MATERIAL FLOW ANALYSIS OF PUBLIC LOGISTICS NETWORKS

Michael G. Kay
North Carolina State University

Ajithkumar N. Parlikad
North Carolina State University

Abstract

A public logistics network is proposed as a means to extend many of the features associated with public warehouses to the entire supply chain. The average transport time of a hypothetical public logistics network covering the southeastern United States is compared to the times of a hub-and-spoke and a point-to-point network covering the same region. It was found that the public logistics network provided the minimum average transport time when the time required for loading/unloading at each transshipment point in the network was short. This result is robust with respect to a range of different transport demands and truck capacities considered in the analysis.

1 Introduction

A public logistics network is proposed as a means to extend many of the features associated with public warehouses to the entire supply chain. In addition to providing traditional warehousing and storage functions for hire, a public logistics network would make it possible to negotiate with multiple firms on a load-by-load basis in order to determine the most efficient means of providing the resources needed to complete each stage of a load's transit through the network. Items could continuously negotiate with the logistics resources of the network using simultaneous auctions in order to determine the best route and cost and schedule. Similar to the dynamic pricing used to sell airline seats, a price for each available space on a truck and storage space at a distribution center (DC) could be negotiated in real time for each individual item. A unique capability of such a network is that a third party can search the network for any type of item in transit. Once located, negotiations can take place and the item might be resold to the third party and redirected to a new destination. The potential utility of this search and negotiate capability depends on the characteristics of items being transported: it is not likely to be needed to locate low-cost, ubiquitous items like toothbrushes because they can be expected to be available at every local store; nor is it needed to locate custom-made, one-of-a-kind products because there are so few of the items available, of uncertain quality, that the use of traditional private logistics networks is likely to be the most efficient. A public logistics network is likely to be most suitable for managing the multitude of commodity-like items (replacement parts, etc.) that fall in the middle ground between ubiquitousness and uniqueness.

This paper will describe the results of a material flow analysis using a model of a hypothetical public logistics network covering the southeastern United States. The network will be compared to two other network configurations: a hub-and-spoke network, like the type of network used by the United Parcel Service (UPS), and a network with only direct, point-to-point (P2P) shipments. The three different network configurations will be compared based on the average time required to transport a package. The average is determined with respect to demand that is proportional to population.

2 Public vs. Private Logistics Networks

Recent advances in information technology (IT) make possible the type of search and negotiate capabilities envisioned for public logistics networks. To date, the principal impact of IT on the operation of logistics networks has been focused on improving business processes that are internal to a single firm. Only limited steps have been taken to automate and standardize some business-to-business processes, mostly purchasing and procurement related (e.g., electronic exchanges), and these have been restricted to firms in a single industry (e.g., RosettaNet in the electronics industry [1]). Once the buyer and seller have agreed to the terms of an exchange, the logistics processes associated with the actual transport of the physical goods is treated as a separate issue. Currently, it is common for a single logistics firm to handle a load throughout its transport. Although companies like FedEx and UPS have very sophisticated proprietary tracking and control infrastructures, the control of the logistics network is highly centralized. The most notable feature of these private logistics networks is that a single firm controls the network and much of the technology used to coordinate the operation of the network is proprietary. As a result, the principal competitive advantage that a private logistics company has is the barrier to entry due to the very large scale of operation (national or international) required in order to be able to underwrite the development of private facilities and propriety technologies. Nevertheless, a single firm, unless it becomes a monopoly, is ultimately limited in the scale of its operation, resulting in the use of single-firm "hub" DCs. With a limited number of large-scale hub DCs, a load can make many circuitous "hops" before it reaches its destination.

A question then arises: what would be the impact if much of the coordination of production and distribution networks could be implemented as a public logistics network. In particular, what would be the impact of making these networks an alternative means for coordinating production and distribution? The most salient impact is likely to be that it would make it possible to separate the different functions of the network so that a single firm is not required for coordination. This would enable scale economies to be realized in performing each logistics function since each element of the network has access to potentially all of the network's demand. The increase in scale might make it economical to ship in full truckloads throughout the network as opposed to more costly less-than-truckload shipments. This could be possible because a single truck could be used to transport all of the demand associated with a lane (or link) in the network. Many of the long-haul single-product full-truckload shipments between private facilities could be replaced by sequences of short-distance hops between public DCs. Links in the network could be served by trucks that are owned and operated by different firms, and each transshipment point (i.e., public DC) in the network could be an independently operated facility. Due to the increase in scale, it would be economical to have many more DCs. Public DCs (which would operate like existing private highly automated hub DCs, but on a smaller scale) could be established in small cities and towns that would never have such facilities if they were served as part of a proprietary, private logistics network.

