 TERMINAL COST OF HUB SYSTEM

3.4.2 PLN system

For the PLN system, the terminal operating cost is zero because terminals are assumed to be fully automatic. Depending on the cooperation of plant equipment and technology equipment, the automatic sorting equipment should move and scan packages at the same time. However, since automatic terminals do not exist, we are not sure of what type of assets or equipment are needed. Depending on the same logistics network cost with a HUB system, which includes transportation cost and terminal cost, the discrepancy of transportation cost could be used to compensate for the HUB terminal cost. The process to calculate PLN terminal cost is shown in Figure 3.7.

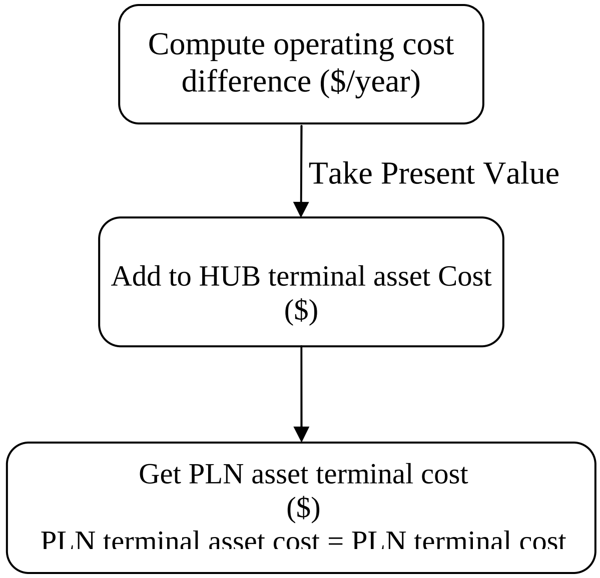

FIGURE 3.7 TERMINAL COSTS OF PLN SYSTEM

Once the line-haul transportation costs and P/D routing costs are computed, the difference of operating cost between the HUB and the PLN can be obtained. The information can provide the annual PLN saving in transportation. Transforming this difference of transportation cost in dollar based on the useful life of assets, adding it to the terminal cost in HUB, the PLN terminal cost can be generated. This terminal cost is an upper bound cost, below which the PLN manager can consider to import terminal assets.

3.5 PLN upper bound cost

After the PLN terminal asset cost is computed, the upper bound cost about terminal sorting cost is found. As we mentioned before, sorting is needed before a truck arrives in a PLN terminal. Terminal assets are designed to support the sorting. In order to fully use the capacity of a terminal, the size of the terminal should be evaluated. Generally, the size of a terminal can be divided into storage area and handling area as shown in Figure 3.8. Trucks unload packages in the storage area and move packages to the loading area for handling. Depending on the destination of the trucks, a sorting technology that robot arms pick up packages from the storage area, scanning them and put them on the handling area. The more trucks pass by the terminals, the sorting equipment are busier. Company should set more sorting equipment for the terminal where lots of transfers are needed. Finding a cost of sorting per truck stop is very helpful to determine the size of terminal for their demand and location.

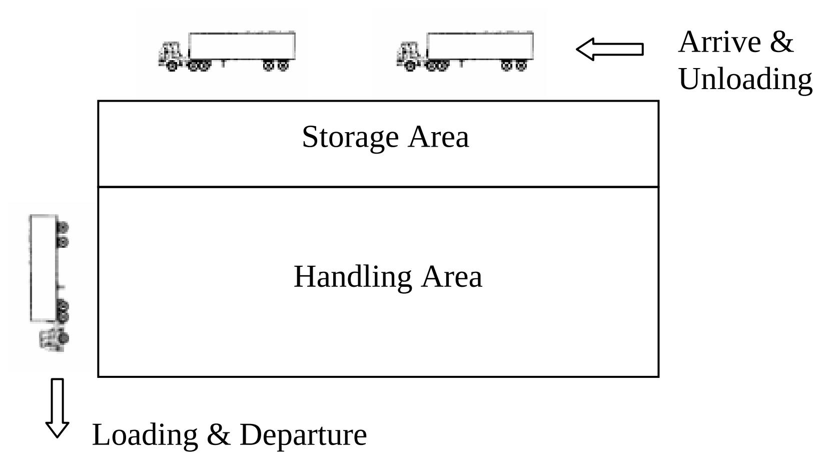

FIGURE 3.8 TERMINAL LAYOUT

The more sorting needs of a terminal, the more PLN should invest on its sorting equipment. The cost of sorting per truck stop is terminal asset cost divided by the daily number of sorting needs in a day. To calculate the number of sorting needs in the logistics system, we count the number of truck stops in line-haul transportation by MATLAB.

TAC: PLN upper bound terminal asset cost in whole logistics network ($)

NS: Daily number of sorting needs in the logistics network.

UBC: Upper bound sorting cost per truck stop ($)

$$UBC = TAC \div NS \tag{3.3}$$

Divide the upper bound terminal asset cost by the daily number of sorting needs, the upper bound sorting cost per truck stop is calculated. This upper bound sorting cost is an average value for overall logistics network system. The more daily number of sorting needs are in the logistics system, the lower the upper bound sorting cost per truck stop should be. This is used to keep the same logistics network cost with a HUB system.

3.6 Depreciation and Present value

The present value of assets depreciates according to accounting policy. This section makes clear the meaning of the asset value and provides economic formula for transforming operating cost and asset cost.

The assets in the balance sheet of financial report have been divided into fixed assets and current assets. Fixed assets are intended for continuing usage in the business, and examples are lands, vehicles, buildings, and machines. Current assets generally refer to costs of normal trades, such as stocks, debtors and cash. Current assets are not discussed in this research and we focused on fixed asset value when evaluating a HUB terminal asset cost. In the UPS financial report, the asset value is not the market value but the discounted expected net revenue in an accounting year. It is a value after depreciation. Fixed assets are recorded when they are bought and they continue to be recorded as cost throughout their useful lives. The asset values shown in the balance sheet are historical cost, not income-generating cost or market value. The fixed asset may be used up or become less useful for a variety of reasons. In accounting, depreciation is a charge designed to recognize the loss of service or assets. The most often used method of depreciation is straight-line method, which is used in UPS financial report, too.

Considering yearly operating costs to the logistics network, the initial investment for company, except asset cost, should include the operating costs. The operating cost can be evaluated based on the useful lives of setting asset. Using an economic formula, the operating present value can be obtained (Figure 3.9).

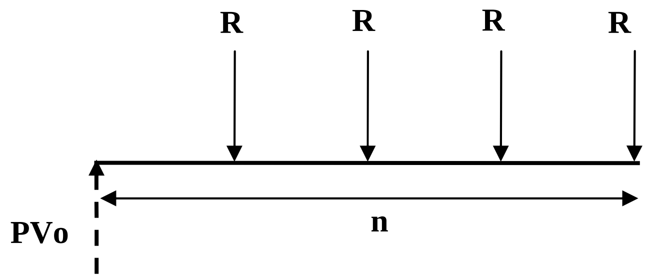

FIGURE 3.9 OPERATING PRESENT VALUE

Let n represent the useful life of assets and r is the market interest rate. The operating cost (R) is represented as dollar per year. The present value of operating cost (PV_0) is calculated in equation 3.4.

$$PV_0 = R \times \left(\frac{(1+r)^n - 1}{r \times (1+r)^n} \right) \tag{3.4}$$

3.7 Parcel transport cost

After all costs are computed, we can discuss the transportation cost for each package. For a package to be shipped, its transportation cost should be able to generate to its pricing policy. The transportation cost includes the line-haul transportation cost and the P/D routing cost. However, line-haul transportation and P/D routing use their own transportation resources. The resources for line-haul are shared by all packages and trucks, each line-haul cost per piece is an average costs in the whole logistics network. P/D cost per piece is determined within a range according to the packages to be handled in a van. In addition, the line-haul cost per piece is changed when the weight of the package is changed, but P/D cost is not affected by package weight. Package transportation cost per piece should be separated into line-haul and P/D and defined as equation (3.5)

$$PC = \frac{CL}{TD} + \frac{(VC + FP + CS)}{D} \tag{3.5}$$

Divide the total line haul costs by total daily demands and divide P/D cost per van by the number of packages in a carrier, we obtain the average line-haul cost per piece as well as P/D cost per piece as shown in equation (3.5). According to UPS prices charts, the rate of package cost varies with the travel distance and weight of package. With the knowledge of an average distance and package weight, this formula can be used to calculate parcel transportation cost for any shipping distance and any weight of package below 70 lbs.

4. Example

In this example, we demonstrate the reliability of our analytical procedure by applying the HUB and PLN logistics systems in a hypothetical network. In order to find the real data about truck, transportation data is collected in advance. The collected data can then be applied to the hypothetical network to obtain useful information for cost evaluation.

4.1 Hypothetical Network

To demonstrate an example, we use a hypothetical network to provide real data. This network, coving the southeastern United States, has a total of thirty-six public terminals that are connected by multiple interstate highways, as shown in Figure 4.1 [15]. Each number in the square represents a public terminal in which packages are consolidated. Line-haul trucks travel on highway and load/unload packages in these terminals.

The HUB logistics system consists of five individual five hubs, located in terminals number 4, 9, 12, 18, and 31. Packages collected from each public terminal (origin) will be sent to the nearest hub, sorted in the hub, and transferred to another hub that is the closest to the destination of terminal. Applying to the PLN logistics network, all terminals have the capability to sort. Packages are then directly transported to the packages' destination terminal. Both HUB and PLN line-haul truck paths are coded using Dijkstra's algorithm in MATLAB (Appendix E).