An example of the operation of the proposed public logistics network is as follows:

> A small machine shop in Raleigh, NC has just had a production machine fail. The spare part needed to repair the machine is too expensive to be stored on-site. In order to acquire the part, the machine shop uses the part's UNSPSC code to contact servers at nearby public DCs to search for items with the same code that are at or inbound to the DCs. Assume that the closest item found was just manufactured yesterday in Jacksonville, FL and is on a truck heading north on I-95. It is intended to be delivered to a firm in Washington, DC. While still in transit, the machine shop's computer can start negotiations with the item's intelligent agent running on a computer onboard the truck or on a server located at the next DC. If the shop has not ever searched for this particular part, the shop's computer would first download a part-specific Java negotiation agent. If additional information about the item, provided by the item via XML, has established that the item can be used by the Raleigh firm and if the Washington firm does not have an immediate need for the item, then, after an agent-mediated auction and bidding process, the item could be purchased by the Raleigh firm. When the truck transporting the item on nears the I-95–I-40 interchange, the item would be unloaded at the interchange's public DC (DC 17 in Figure 1) and loaded onto the next truck heading to Raleigh along I-40. Within two hours, the item could be in Raleigh and, shortly thereafter, the production machine could be repaired. At the same time, the Washington firm could locate an identical replacement item and, with the revenue from the sale of the item to the Raleigh firm minus the cost of the replacement, may have been able to realize a net gain.

Currently, without a public logistics network, the firm in Raleigh would most likely have to either use overnight express delivery to acquire the replacement part, or store in house what might be an expensive part, or use a private company like UPS Logistic Group's Service Part Logistics [2] to provide the urgent delivery of the part within hours. With a public logistics network, the firm can get the quick-response benefits of on-site inventory without its associated carrying cost and most of the benefits of urgent delivery at what is likely to be a much lesser cost due to the increase in scale.

Several key standards and technologies have recently been developed that make the above example possible:

- XML [3], a universal format for web communications, makes it possible to translate information between different computer systems.
- UNSPSC (United Nations Standard Products and Services Code) [4] will make it possible to hierarchically search for an item by using general categories of products, as opposed to producer-specific coding schemes such as UPC, making it possible to use the Internet to search for similar products from multiple vendors that are located in close geographic proximity.
- RFID (Radio Frequency Identification) or "smart" tags, that contain information about the product to which it is attached and will make it possible for an individual package to be controlled by its own intelligent agent. The Auto-ID Center [5] is using these technologies to develop a ubiquitous electronic product coding and smart-tag environment to extend current bar coding technologies.
- GUIDs (Globally Unique Identifiers) can be used as unique serial numbers and can be embedded in an item's RFID tag at the time of its manufacture so that each item is individually identifiable for tracking and negotiating purposes. GUIDs are commonly used in software products and many generators are publicly available on the Internet (e.g., [6]).

3 Hypothetical Network

Figure 1 shows an example of how a public logistics network might be established. Focusing on the southeastern United States, a total of thirty-six public distribution centers (DCs) could cover the region and be connected via interstate highways (see Figure 1 and Table 1). Each public DC would be located next to an interstate highway interchange in order to enable direct access to and from the DCs adjacent to the DC (see Figure 2). (The Oak Ridge National Highway Network [7] road data was used in the analysis.) Each of the DCs in Figure 1 could serve as the central DC in a sub-network of similar DCs covering the local region surrounding the central DC, where the local DCs would be connected via major state highways instead of interstate highways.

Figure 3 shows a possible configuration of a public DC. Side access is used for the DC-to-DC receiving and shipping bays to allow fast loading and unloading, while traditional loading docks are used for shipping and receiving loads to and from the region local to the DC and for long-haul, non-stop transport. Although not shown, there are multiple identical levels of conveyors at each receiving and shipping bay. The cargo area of each truck used for DC-to-DC transport could use onboard powered conveyors to enable automatic loading and unloading, and could use standard-sized load containers. (The capacity of the truck will be one of the parameters that will be varied in the analysis reported in Section 4, below.) A three-lane single-deep unit load automated storage/retrieval system (AS/RS) is used for the temporary storage of loads in transit. Each shipping bay has two full-truckload staging areas located in series so that, once a truck departs, the load for the next truck can quickly be moved from the back to the front staging area. In addition, takeaway conveyors are positioned at the end of each staging area to allow the composition of the load to be changed at any time prior the final loading of a truck.

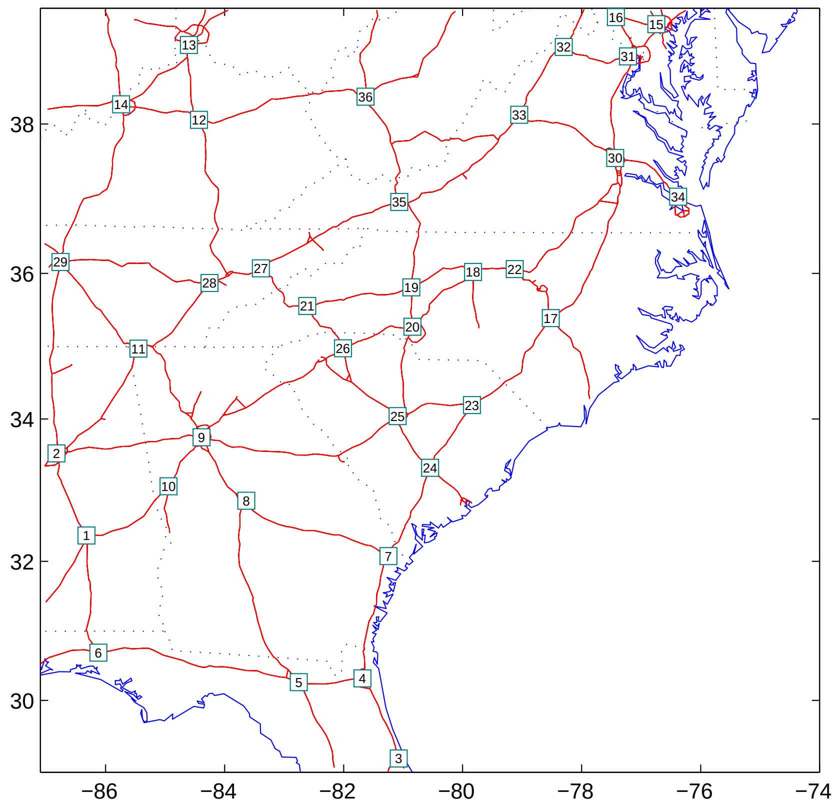

Figure 1: Hypothetical public logistics network showing 36 public DCs covering the southeastern portion of the USA and connected via interstate highways.

4 Network Comparison

The three different network configurations will be compared:

PLN: Public logistics network as described in Section 3 and Figure 1, above. There are 36 DCs in the network. A package being transported from DC 10 to DC 29 (see Figure 1) would travel from 10 to 9, to 11, to 29.

HUB: Hub-and-spoke network, like the type of network used by the United Parcel Service (UPS). Figure 4 shows a five-hub network, where the hubs are DCs 4, 9, 12, 18, and 31; all of the remaining DCs are just supply and demand points, not transshipment points (although they will still be referred to as DCs). A package being transported from DC 10 to DC 29 (see Figure 4) would travel from 10 to the hub at 9, and then directly to 29.

P2P: Point-to-point network, with direct shipments between all DCs and no hubs: all DCs are just supply/demand points. A package being transported from DC 10 to 29 (see Figure 1) would travel directly from 10 to 29 without stopping at 9 or 11.

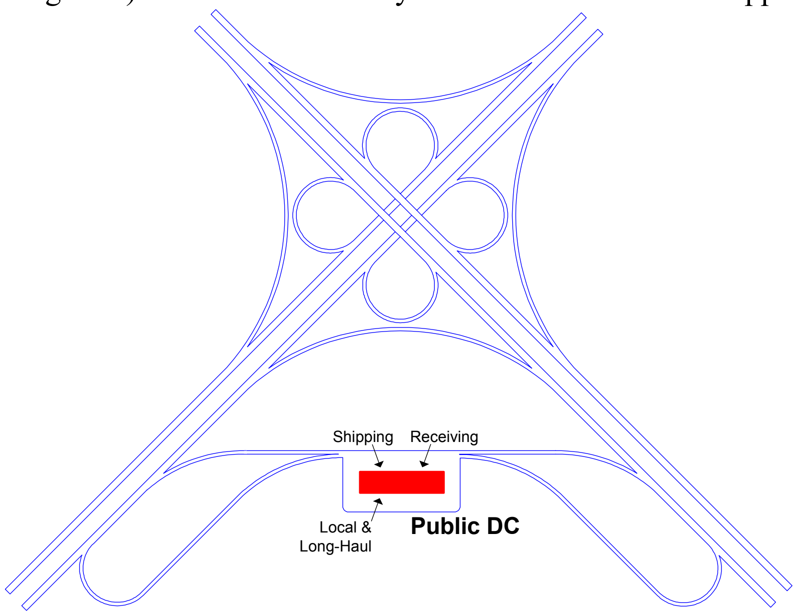

Figure 2: Location of public DC in relation to interstate highway interchange—with this arrangement, the DC has direct access to all eight interstate travel directions.