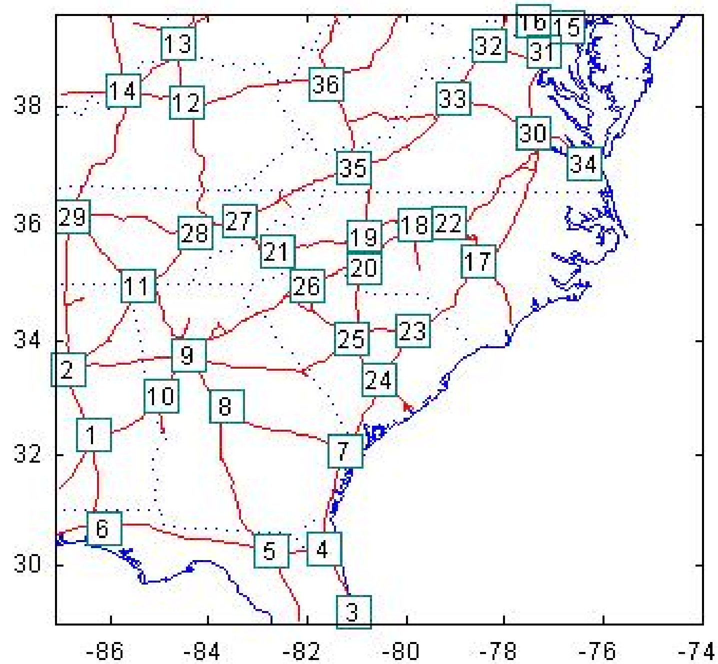

FIGURE 4.1 HYPOTHETICAL PUBLIC LOGISTICS NETWORK [15]

4.2 Assumptions

In the hypothetical network, some assumptions based on the trucking environment are made to reduce the complexity of cost evaluation.

1. The loading weight of a line-haul truck is fixed (truck capacity).
2. Daily demand is satisfied completely.
3. All the trucks and vans are rented.

In a real parcel shipping, the ground service usually has different price rates for different speeds of shipping service, such as “Next Day” and “3–5 Days.” Various truck schedules and truck capacity determine numbers of transport time, which create numerous logistics network costs. Therefore, the first two assumptions can limit our problem in one truck schedule and one truck capacity. For example, suppose there are a total of 500 packages waiting to be shipped in a terminal, and each truck is able to load 100 packages. Suppose trucks operate 8 hours a day, there will be a need of 5 trucks and the average waiting time for each package in the terminal is 1.6 hours (8 hrs/5 trucks). In order not to discuss the asset cost of transportation in the example, the third assumption is used to let vehicle asset cost equal zero. This asset cost incurred from buying and maintaining trucks or vans will be replaced by purchasing transportation or renting trucks from other trucking companies.

4.3 Parameters

4.3.1 MATLAB Parameters

The following variables are used for line-haul transportation in MATLAB.

- Loading time: 20, 25, 30 minutes. To have similar average transportation time as transportation service for both HUB and PLN, loading time in each terminal should be around 20–30 minutes to have similar average transport time with HUB [15].
- Line-haul truck speed: 60 mph [15]
- Load factor: on average 80% of entire truck capacity is utilized [15]
- Average mile per gallon: 8 miles (chapter 4.1)
- Truck operating time per day: 8 hours (chapter 4.1)
- Carriers daily work hour: 8 hours (chapter 4.1)

4.3.2 Trucking Data

It has been discussed in Chapter 3 that some data such as truck capacities, rented/purchased cost, fuel price, and carrier salaries, are needed for line-haul transportation costs. Here the data collected from U.S. Department of Transportation bureau of transportation statistics and economic census are important for transportation cost calculation.

Truck Capacity < 8000 pounds

As we have seen, to maintain a good highway system, truck size and weight have been chosen over highway safety and shipping needs. Truck size is defined by the length, height, and width; truck weight includes trailers and carrying products. In the data of vehicle inventory and survey in 2002 [32], truck sizes were categorized into four weight groups:

1. Light. The average vehicle weight is 10,000 pounds or less.
2. Medium. The average vehicle weight is 10,001 to 19,500 pounds.
3. Light-heavy. The average vehicle weight is 19,501 to 26,000 pounds.
4. Heavy-heavy. The average vehicle weight is 26,001 pounds or more.

Light trucks are the majority compared with other sizes of trucks. Trucks lighter than 6001 pounds, and those between 6001 and 8500 pounds are more prevalent than others. Light trucks are often used for frequent shipments in a need of parcel shipping. Line-haul trucks are assigned as a light truck that load parcels below 8000 pounds. We assumed three truck capacities, and the total weight of packages can be load in one truck, 4000, 6000, and 8000 pounds, respectively. These truck capacities are used for determining the number of loading packages for line-haul transportation.

Truck/Carriers Operating time = 8 hours per day

A carrier can be cumulatively drive up to 10 hours or be on duty up to 15 hours after the end of their last 8 consecutive hour break [26]. Local trucking operations rarely reach the 10 hours driving limit, though some reach the 15 hours on duty limit in peak period. LTL line-haul operations rarely exceed 12 hours for on-duty shifts and driving time are always within 10 hours.

Also, Commodity Flow Survey Transportation (CFS) [32] provided data on the movement of goods in the United States. It included the information of value, weight, and mode of transportation, as well as the origin and destination of shipments of manufacturing, mining, wholesale, and select retail establishments by mode of transportation [28]. Since CFS showed that for-hire trucks traveled 523 miles per shipment in average, and parcel shipping with multiple modes traveled 894 miles per shipment in average, shipping truck would travel lower than 894 even lower than 523 miles per shipment without using Air or Rail. If the average highway speed is 60 mph, trucks travel at least 8.7 hours in a shipment. Considering both for-hire truck operating time and LTL operations limitations, we conservatively estimate the truck operating time to be 8 hours per day.

Average Truck rental/ purchasing cost = $320 per day

The way to evaluate truck rental cost varies depending on different company policies or financial situations. For example, some companies, using their own trucks for regular 80% demands, may rent extra trucks to support special needs. Here, we want to get an average rental cost for one truck on a daily basis. Motor freight transportation and warehouse survey in 1995 [27] presented annual reports about transportation firms and public warehouse firms. The survey showed the detail of revenue and operation expense for all U.S. trucks and couriers by year. We organized related information of rented transportation and purchased transportation from 1993 to 1995 in Table 4.1.

To calculate the operating cost on transportation, the items of rental expense and purchased expense are considered as the transportation expense. Purchased transportation can be treated as cost of transportation service for peak time delivery or special carrying needs. Dividing purchased transportation by truck units, the yearly rental/purchased cost per truck is generated and daily total rental/purchased cost per truck is also computed by dividing 365 days/year. All the daily purchased/rental costs per truck are slightly above $300 dollars. Taking into account ten-year-old data, we inferred that line-haul transportation expenses should be higher than $309 and close to $320 by adding one dollar per year.

Table 4.1 Motor freight transportation and warehouse service, summary statistic, 1995 [27]

Truck and Courier	1993	1994	1995
Revenue (millions)	$143,601	$157,910	$165,271,
Operation expense Revenue (millions)	$135,144	$147,911	$155,920
Truck (units) Revenue (Thousands)	260	287	295
Rented transportation Revenue (millions)	$2,545	$2,732	$2,894
Purchased transportation Revenue (millions)	$26,678	$29,329	$30,379
Transportation Revenue (millions)	$29,223	$32,061	$33,273
Yearly purchased/rental cost per truck	$112,396.15	$111,710.80	$112,789.83
Daily purchased/rental cost per truck	$307.93	$306.06	$309.01

Average mile per gallon = 18 mile for line-haul truck and 8 mile for P/D van

The average mile per gallon of fuel is used in determining fuel consumption. Via the fuel consumption, the fuel cost is calculated as the fuel consumption multiplied by the price of fuel (current ¢ / gallon). We referenced the average mile per gallon from National Transportation Statistics (NTS) 2004 issued by the Bureau of Transportation Statistics [32]. The average miles per gallon of fuel for two types of trucks from years 2000 to 2003 are organized in Table 4.2.

Table 4.2 Average mile per gallon, miles [32]

	2000	2001	2002	2003
Average Motor vehicle	16.9	17.1	(R) 16.9	17.0
Other 2-Axle 4-Tire Vehicle	17.4	17.6	(R) 17.5	17.7
Single-Unit 2-Axle 6-Tire or More Truck	7.4	7.5	7.4	7.3

(R) = revised

Different kinds of trucks and their carrying weights result in different average mile per gallon. The reason for “Single-Unit 2-Axle 6-Tire or More” (truck) having the smallest miles traveled per gallon is because the weights they carried were heavier than other motor vehicles. Table 4.2 shows that the variance of those average miles per gallon is not significant. For the convenience of calculation, the data of average mile per gallon are rounded into an integer. The average mile traveled per gallon for line-haul truck is 8 miles (Single-Unit 2-Axle 6-Tire truck) and for P/D van is 18 miles (Other 2-Axle 4-Tire truck).

Carrier/driver Salary = $600 per week (5 days)

Drivers, conveyors, material movers, packager, and loaders are main occupations in trucking industry. Workers other than drivers work in the terminals. The average wage and salary of motor/truck industry was $36,945 per year in 2002. Table 4.3 shows full-time wages and salaries for these occupations in trucking industry. The median of weekly salary for a truck driver shown in Table 4.3 will be used to apply to both drivers of P/D routing van and drivers of line-haul trucks. Since the terminal operating cost is approximately estimated based on their line-haul transportation, the worker costs in terminals are already included.

Table 4.3 Earnings of Full-Time Wage and Salary Workers in Transportation by Detailed Occupation, ($/week) [32]

	2000	2001	2002	2003
Driver/sales workers and truck drivers	$551	$585	$599	$603
Conveyor operators and tenders	$465	$488	$350	$363
Laborers and freight, stock, and material movers, handler	$401	$426	$420	$464
Packers and packagers, hand	$313	$332	$338	$348
Tank car, truck, and ship loaders	$420	$703	$506	$589

4.4 Analytical Procedure

There are three steps in our analytical procedure: inputting constraints, computing costs, and estimating PLN upper bound costs. To find the PLN upper bound sorting cost in the hypothetical network, we demonstrate three steps in next to provide all costs data. With previous truck information, line-haul transportation costs and P/D routing cost may describe the real cost of parcel delivery. In the end of analytical procedure, the upper bound sorting cost would be found and is useful to evaluate the investment of PLN automatic terminals.