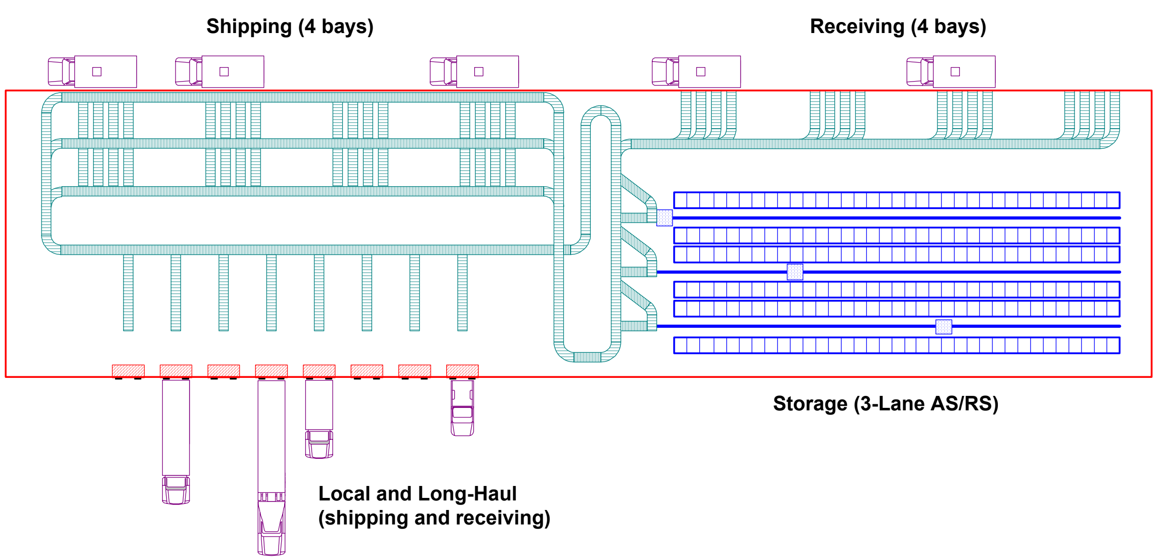

Figure 3: Interior details of public DC showing side access receiving and shipping bays for DC-to-DC transport, traditional loading docks for local and long-haul shipping and receiving, and a three-lane AS/RS used for temporary storage of loads in transit.

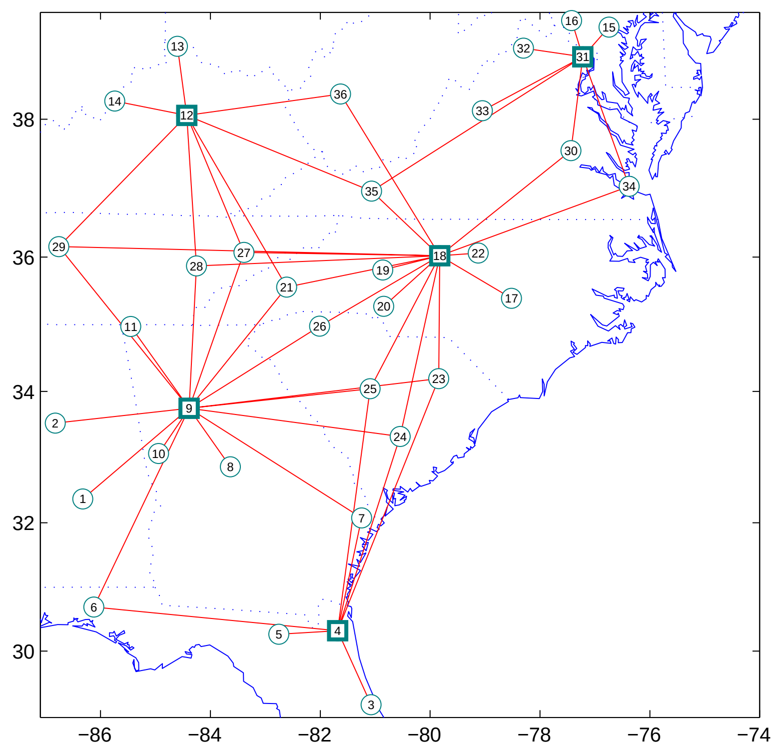

Figure 4: Hub-and-spoke logistics network showing five hubs at DCs 4, 9, 12, 18, and 31; although not shown, each of the five hubs is directly connected to all of the other hubs.