Step 1: Input constraints

Proximity factors: 0, 1, and 2 [15]

Total daily demand: Because 18% of the US population in the region is covered by the network [15], we assume total daily demand in the hypothetical system to be 18% of the average daily demand UPS domestic. The total demand that we use is equal to 2,300,400 packages from "U.S. domestic" in 2004 UPS financial report.

Expected Package Weight: No survey has provided their expected package value in detail. Some parcel delivery company might have smaller expected weight based on their major packages in market. For example, the major packages of FedEx are letters and document. Its expected package weight might be below 5 lb. Here, we assume that the percentage of packages is 50%, 30%, 10%, 7.5%, and 2.5% for the average weight of 10, 20, 30, 40, and 50 lbs respectively in the whole hypothetical network, the expected package weight is 18.25 lb.

Loading weight of trucks: 4000 lb, 6000 lb, and 8000 lb (chapter 4.1)

Loading weight of trucks determine the truck capacity for loading packages. With the package in weight of 18.25 lb, line-haul trucks can carry 219, 329 and 438 packages when the loading weights of truck are 4000 lb, 6000 lb and 8000 lb respectively.

Step 2: Compute Costs

We computed the number of trucks, the number of carriers, the gallons of gasoline and the number of sorting needs for both HUB and PLN (Appendix E) through these constraints. Using cost formula presented in chapter 3 and trucking data, line-haul transportation costs and P/D routing costs of HUB and PLN are computed. In this example, we provide the results of each cost and the results of running by MATLAB program are organized in Appendix C. The sequence of cost results of line-haul transportation cost, P/D transportation cost, and terminal cost are shown as follows. With three proximity factors and three sizes of trucks, we get nine results for each truck schedules. The average value of nine results can be used to represent real situation.

4.4.1 Line-haul transportation cost

Once constraints are inputted, number of trucks, number of carriers, and gallons of gasoline are computed by MATLAB (Appendix C). Also, with the rented/purchased truck cost, carrier daily salary, fuel cost per gallon presented, and average miles per gallon presented in chapter 4.1 and the equation (3.1), line-haul transportation costs for both HUB and PLN are calculated as shown in Table 4.4. There are nine results for both HUB and PLN because of giving three proximity factors and three sizes of truck capacities.

As described in chapter 2, it is because the traveling routes in a PLN are shorter than in a HUB. Table 4.3 also shows that the line-haul transportation costs of a PLN are less than that of a HUB. We concluded that PLN line haulage is efficient to ship in the line haulage. Besides, the line-haul transportation costs decrease with truck capacity. We know that using larger trucks can reduce line-haul transportation cost dramatically even though it causes a small amount of delay in wait-for-truck. (The average transportation times for the HUB and the PLN systems are provided in Appendix C.)

Table 4.4 Line-haul transportation daily cost, 18.25 lb

Proximate-factor	Truck Capacity (unit)	HUB	PLN
0	219	$7,027,872	$6,020,158
0	329	$4,678,164	$4,006,452
0	438	$3,514,016	$3,009,830
1	219	$6,270,334	$5,239,034
1	329	$4,174,228	$3,487,740
1	438	$3,136,198	$2,618,668
2	219	$5,525,230	$4,491,194
2	329	$3,678,842	$2,988,536
2	438	$2,763,264	$2,244,326
Average		$4,529,794	$3,789,549

4.4.2 Pick-up/Delivery routing cost

P/D routing cost was mentioned as an independent cost from line-haul transportation cost. A few assumptions are provided to compute P/D routing cost.

1. Average handled package per van, 100–150.One van might deliver 100–150 packages of any size in a day, and the average handled package of UPS is 130 packages/day [Michael L.E., UPS CEO, IIE Conference, Atlanta, GA].
2. Van and drivers work 8 hours a day
3. The average speed in the intercity area is 40 mph
4. The average travel miles per gallon are 18 miles/gallon.

The cost of operating a van is rental/purchasing fee $320 + gasoline cost $32 ($1.8/ gallon × 8 hour × 40 mph /18 mils per gallon) + van daily driver salary $120 ($ 600/week) = $472. With the daily basis of 2,300,400 packages, we estimated the number of van needs, daily total P/D cost, and P/D cost per piece shown in Table 4.5.

Table 4.5 Daily P/D routing cost

Handled Packages	Number of van needs	Daily P/D cost	P/D routing cost per package
100	23,004	$10,926,900	$4.72
110	20,913	$9,933,546	$4.29
120	19,170	$9,105,750	$3.93
130	17,695	$8,405,308	$3.63
140	16,431	$7,804,929	$3.37
150	15,336	$7,284,600	$3.15

Table 4.5 shows that daily P/D routing cost is around $7–11 millions in the hypothetical network. With assuming the same cost on operating a van, the more packages can be shipped in one van, the less P/D routing costs are. Therefore, improving the average handled package is the only key to reduce P/D routing cost. Also, if we divide daily P/D routing cost by daily demand, the average P/D routing cost per package is found. In this case, a range of P/D cost per package is between $3.15 and $4.72. For some express delivery service, a van might carry fewer packages and causes vary high P/D routing cost.

4.4.3 Terminal cost

Terminal cost includes terminal operating cost and terminal asset cost. For the larger number of sort needs of the PLN (Appendix C), PLN certainly needs more terminal cost than that of HUB. Based on the assumption that logistics network cost of PLN is equal to that of HUB, terminal costs of PLN would be computed when HUB costs are known. The results of terminal operating costs and terminal asset costs of HUB and PLN are discussed below.

Terminal Operating cost ($/ day) ($/year)

Terminal operating costs for a HUB and a PLN are presumed by two assumptions. Terminal operating cost of a HUB is assumed to be equal to line-haul transportation cost of HUB ($4,529,794/day). Terminal operating cost of a PLN, by assuming fully automatic sorting in terminals, is equal to zero dollars a day.

On the other hand, we will need yearly operating cost to operate with asset cost. Depending on the operating day for UPS in 2004, say 254, the daily operating cost should also use the same operating days to compute yearly operating cost. The yearly operating costs of line-haul transportation, P/D routing and terminal are shown in Table 4.6. HUB transportation costs minus PLN transportation cost is the saving in transportation cost for the PLN which is shown as a difference in Table 4.6.

Table 4.6 Operating Cost Summary report

Operating cost ($/year)	HUB system	PLN system	Difference
Line-haul transportation cost	$1,150,567,732	$962,545,361	$188,022,371
P/D transportation cost	$2,134,948,154	$2,134,948,154	$0
Terminal operating cost	$1,150,567,732	$0	$1,150,567,732
Total operating cost ($/year)	$4,436,083,619	$3,099,990,531	$1,338,590,104

In Table 4.6, first, we observed that the line-haul transportation cost in the PLN is almost 10% less than in the HUB. Using automatic sorting system can save $1.15 billions per year in terminal operation. In summary, the difference of total operating cost shows using a PLN system would save around $1.34 billions per year. That saving allows the manager to enhance automatic sorting equipment for 36 PLN terminals.

Terminal Asset cost

Asset costs for a parcel delivery company are hard to estimate due to unknown demand and location. In the hypothetical network, both HUB and PLN set terminals at the same locations. The building asset cost would not be discussed in this research. UPS asset costs, especially for plant and technology assets, are very helpful information for the HUB system. Taking 18% of those UPS assets, the asset cost of HUB for the hypothetical network is approximated in Table 4.7. The HUB system in the hypothetic network would need $1,122 billion for moving and scanning packages. The useful lives and values of assets are shown in Table 4.7.

Table 4.7 HUB asset present value

Asset cost ($)	Useful life (years)	18% UPS asset value, 2004
Plant Equipment	5	$835,380,000
Technology equipment	8	$287,280,000
Total		$1,122,660,000

Since the logistics network cost of the HUB is known, we can start to estimate the upper bound cost for the PLN terminals. The process and results are shown in Figure 4.2 and Table 4.8. With the cost saving from the different operating cost between HUB and PLN, PLN would invest these saving from operating cost to enhance sorting equipments. If sorting equipments are designed to operate for 5 years, there would be a savings of 5-year operating cost for PLN terminals. Therefore, the upper bound sorting cost of the PLN includes to *n*-year operating costs saving plus terminal asset cost of HUB. However, due to the unit difference in the operating costs and the asset costs, we use economic formula to transform operating cost into a present value.

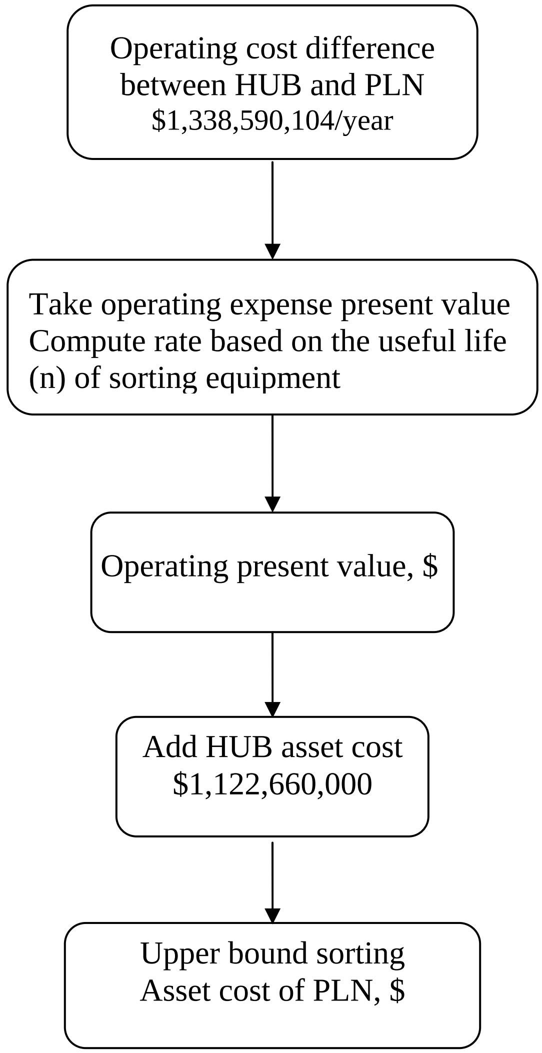

FIGURE 4.2 PLN ASSET COSTS

Assuming 5% interest rate per year, a transformation rate is computed as shown in equipment (3.4). The rate is interpreted as a present value for investing one dollar every year for *n* years as shown in Figure 4.3. Based on the useful lives of UPS assets, we consider that the possible useful lives of PLN terminal assets are from 4–10 years as shown in Table 4.8. Multiplying the different operating cost with the transformation rate, the present values of those different operating costs are listed in Table 4.8. Adding to terminal asset cost of the HUB, the upper bound PLN sorting costs can be computed and represent the maximum cost of automatic sorting equipments with n useful lives.

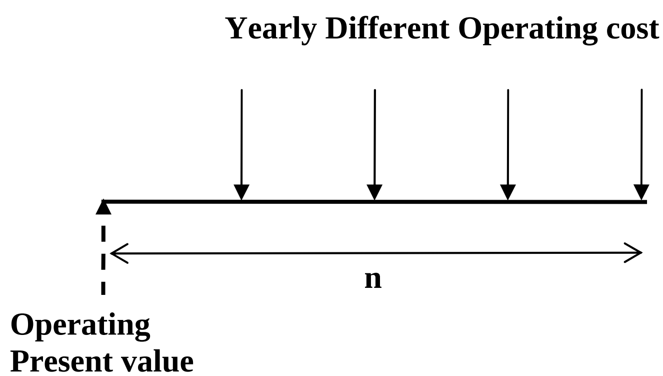

FIGURE 4.3 OPERATING PRESENT VALUE

For whole 36-terminals in the hypothetical network, the upper bound sorting asset costs of PLN terminals is from $5.8 billions for 4-year sorting equipments to $11.5 billion for 10-year sorting equipment. The longer the useful life, the larger upper bound sorting asset cost should be due to more saving from yearly operating cost to PLN. As shown in the third column of Table 4.8, PLN terminals may be able to save $10.3 billion for 10-year sorting equipments.

Table 4.8 PLN upper bound sorting asset cost

Useful life (n)	Rate	Operating cost Difference ($)	Upper bound asset cost ($)
4	3.55	$4,746,574,253	$5,869,234,253
5	4.33	$5,795,394,625	$6,918,054,625
6	5.08	$6,794,271,170	$7,916,931,170
7	5.79	$7,745,582,165	$8,868,242,165
8	6.46	$8,651,592,637	$9,774,252,637
9	7.11	$9,514,459,753	$10,637,119,753
10	7.72	$10,336,237,958	$11,458,897,958

Step 3: Get upper bound sorting cost for PLN

Upper bound Sorting Cost

After finding the upper bound sorting asset cost, we are able to provide average terminal asset cost for each terminal. First, dividing the upper bound sorting cost by number of terminals, the average sorting asset cost per terminal is generated for general situation. Second, dividing upper bound sorting asset cost by total number of sorting needs, the upper bound sorting cost per truck stop is provided to fit diversity sizes of terminals. Some terminals might handle fewer sorting in hundreds per day; others might handle lots of sorting due to thousands of truck passing in a day. Therefore, the numbers of sorting needs for the HUB and the PLN are computed in MATLAB. The average numbers of sorting needs for the HUB and for PLN separately are 18,351 and 63,913 (Appendix C). Due to the number of sorting needs, we know that the terminals of the PLN are much busier than those of the HUB. These two upper bound results for the hypothetical network are demonstrated in Table 4.9.

Table 4.9 PLN asset cost and upper bound sorting cost per truck stop

Useful life (n)	Rate	PLN Upper bound asset cost ($)	Average terminal asset cost ($)	Upper bound sorting cost per truck stop ($)
4	3.55	$5,869,234,253	$163,034,285	$91,832
5	4.33	$6,918,054,625	$192,168,184	$108,242
6	5.08	$7,916,931,170	$219,914,755	$123,870
7	5.79	$8,868,242,165	$246,340,060	$138,755
8	6.46	$9,774,252,637	$271,507,018	$152,931
9	7.11	$10,637,119,753	$295,475,549	$166,431
10	7.72	$11,458,897,958	$318,302,721	$179,289

Suppose there is a terminal that handles 1000 trucks per day and sorting equipment is designed to have a 5-year life, the upper bound sorting cost of the terminal would be $108 million, which equal to the value of upper bound sorting cost per truck times 1000 loads. If a PLN terminal manager proposed a lower asset cost than the upper bound cost provided in Table 4.8, this terminal would be cost-efficient to the PLN system.

4.5 Example Discussion

4.5.1 Operating cost

As mentioned, the operating cost includes line-haul transportation cost, terminal operating cost, and P/D routing cost. To reduce the operating cost, we look at the percentages of operating costs in the hypothetical logistics network. Depending on handled packages may happen for P/D routing, we analyzed the operating costs. These operating costs on yearly basis are organized for HUB in Table 4.10 and for PLN in Table 4.11.

Table 4.10 Line-haul cost, P/D routing cost and Terminal operating cost in HUB

Handled Packages	P/D routing	Line-haul transport	Terminal operating cost
100	$10,926,900	$4,529,794	$4,529,794
110	$9,933,545	$4,529,794	$4,529,794
120	$9,105,750	$4,529,794	$4,529,794
130	$8,405,308	$4,529,794	$4,529,794
140	$7,804,929	$4,529,794	$4,529,794
150	$7,284,600	$4,529,794	$4,529,794
Handled Packages	P/D routing %	Line-haulage %	Terminal operation %
100	55%	22.66%	22.66%
110	52%	23.85%	23.85%
120	50%	24.94%	24.94%
130	48%	25.94%	25.94%
140	46%	26.86%	26.86%
150	45%	27.72%	27.72%

In the Table 4.10, we can see that the percentages of P/D routing cost are around 50% of overall operating costs. P/D routing is the key issue if we want to improve the efficiency of HUB logistics network. Kee-haug Lai also concluded the percentages of P/D routing cost is around 50% of overall operation cost in the HUB system [5]. Because these percentage are closer to results presented by Lai and Michael [5] [15], we believe that the logistics network cost of HUB is reliable.

Table 4.11 Line-haul cost, P/D routing cost and Terminal operating cost in PLN

Handled Packages	P/D routing	Line-haul transport	Terminal operating cost
100	$10,926,900	$3,789,549	$0
110	$9,933,545	$3,789,549	$0
120	$9,105,750	$3,789,549	$0
130	$8,405,308	$3,789,549	$0
140	$7,804,929	$3,789,549	$0
150	$7,284,600	$3,789,549	$0
Handled Packages	P/D routing %	Line-haulage %	Terminal Operation %
100	74.25%	25.75%	0.00%
110	72.39%	27.61%	0.00%
120	70.61%	29.39%	0.00%
130	68.93%	31.07%	0.00%
140	67.32%	32.68%	0.00%
150	65.78%	34.22%	0.00%

On the other hand, Table 4.11 shows that P/D routing is very high because of zero terminal operating cost. The percentages of P/D routing illustrate that operation of PLN will spent most operating cost on P/D routing. P/D routing becomes a very important issue for applying PLN in order to improve operating cost.

4.5.2 Parcel transport cost

After discussing operating costs, we further present parcel transport cost for parcel shippers. Based on the equation (3.6), parcel transport cost is able to be estimated after line-haul cost and P/D routing cost. By analyzing transport distance for parcel within the hypothetical network, it helps us to compare results of parcel transport costs to UPS prices.

In this example, at first, the average parcel transport cost for an 18.25 lb package is generated. Then the other parcel transport costs for other weights of package can be calculated based on the ratio of weight to 18.25 lbs, especial for the line-haul transportation. As for the P/D routing, however, shipping cost for the parcel is kept the same, no matter the weights of package or shipping distance. For example, the weight of a 5 lb package is 27% of an 18.25 lb package and the line-haul transportation cost for the 18.25 lb package is $5. The line-haul cost for such a 5 lb package is taking $5 times 27%, i.e., $1.35. In contrast, the P/D routing cost for the 18.25 lb package is the same as shipping the 5 lb parcel. By summing these two stage (Line-haul transportation and P/D routing) costs, the average parcel transport cost for any weight of packages can be decided.

On the other hand, since UPS is the most shippers' preference, their prices can be the index to evaluate our results. As shown in chapter 2, the UPS prices varied with zones (shipping distance) and weight of packages. Since we have discussed the weights of packages as shown above, the average travel distances will help us to decide the specific zone of UPS, which we need to compare for the hypothetical network. The average travel distances of HUB and PLN are affected by the proximate factors to the locations of shippers and destinations. We provide the average travel distance of shipping one trip with proximate factors in Table 4.12.

Table 4.12 shows that the average travel distance of HUB is longer than that of PLN, and both the average travel distances of the HUB system and the PLN system are around 300-500 miles. Based on the a study of UPS zone in Appendix D, a package shipped between 150 mile and 450 miles would cost as the price rate in the zone 3. This means that most of shipments in the hypothetical network would fall into the zone 3 of UPS.

Table 4.12 Average travel distance, miles

P	Hub	PLN
0	468.81	401.58
1	412.58	345.19
2	357.47	290.82
Average	412.95	345.87

Since trucking is the only transportation mode in the example, UPS prices in zone 3 of Residential ground service can be a good index for us. In the HUB system, average line-haul cost per 18.25 lb is $3.94 (line-haul cost dividing by total demand) and P/D routing cost per piece is around $3.15 – $4.72 (Table 4.4). As for the PLN system, the average line-haul cost per 18.25 lb is $1.65 (line-haul cost dividing by total demand) and P/D routing cost per piece is still around $3.15 – $4.72. By adding P/D routing transport cost per piece to line-haul cost per piece, the range of parcel transport cost of HUB is shown in Table 4.13, and the parcel transport costs of PLN are demonstrated in Table 4.14.

There are two issues that we should be careful of when we compare average transport costs of HUB with UPS prices. One is delivery days and the other is transportation modes. As we explained in chapter 2, ground service of UPS usually takes 5–7 days to ship and might use trains as line-haul transportation mode. However, we assumed all shipments in the example are shipped within one day. Its must cover higher costs than ground service of UPS.

Table 4.13 Package transport cost per piece and UPS zone 3 prices, HUB

lb	Long-haul transportation cost Per piece	Parcel transport cost	Residential (Zone 3)
5	$1.08	$4.23–$5.80	$5.79
10	$2.16	$5.31–$6.88	$6.45
15	$3.24	$6.39–$7.96	$7.39
20	$4.32	$7.46–$9.04	$8.38
25	$5.40	$8.54–$10.12	$9.42
30	$6.48	$9.62–$11.20	$10.37
35	$7.56	$10.70–$12.28	$11.38
40	$8.64	$11.78–$13.36	$12.41
45	$9.72	$12.86–$14.44	$13.39
50	$10.79	$13.94–$15.51	$14.23
55	$11.87	$15.02–$16.59	$14.83
60	$12.95	$16.10–$17.67	$15.42
65	$14.03	$17.18–$18.75	$15.95
70	$15.11	$18.26–$19.83	$16.48

To see the results in Table 4.14, most UPS zone 3 prices (below 50 lb) are within the average transport cost of HUB. Based on one-delivery and trucking in the hypothetical network, we believe that the average transport cost of HUB can represent the cost of UPS in the southeast trucking shipping.

Based on the results of Table 4.14, we found that most UPS zone 3 prices are higher than the ranges of parcel transport costs. In addition, by comparing the average transport costs for HUB and PLN systems, the results show that PLN can provide lower-cost service than HUB had. In order to keep low cost for such high sorting need network of PLN, PLN users should decrease the other internal expenses in sorting and scanning.

Table 4.14 Package transport cost per piece and UPS zone 3 prices, PLN

lb	Long-haul transportation cost Per piece	Parcel transport cost	Residential (Zone 3)
5	$0.45	$3.60–$5.17	$5.79
10	$0.90	$4.05–$5.62	$6.45
15	$1.36	$4.50–$6.08	$7.39
20	$1.81	$4.95–$6.53	$8.38
25	$2.26	$5.41–$6.98	$9.42
30	$2.71	$5.86–$7.43	$10.37
35	$3.16	$6.31–$7.88	$11.38
40	$3.62	$6.76–$8.34	$12.41
45	$4.07	$7.22–$8.79	$13.39
50	$4.52	$7.67–$9.24	$14.23
55	$4.97	$8.12–$9.69	$14.83
60	$5.42	$8.57–$10.14	$15.42
65	$5.88	$9.02–$10.60	$15.95
70	$6.33	$9.48–$11.05	$16.48

4.5.3 Total logistics network cost

Without including building construction cost, total logistics network cost is the summation of network operating cost and sorting asset cost. As shown in Table 4.4, operating costs are varied when the average handled package per van is changed. Taking operating cost of 130 average handled packages as the target value, logistics network cost for HUB system are organized in Table 4.15. Table 4.15 contains one fixed sorting equipment cost which derived from UPS and some operating present values depended on possible useful lives. Also, taking the operating cost of 130 average handled packages as target value, logistics network cost for PLN system are presented in Table 4.16. In contrast, Table 4.16 includes some sorting asset costs with designed useful lives and multiple operating present values for these useful lives of sorting equipments.

Table 4.15 Logistics network cost, HUB system

n	Rate	Sorting equipment cost ($)	Operating present values ($)	Total Logistic network cost ($)
4	3.55	$1,122,660,000	$15,738,987,237	$16,861,647,237
5	4.33	$1,122,660,000	$19,216,731,306	$20,339,391,306
6	5.08	$1,122,660,000	$22,528,868,515	$23,651,528,515
7	5.79	$1,122,660,000	$25,683,284,903	$26,805,944,903
8	6.46	$1,122,660,000	$28,687,490,988	$29,810,150,988
9	7.11	$1,122,660,000	$31,548,639,640	$32,671,299,640
10	7.72	$1,122,660,000	$34,273,543,118	$35,396,203,118
Average of total logistics network cost				$26,505,166,530

Table 4.16 Logistics network cost, PLN system

n	Rate	Upper bound Sorting equipment cost ($)	Operating present values ($)	Total Logistics network cost ($)
4	3.55	$5,869,234,253	$10,992,412,985	$16,861,647,237
5	4.33	$6,918,054,625	$13,421,336,681	$20,339,391,306
6	5.08	$7,916,931,170	$15,734,597,345	$23,651,528,515
7	5.79	$8,868,242,165	$17,937,702,738	$26,805,944,903
8	6.46	$9,774,252,637	$20,035,898,351	$29,810,150,988
9	7.11	$10,637,119,753	$22,034,179,887	$32,671,299,640
10	7.72	$11,458,897,958	$23,937,305,160	$35,396,203,118
Average of total logistics network cost				$26,505,166,530

Through Table 4.15 and Table 4.16, we showed that both logistics network costs for the HUB and PLN system are identical as we assumed in chapter 3. If the results of total logistics network cost for HUB can represent costs that UPS spend in the southeast area, we would expect PLN to provide the same or even less cost. When a PLN is able to install sorting equipment less than the sorting equipment costs showing in Table 4.16, the PLN system would be worthy to implement.

5. Conclusion and Future work

In this report, we focused on the logistics network cost on ground delivery. It included line-haul transportation cost, P/D routing cost, and terminals cost. Since a PLN allows each terminal to sort packages, it will need automatic equipment in its terminals. To determine the upper bound sorting cost for the PLN system, we provided an analytical procedure to find upper bound sorting cost for PLN. We calculated the line-haul transportation costs and P/D routing costs in the first, and then through the UPS financial report to see how much cost HUB system needs in assets. Based on the assumption of the same logistics network costs between HUB and PLN, we used a economic cost transformation to find the present value of PLN upper bound sorting cost. In the hypothetical network with 36-terminals, the relationships between line-haul transportation costs, P/D routing costs and terminal costs were discussed. We concluded as follows:

- The P/D routing cost plays a very important role for both HUB and PLN, especial for PLN. It costs more than 50 % of total operating cost in the logistics network.
- The hypothetical network might need $26.5 billions to ship 2,300,400 packages by trucks. This cost includes transportation cost and terminal cost.
- By comparing parcel transport costs and UPS zone 3 prices, we found the parcel transport cost of HUB is good enough to stand for the situation of UPS, and PLN is able to provide lower parcel transport cost than HUB.
- Based on the collected truck data, we found the upper bound sorting cost for the PLN system may need around $5-11 billions to operate 4–10 years. For each terminal, its upper bound cost is around $163–318 millions to operate 4–10 years. As the useful lives of terminals increased, the ranges of upper bound costs also increased.

The extension of PLN study is to use the upper bound sorting costs per truck stop to design automatic sorting equipment. Since existing sorting technologies are only cost-efficient for one large sorting requirement in hubs, a new concept of sorting technology needs to be developed cost-efficiency for smaller terminals. A survey of evaluating current sorting technology would help further details cost analysis for terminal assets. In addition, since upper bound cost would be varied with the input constraints and parameters, a sensitive analysis by using a simulation will be very important for controlling the operations of terminals. Via the automatic sorting equipment settled in the terminals, it will be possible for small cities or towns to have a low-cost and fast parcel delivery service (e.g., same-day and next-morning), that are currently only available in larger cities by applying PLN into local area.

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Appendix A: National Transportation Statistics (NTS) 2004

Chapter 1 in NTS provides data on the extent, condition, use, and performance of the physical transportation network. Chapter 2 in NTS details transportation's safety record, giving data on accidents, crashes, fatalities, and injuries for each mode and hazardous materials. Chapter 3 in NTS focuses on the relationship between transportation and the economy, presenting data on the contribution of transportation to the gross domestic product on employment by industry and occupation, and transportation-related consumer and government expenditures. Chapter 4 I NTS presents data on transportation energy use and transportation-related environmental impacts. Data relative to fuel consumptions of trucks were shown in chapter 4 of the report and employee's salaries were shown in chapter 3 of the report.

http://www.bts.gov/publications/national_transportation_statistics/

Table 1-21 Numbers of Trucks by Weight, [32]

	Thousands of trucks		
	1992	**1997**	**2002**
ALL trucks	**59,200.8**	**72,800.3**	**85,174.8**
Light Trucks			
Less than 6,001 lb	50,545.7	62,798.4	62,617.3
Medium Trucks			
6,001 to 10,000 lb	4,647.5	5,301.5	17,142.3
10,001 to 14,000 lb	694.3	818.9	1,142.1
14,001 to 16,000 lb	282.4	315.9	395.9
16,001 to 19,500 lb	282.3	300.8	376.1
Light-heavy Trucks			
19,501 to 26,000 lb	732.0	729.3	910.3
Heavy Trucks			
26,001 to 33,000 lb	387.3	427.7	436.8
33,001 to 40,000 lb	232.6	256.7	228.8
40,001 to 50,000 lb	338.6	399.9	318.4
50,001 to 60,000 lb	226.7	311.4	326.6
60,001 to 80,000 lb	781.1	1,069.8	1,178.7
80,001 to 100,000 lb	33.3	46.3	68.9
100,001 to 130,000 lb	12.3	17.9	26.4
130,000 lb or more	4.6	5.9	6.3
Not reported	<50	<50	N

KEY: lb = pound; N = data do not exist.

Adapted from Table 3-8 Sales Price of Transportation Fuel to End-Users (Current ¢ / gallon), [32]

	1999	2000	2001	2002	2003	2004
Aviation fuel (excluding taxes)						
Aviation gasoline[a]	105.9	130.6	132.3	128.8	149.3	182.3
Jet fuel kerosene[a]	54.3	89.9	77.5	72.1	(R) 87.2	120.7
Highway fuel (including taxes)						
Gasoline, premium[b]	135.7	169.3	165.7	155.6	177.7	206.8
Gasoline, regular[b]	116.5	151.0	146.1	135.8	159.1	188.0
Gasoline, all types	122.1	156.3	153.1	144.1	163.8	192.3
Diesel no. 2 (excluding taxes)[a]	58.4	93.5	84.2	76.2	(R) 94.4	124.2
Railroad fuel						
Diesel	55.5	87.5	85.5	73.3	89.3	U

KEY: R = revised; U = data are not available.

[a] Sales to end-users (those sales made directly to the ultimate consumer, including bulk customers in agriculture, industry, and utility).

b Average retail price.

Adapted from Table 3-21a Average Wage and Salary Accruals per Full-Time Equivalent Employee by Transportation Industry (Standard Industrial Classification [SIC] basis)b (Current $), [32]

	1995	1996	1997	1998	1999	2000
All industries	31,034	32,087	33,490	35,201	36,754	38,846
Transportation, total	**32,283**	**33,074**	**34,407**	**35,907**	**37,178**	**38,484**
Air	36,419	36,989	38,691	40,441	42,523	43,820
Trucking and warehousing	29,605	30,342	31,754	32,949	34,007	35,024
Local and interurban passenger transit	19,980	20,648	21,219	22,008	22,792	23,745
Railroad	50,465	55,299	57,235	60,632	60,623	62,673
Water	37,769	38,857	40,329	42,317	43,436	44,980
Pipelines, except natural gas	58,186	54,782	58,881	64,991	65,379	66,540
Transportation services	30,801	31,511	32,794	34,603	36,204	38,602

a Wages do not include supplements to wages and salaries such as pension, profit-sharing, and other retirement plans, and health, life, and unemployment insurance compensation.

b The data in this table have been revised as a result of the Bureau of Economic Analysis' comprehensive revision of the National Income and Product Accounts (NIPA).

c Establishments furnishing services incidental to transportation, such as forwarding and packing services and the arrangement of passenger and freight transportation.

Adapted from Table 3-22a Median Weekly Earnings of Full-Time Wage and Salary Workers in Transportation by Detailed Occupation (Current $), [32]

	1997	**1998**	**1999**	**2000**	**2001**	**2002**
All occupations	**503**	**523**	**549**	**576**	**597**	**609**
Airplane pilots and navigators	1,079	1,383	1,048	1,283	1,150	1,245
Public transportation attendants	521	524	604	568	552	611
Motor vehicle operators	496	503	514	543	575	582
Supervisors, motor vehicle operators	589	595	585	688	609	688
Truck drivers	506	516	527	564	593	600
Drivers-sales workers	524	526	534	558	630	600
Bus drivers	405	428	428	460	457	493
Taxicab drivers and chauffeurs	405	379	427	468	487	476
Non motor vehicle operators	761	834	761	816	911	884
Rail transportation operators	814	849	816	863	947	866
Water transportation	641	812	604	778	794	934

a Earnings for all full-time workers, 16 years and older workers, not just transportation related.

Adapted from Table 3-22b Median Weekly Earnings of Full-Time Wage and Salary Workers in transportation by Detailed Occupation (Current $), [32]

	2000	2001	2002	2003
All occupations	**576**	**596**	**608**	**620**
Transportation and material moving occupations	**481**	**504**	**514**	**520**
Driver/sales workers and truck drivers	551	585	599	603
Taxi drivers and chauffeurs	451	484	488	481
Motor vehicle operators, all other	509	508	409	353
Locomotive engineers and operators	870	953	963	925
Railroad brake, signal, and operators	689	753	792	880
Railroad conductors and yardmasters	817	927	818	884
Subway, and other rail transportation workers	754	727	579	515
Sailors and marine	508	697	701	616
Ship and boat captains and operators	779	848	899	944
Ship engineers	712	1,190	1,181	1,154
Bridge and lock tenders	935	560	667	726
Parking lot attendants	316	329	341	350
Service station attendants	314	335	362	369
Transportation inspectors	731	696	747	847
Other transportation workers	483	491	645	652
Conveyor operators and tenders	465	488	350	363
Crane and tower operators	675	688	694	589
Dredge, excavating, and loading machine operators	572	617	602	653
Hoist and winch operators	733	610	604	789
Industrial truck and tractor operators	448	477	499	488
Cleaners of vehicles and equipment	361	363	354	373
Laborers and freight, stock, and material movers, hand	401	426	420	464
Machine feeders and off bearers	412	403	433	437
Packers and packagers, hand	313	332	338	348
Pumping station operators	730	622	786	801
Refuse and recyclable material collectors	435	505	430	456
Shuttle car operators	992	696	1,030	741
Tank car, truck, and ship loaders	420	703	506	589
Material moving workers, all other	491	463	516	515

Adapted from Table 4-12 Other 2-Axle 4-Tire Vehicle Fuel Consumption and Travel, [32]

	1998	1999	2000	2001	2002	2003
Number registered (thousands)	71,330	75,356	79,085	84,188	85,011	87,032
Vehicle-miles traveled (millions)	868,275	901,022	923,059	943,207	(R) 966,034	998,004
Fuel consumed (million gallons)	50,462	52,859	52,939	53,522	(R) 55,220	56,302
Average miles traveled per vehicle (thousands)	12.2	12.0	11.7	11.2	11.4	11.5
Average miles traveled per gallon	17.2	17.0	17.4	17.6	(R) 17.5	17.7
Average fuel consumed per vehicle (gallons)	707	701	669	636	(R) 650	647

KEY: R = revised.

Adapted from Table 4-13 Single-Unit 2-Axle 6-Tire or More Truck Fuel Consumption and Travel, [32]

	1998	1999	2000	2001	2002	2003
Number registered (thousands)	5,735	5,763	5,926	5,704	5,651	5,667
Vehicle-miles (millions)	68,021	70,304	70,500	72,448	(R) 75,866	77,562
Fuel consumed (million gallons)	6,817	9,372	9,563	9,667	(R) 10,321	10,690
Average miles traveled per vehicle (thousands)	11.9	12.2	11.9	12.7	13.4	13.7
Average miles traveled per gallon	10.0	7.5	7.4	7.5	7.4	7.3
Average fuel consumed per vehicle (gallons)	1,189	1,626	1,614	1,695	(R) 1,826	(R) 1,886

KEY: R = revised.

Appendix B: Commodity Flow Survey (CFS) 2002 - United States

This report presents data from the 2002 Commodity Flow Survey (CFS) on the movement of raw materials and products shipped by manufacturing, mining, wholesale, and selected retail establishments in the United States. The data cover domestic shipments plus exports but exclude imports. The report provides information on commodities shipped, their value, weight, size, distance shipped, and mode of transportation as well as the origin and destination of shipments.

The 2002 CFS is undertaken through a partnership between the U.S. Census Bureau, U.S. Department of Commerce, and the Bureau of Transportation Statistics (BTS), U.S. Department of Transportation. This survey produces data on the movement of goods in the United States. It provides information on commodities shipped, their value, weight, and mode of transportation, as well as the origin and destination of shipments of manufacturing, mining, wholesale, and select retail establishments. The data from the CFS are used by public policy analysts and for transportation planning and decision making to assess the demand for transportation facilities and services, energy use, and safety risk and environmental concerns. The CFS was last conducted in 1997.

https://www.bts.gov/pdc/user/products/src/products.xml?p=1836&c=-1

Adapted from Table 1a Shipment Characteristics by Mode of Transportation for the United States 2002, [28]

Mode of Transportation	Value 2002 (million $)	Tons 2002 (thousands)	Ton-Mile 2002 (millions)	Average miles per shipment
Total	8,397,210	11,667,919	3,137,898	546
Single modes	7,049,383	11,086,660	2,867,938	240
Truck (2)	6,235,001	7,842,836	1,255,908	173
For-hire truck	3,757,114	3,657,333	959,610	523
Private truck	2,445,288	4,149,658	291,114	64
Rail	310,884	1,873,884	1,261,612	807
Water	89,344	681,227	282,659	568
Shallow draft	57,467	458,577	211,501	450
Great Lakes	843	38,041	13,808	339
Deep draft	31,034	184,610	57,350	664
Air (incl truck and air)	264,959	3,760	5,835	1,919
Pipeline (3)	149,195	684,953	S	S
Multiple modes	1,079,185	216,686	225,715	895
Parcel, U.S.P.S. or courier	987,746	25,513	19,004	894
Truck and rail	69,929	42,984	45,525	1,413
Truck and water	14,359	23,299	32,413	1,950
Rail and water	3,329	105,107	114,986	957
Other multiple modes	3,822	19,782	13,788	S
Other and unknown modes	268,642	364,573	44,245	130

(1) Ton–miles estimates are based on estimated distances traveled along a modeled transportation network. See the "Mileage Calculation" section for additional information.

(2) "Truck" as a single mode includes shipment that were made by only private truck only for-hire truck, or a combination of private and for-hire truck.

(3) Estimates for pipeline exclude shipments of crude petroleum.

Appendix C: Hypothetical Network Example MATLAB Results

Package weight = 18.75 lb

Loading weight of truck = 4000, 6000, 8000

Average Time for the weight of 18.25 lb package

		Lt = 20		**Lt= 25**		**Lt = 30**	
Proximity Factor	Capacity	Hub	PLN	Hub	PLN	Hub	PLN
0	219	9.56	9.33	9.93	9.97	10.30	10.62
0	329	9.71	9.37	10.07	10.01	10.44	10.65
0	438	9.85	9.40	10.21	10.05	10.58	10.69
1	219	8.55	8.04	8.90	8.59	9.25	9.15
1	329	8.69	8.08	9.04	8.63	9.39	9.18
1	438	8.83	8.12	9.18	8.67	9.53	9.22
2	219	7.56	6.80	7.89	7.27	8.22	7.74
2	329	7.70	6.84	8.03	7.31	8.36	7.78
2	438	7.83	6.88	8.16	7.35	8.49	7.82
	Average	8.70	8.10	9.05	8.65	9.40	9.20

Ton-Mile

Proximity Factor	Ton-Mile	
	HUB	PLN
0	9840800	8429700
1	8781700	7337800
2	7737100	6289000

Tons-miles are a combined measure, incorporating the weight of the goods and the distance they are transported. Total ton-miles were calculated by distance multiplied by the weight of the loaded trucks; average mile were calculated by shipping distance from DCi to DCj multiplied with their weights.

Number of truck and number of carriers

Proximity factor	Capacity	Number of trucks		Number of Carriers		Gallons of gasoline	
		HUB	PLN	HUB	PLN	HUB	PLN
0	219	12825	10985	12824	10988	769440	659110
0	329	8535	7311	8542	7310	512180	438740
0	438	6412	5494	6414	5488	384720	329550
1	219	11438	9559	11452	9562	686630	573730
1	329	7616	6363	7620	6368	457060	381900
1	438	5726	4781	5716	4770	343310	286860
2	219	10079	8197	10092	8192	604950	491730
2	329	6712	5452	6718	5456	402690	327320
2	438	5046	4096	5034	4092	302480	245870

Number of sorting need

Proximity factor	Capacity (number of packages)	HUB	PLN
0	219	26660	101140
0	329	17750	67320
0	438	13330	50570
1	219	25490	88330
1	329	16970	58800
1	438	12750	44170
2	219	24110	76140
2	329	16050	50680
2	438	12050	38070

Average sort per shipment

Proximity factor	Capacity (number of packages)	Hub	PLN
0	219	1.23	4.81
0	329	1.23	4.81
0	438	1.23	4.81
1	219	1.16	4.25
1	329	1.16	4.25
1	438	1.16	4.25
2	219	1.08	3.71
2	329	1.08	3.71
2	438	1.08	3.71

Appendix D: Zone and Price of UPS

UPS use seven geographic zones (zones 2 through 8) for distance-based pricing. Zone 1 for destinations is within 50 miles of the origin point. (Satish Jindel, "Parcel Carriers Should Link Zone-based Pricing To Established Service Standards," Traffic World, February 26, 1996)

Zone/Service Standard Matrix				
Zone	Distances used for zone-based pricing	USPS Standard Service	Distances for UPS/RPS Service Standard	UPS/RPS Service Standard
One	<50 miles	1 day		1 day
Two	<150 miles	2 days	up to 150 miles	1-2 days
Three	<300 miles	3 days	up to 450 miles	2 days
Four	<600 miles	4 days	up to 900 miles	3 days
Five	<1,000 miles	5 days		4 days
Six	<1,400 miles	6 days	up to 1,500 miles	4 days
Seven	<1,800	7 days		5 days
Eight	>1,800 miles	8 days		5-6 days

Appendix E: MatLab Code

This appendix provides the MatLab functions.

Drive

This function is used to provide nine results of average transport time, ton-mile, number of trucks and etc by giving expected weight in the function. It allows users to change parameters in the beginning.

```
function [Avg_Time, TonMile, No_Truck, Carrier, Gallon, T_sort, Avg_sort] = drive(Lb)
% Lb = expected package weight;
Sp =60;
Load_f= 0.8;
T_Capacity =[4000 6000 8000];
prox =[0 1 2];
[Capacity, Lb] = Capt(T_Capacity, Lb)
Load_time = [20 25 30];
Pct_Demand = 1;
% Avg_Time = zeros(27,6);
% No_Trip = zeros(27,6);
for k = 1: 3
a = [];
b = [];
c = [];
d = [];
e = [];
f = [];
u = [];
Lt = Load_time(k);
Total_D = 1921680*Pct_Demand;
for i= 1:3
p = prox(i);
for j = 1: 3
Capt = Capacity(j);
[Hub_No_Truck, Hub_No_Carrier, Hub_Avg_T, Hub_Total_TonMile, Hub_Gallon,...
Hub_avg_sort, Hub_Total_sort]= Hub_T(Total_D, Sp, Capt, p, Lt, Load_f, Lb);
[PLN_No_Truck, PLN_No_Carrier, PLN_Avg_T, PLN_Total_TonMile,PLN_Gallon,...
```

```
PLN_avg_sort, PLN_Total_sort]= PLN_T(Total_D, Sp, Capt, p, Lt, Load_f, Lb);
b = [b ; Hub_Avg_T PLN_Avg_T];
a = [a ; Hub_No_Truck PLN_No_Truck];
c = [c ; Hub_Total_TonMile PLN_Total_TonMile];
d = [d ; Hub_No_Carrier PLN_No_Carrier];
e = [e ; Hub_Gallon PLN_Gallon];
f = [f ; Hub_avg_sort PLN_avg_sort];
u = [u ; Hub_Total_sort PLN_Total_sort];
end
end
Avg_Time(:, (2*k-1)) = b(:,1);
Avg_Time(:,2*k) = b(:,2);
end
No_Truck(:,1) = a(:,1);
No_Truck(:,2) = a(:,2);
TonMile(:, 1) = c(:,1);
TonMile(:, 2) = c(:, 2);
Carrier(:,1) = d(:,1);
Carrier(:,2) = d(:,2);
Gallon(:, 1) = e(:,1);
Gallon(:, 2) = e(:,2);
Avg_sort(:, 1) = f(:,1);
Avg_sort(:, 2) = f(:,2);
T_sort(:, 1) = u(:,1);
T_sort(:, 2) = u(:,2);
Return
```

HUB line-haul truck

This function is used to compute average travel time, ton-miles, number of trucks and etc for a HUB system.

```
function [Hub_No_Truck, Hub_No_Carrier, Hub_Avg_T, Hub_Total_TonMile, Hub_Gallon,...
Hub_avg_sort, Hub_Total_sort]= Hub_T(Total_D, Sp, Capt, p, Lt, Load_f, Lb)
load plnex36;
m=36;
Avg_mile_pergallon = 7.5;
[w,Tw] = Weight(p,m);
Max_L = Capt * Load_f;
Hub= [4;9;12;18;31];
[Min_tij, Ship, Rece, Dist, n]= HubPath(Hub, Sp, Lt);
[Hub_D, H_sizeA, H_sizeB, H_sizeC, H_sizeD]= Hub_Demand(Total_D, p, Sp, Lt);
% Finding wait time for each path based on the path you choose.
No_Trip = zeros(m);
Hub_wait = zeros(m);
WaitT = zeros(m);
No_truck= zeros(m);
No_carrier = zeros(m);
Gallon = zeros(m);
for i = 1:m
for j= 1:m
if Hub_D(i,j)==0
No_Trip(i,j)=0;
WaitT(i,j) =0;
else
No_Trip(i,j) = Hub_D(i,j)/Max_L;
WaitT(i,j) = 24/ No_Trip(i,j);
end
end
end
No_Trip = No_Trip- diag(diag(No_Trip));
WaitT = WaitT- diag(diag(WaitT));
No_sort = n.*No_Trip;
Hub_TonMile = zeros(m);
```

```
No_truck = zeros(m);
Hub_wait = zeros(m);
tij= zeros(m);
% Estimating possible truck need for each shipment form node i to node j.
for i =1:m-1
for j=i+1:m
Hub_TonMile(i, j) = Dist(i, j) * Hub_D(i,j) * Lb/2000;
No_truck(i,j) = round((Dist(i,j)+Dist(j,i))* No_Trip(i,j)/(Sp*8));
path = [i, Ship(i,j), Rece(i,j), j];
b = length(path);
for g= 1: b-1
Hub_wait(i, j)= Hub_wait(i, j) + WaitT(path(g),path(g+1));
end
tij(i,j) = Min_tij(i,j) + Hub_wait(i, j);
end
end
Hub_TonMile = Hub_TonMile + Hub_TonMile' ;
tij = tij + tij';
for i =1 :m
for j = 1:m
Gallon(i,j) = Dist(i,j) * No_Trip(i,j)/Avg_mile_pergallon;
No_carrier(i,j) = round(Dist(i,j) * No_Trip(i,j)/ (Sp*8));
end
end
Hub_Avg_T = sum(sum(tij .* w));
Hub_No_Truck = sum(sum(No_truck));
Hub_No_Carrier = sum(sum(No_carrier));
Hub_Gallon = sum(sum(Gallon));
Hub_Total_TonMile = sum(sum(Hub_TonMile));
Hub_avg_sort = sum(sum(n .*w));
Hub_Total_sort = sum(sum(No_sort));
return
```

HUB Path

This function is used to determine minimum travel time, locations of passing hubs, travel distance and passing terminals in a HUB system for each terminal by providing hub nodes, speed, and average loading time.

```
Function [Min_tij, Ship, Rece, Dist, n]= HubPath(Hub, Sp, Lt)
% Count dist, path and number of terminal or hub passing from node s to
% node s.
% Hub = Hub's idex is a 1 by n matrix. Ex:[4;9;12;18;31]
% dist = shortest distance from node i to node j.
% path = idex of passing terminal or hub from node i to node j.
% n = number of stops in terminals or hub.
% dist = distance from node i to node j
% n= number of stops.
% D_HtoH = distance from hub to another hub
% Dth = distance from terminal to hub
% idy = hub index
% Ship = index of hub that terminal i ship to.
% Rece = index of hub that terminal i receieve from.
load plnex36;
m=36;
idx= 1:length(DC.Name);
h = length(Hub);
DCs =[idx];
%D_TtoH = dists(DC.XY(DCs,:),DC.XY(Hub,:),'mi');
%D_HtoH = dists(DC.XY(Hub,:),DC.XY(Hub,:),'mi');
%[Dth,idy] =sort(D_TtoH,2);
A = list2adj(IJD);
[dist, path] = dijk(A,idx,idx);
time = dist / Sp;
T_th= time(:,Hub);
T_hh = time(Hub,Hub);
temp1= sort(T_th,2);
Min_d = temp1(:,1);
% c(i,j) is a temportary matrix for getting smallest distance from
% terminal i to hub j.
```

```
for i= 1: m
if Min_d(i) == 0
c(i,:)=0;
else
c(i,:)= T_th(i,:)/ Min_d(i);
end
end
Tij = zeros(m);
[S] = zeros(m);
Ship = zeros(m);
[R] = zeros(m);
Rece = zeros(m);
travel_t = zeros(m);
Dist = zeros(m);
n= zeros(m);
Min_tij= zeros(m);
% find the minimum travel time with loading time.
for i= 1: m-1
for j= i+1: m
[a]= find(c(i,:)<2);
a1= length(a);
[b]= find(c(j,:)<2);
b1= length(b);
Compare =[];
for v = 1:a1
for u = 1: b1
path = [i, Hub(a(v)), Hub(b(u)), j];
n(i,j) = length(path);
S(i,j) = Hub(a(v));
R(i,j) = Hub(b(u));
if S(i,j) == R(i,j)
n(i,j)= n(i,j)-1;
else
n(i,j) = n(i,j);
end;
travel_t(i,j)= T_th(i,a(v)) + T_hh(a(v), b(u))+ T_th(j,b(u));
Load(i,j) = 2 * (n(i,j)-1) * (Lt/60);
Tij(i,j) = travel_t(i,j)+ Load(i,j);
```

```
Compare = [Compare;  Tij(i,j) S(i,j) R(i,j), travel_t(i,j)];
end
end
[Min_tij(i,j), q] = min(Compare(:,1));
Ship(i,j)= Compare(q,2);
Rece(i,j) = Compare(q,3);
Dist(i,j) = Compare(q,4)* Sp;
path = [i, Ship(i,j), Rece(i,j), j];
n(i,j) = length(path)-2;
if Ship(i,j) == Rece(i,j)
n(i,j)= n(i,j)-1;
else
n(i,j) = n(i,j);
end;
end
end
Ship = Ship+Ship';
Rece = Rece + Rece';
Min_tij = Min_tij+ Min_tij';
Dist =  Dist + Dist';
n = n + n';
return
```

HUB Demand

This function is used to determine total demand among 36 terminals in a HUB system by total daily demands, proximity factor, speed, and average loading time.

```
function [Hub_D, sizeA, sizeB, sizeC, sizeD]= Hub_Demand(Total_D, p, Sp, Lt)
load plnex36;
m=36;
[w,Tw] = Weight(p,m);
Hub= [4;9;12;18;31];
% h = length(Hub);
[Min_tij, Ship, Rece, Dist, n]= HubPath(Hub, Sp, Lt);
% Get demand of Hub from node i to node j through hubs, goods are consolidated and resigned.
Hub_D = zeros(m);
Hub_Dist = zeros(m);
for i= 1: m-1
for j= i+1: m
HUBp = [i, Ship(i,j), Rece(i,j), j];
k = length(HUBp);
for g = 1:(k-1)
Hub_D(HUBp(g), HUBp(g+1)) = Hub_D(HUBp(g), HUBp(g+1)) + w(i, j);
%    Hub_Dist(HUBp(g), HUBp(g+1)) = Hub_Dist(HUBp(g), HUBp(g+1)) + Dist(i, j);
end
end
end
Hub_D= Hub_D + (Hub_D)';
Hub_D= Total_D * Hub_D;
% computing DC size by the demand.
sizeA= 0;
sizeB= 0;
sizeC= 0;
sizeD= 0;
Sum_D = [sum(Hub_D)];
for i = 1: m
a(i) = Sum_D(i);
if a(i) > 200000
sizeA= sizeA +1;
```

```
elseif (a(i)< 200000) & (a(i)> 70000)
sizeB = sizeB + 1;
elseif (a(i)< 70000) & (a(i)>50000)
sizeC = sizeC+1;
else
sizeD = sizeD +1 ;
return
```

PLN line-haul truck

This function is used to compute average travel time, ton-miles, number of trucks and etc for a PLN system.

```
function [PLN_No_Truck, PLN_No_Carrier, PLN_Avg_T, PLN_Total_TonMile,PLN_Gallon,...
PLN_avg_sort, PLN_Total_sort]= PLN_T(Total_D, Sp, Capt, p, Lt, Load_f, Lb)
load plnex36;
m=36;
[w,Tw] = Weight(p,m);
Max_L = Capt * Load_f;
idx= 1: m;
A= list2adj(IJD);
[dist, path] = dijk(A, idx, idx);
rte = pred2path(path);
Avg_mile_pergallon = 7.5;
 [PLN_D, dist, P_sizeA, P_sizeB, P_sizeC, P_sizeD] = PLN_Demand(Total_D, p);
PLN_Trip = zeros(m);
PLN_wait = zeros(m);
PLN_trav = zeros(m);
PLN_load = zeros(m);
PLN_tij = zeros(m);
PLN_TonMile = zeros(m);
No_truck = zeros(m);
wait_t = zeros(m);
No_truck = zeros(m);
k = zeros(m);
for i =1:m-1
for j= i+1:m
[b] = rte{i,j};
k(i, j) = length(b);
PLN_Trip(i, j) = PLN_D(i, j)/ Max_L;
if PLN_Trip(i, j)>0
PLN_wait(i, j) = 24/ PLN_Trip(i,j);
end
PLN_trav(i, j) = dist(i,j)/Sp;
PLN_load(i, j) = 2* (k(i ,j)-1) * (Lt/60);
PLN_tij(i, j) = PLN_trav(i,j) + PLN_load(i, j);
```

```
PLN_TonMile(i, j) =  dist(i, j) * PLN_D(i, j) * Lb/2000;
No_truck(i,j) = round(dist(i, j) * PLN_Trip(i,j)/(Sp*4));
for g= 1: k(i,j)-1
wait_t(i,j)= wait_t(i,j) + PLN_wait(b(g), b(g+1));
end
PLN_tij(i, j)=PLN_tij(i, j) + wait_t(i,j);
end
end
PLN_Trip = PLN_Trip +(PLN_Trip)';
n = k +k';
No_sort = n .* PLN_Trip;
PLN_tij = PLN_tij + (PLN_tij)';
PLN_TonMile = PLN_TonMile + PLN_TonMile';
% No_carrier = zeros(m);
% Gallon = zeros(m);
for i = 1:m
for j= 1:m
Gallon(i,j) = dist(i,j) * PLN_Trip(i,j)/Avg_mile_pergallon;
No_carrier(i,j) = round(dist(i,j) * PLN_Trip(i,j)/ (Sp*8));
end
end
PLN_Avg_T = sum(sum(PLN_tij .* w));
PLN_avg_sort = sum(sum(n .* w));
PLN_No_Truck = sum(sum(No_truck));
PLN_No_Carrier = sum(sum(No_carrier));
PLN_Gallon = sum(sum(Gallon));
PLN_Total_TonMile = sum(sum(PLN_TonMile));
PLN_Total_sort = sum(sum(No_sort));
Return
```

PLN demand

This function is used to determine total demand among 36 terminals in a PLN system by total daily demands and proximity factor.

```
function [PLN_D, dist, sizeA, sizeB, sizeC, sizeD] = PLN_Demand(Total_D, p)
load plnex36;
m=36;
[w,Tw] = Weight(p,m);
idx= 1: m;
A= list2adj(IJD);
[dist, path] = dijk(A, idx, idx);
rte = pred2path(path);
PLN_D=zeros(m);
for i =1:m-1
for j= (i+1): m
[b] = rte{i,j};
k(i, j) = length(b);
for g = 1: (k(i, j)-1)
PLN_D(b(g), b(g+1)) = PLN_D(b(g), b(g+1)) + w(i,j);
end
end
end
PLN_D = PLN_D + (PLN_D)';
PLN_D= Total_D * PLN_D;
% computing DC size by the demand.
sizeA= 0;
sizeB= 0;
sizeC= 0;
sizeD= 0;
Sum_D = [sum(PLN_D)];
for i = 1: m
a(i) = Sum_D(i);
if a(i) > 200000
sizeA= sizeA +1;
elseif (a(i)< 200000) & (a(i)> 70000)
sizeB = sizeB + 1;
```

```
elseif (a(i)< 70000) & (a(i)>50000)
sizeC = sizeC+1;
else
sizeD = sizeD +1 ;
return
```

Weight

This function is used to determine weight of demands among 36 terminals by giving proximity factor and number of terminals.

```
function [w,Tw] = Weight(p,m)
% Retrun weight and daily demand in the 36 city
% daily demand is proportional to the population of the region surrounding the DC.
% P = Proximity factor; control the degree to which a DC is more likyly
%     transport package to nearby DCs as oppose to DCs located further away.
% m = number of city in the example.
load plnex36;
PopP = 100*DC.Pop/sum(DC.Pop);
Dist = dists( DC.XY, DC.XY,'mi');
y = 0;
for k= 1:m
x = p/m;
y = y + x*(1-x)^(k-1);
end
for i= 1:m;
[D,L]= sort(Dist(:,i));
for j= 1:m
wij0= PopP(i)*PopP(L(j));
if p==0
wij(i, L(j))= wij0;
else
wij(i, L(j))= wij0*(36* (x*(1-x)^(j-1))/y);
end
end
end
w= wij/ sum(sum((wij)));
wi = sum(w,2);
wj = sum(w,1);
Tw = sum(sum(w));
return
```