In the hub-and-spoke network, five hubs were chosen based on the fact that UPS has 27 ground hubs throughout the US [2]. Since 18.10% of the US population is in the region covered by the network, 18.10% of 27 is approximately five. Each DC in the network is connected to its nearest hub. A DC can be served by up to three hubs if the distance to an additional hub does not exceed twice the road distance to its nearest hub (e.g., in Figure 4, DC 23 is served by hubs at 4, 9, and 18). Also, although not shown in Figure 4, each of the five hubs is directly connected to all of the other hubs (thus, e.g., a package being transported from DC 1 to DC 15 would travel from 1 to 9, to 31, to 15).

4.1 Transport Demand

The average time that is required to transport a package is determined with respect to total package supply and demand for each DC that is assumed to be proportional to the population of the region surrounding the DC. Table 1 shows, for each DC, the population of the surrounding region and the population as a percentage of the total population. The population of each region was estimated using the population of the five-digit ZIP Code Tabulation Areas (ZCTAs) [8] surrounding the DC.

Table 1: DC Population and Total Transport Demand Percentages.

DC	City	State	Population (000's)	Pct. of Total Population	Percent of Total Transport Demand (for Proximity Factor) 0	1	2
1	Montgomery	AL	604	1.17	4.42	3.72	3.19
2	Birmingham	AL	1,509	2.92	4.62	4.13	3.72
3	South Daytona	FL	649	1.26	1.26	0.91	0.66
4	Jacksonville	FL	1,318	2.55	**7.35**	**5.88**	**4.68**
5	Lake City	FL	1,147	2.22	5.23	4.52	3.90
6	De Funiak Springs	FL	947	1.84	1.98	1.61	1.34
7	Pooler	GA	807	1.56	9.22	7.33	5.68
8	Macon	GA	1,024	1.98	7.16	6.54	5.87
9	Atlanta	GA	4,472	8.66	**23.72**	**21.57**	**19.48**
10	LaGrange	GA	804	1.56	4.88	4.20	3.70
11	Chattanooga Valley	GA	1,579	3.06	13.48	12.06	10.65
12	Lexington-Fayette	KY	1,096	2.12	**14.16**	**12.80**	**11.19**
13	Erlanger	KY	2,261	4.38	4.38	4.04	3.70
14	Louisville	KY	2,049	3.97	5.13	4.81	4.48
15	Woodlawn	MD	3,447	6.68	6.68	5.83	5.48
16	Ballenger Creek	MD	452	0.88	0.88	0.79	0.75
17	Benson	NC	2,339	4.53	18.63	14.80	11.56
18	Greensboro	NC	1,292	2.50	**11.28**	**10.92**	**10.22**
19	Statesville	NC	800	1.55	8.69	8.09	7.26
20	Charlotte	NC	1,588	3.08	12.11	11.32	10.25
21	Asheville	NC	809	1.57	5.62	5.63	5.41
22	Hillsborough	NC	1,182	2.29	9.97	9.92	9.55
23	Florence	SC	978	1.89	18.39	13.98	10.22
24	St. George	SC	774	1.50	10.54	8.52	6.70
25	St. Andrews	SC	1,218	2.36	16.83	13.93	11.28
26	Southern Shops	SC	1,414	2.74	11.37	10.77	9.84
27	Dandridge	TN	828	1.60	11.32	9.58	7.93
28	Farragut	TN	1,070	2.07	14.67	12.65	10.71
29	Nashville-Davidson	TN	1,723	3.34	6.60	5.96	5.30
30	Richmond	VA	1,294	2.51	25.18	21.75	18.72
31	Dunn Loring	VA	4,261	8.25	**21.39**	**18.95**	**17.20**
32	Strasburg	VA	446	0.86	10.44	8.93	7.48
33	Staunton	VA	830	1.61	14.88	12.52	10.16
34	Hampton	VA	1,923	3.73	3.73	3.44	3.25
35	Wytheville	VA	1,055	2.04	15.27	12.93	10.61
36	Charleston	WV	1,624	3.15	11.63	10.63	9.30
	Total		51,617	100.00	373.08	325.97	281.41

4.1.1 Daily UPS Demand

The average daily demand of 1.888 million packages was used as the basis for determining a representative range of likely package demands for the region. Since 18.10% of the US population is in the region covered by the network (51.617 out of 285.187 million people [8]), this demand is 18.10% of the average daily demand of 10.434 million packages handled by UPS throughout the entire United States [2]. In the analysis, 50, 100, and 200 percent of the 1.888 million daily UPS packages was used as demand estimates (see Table 2).

UPS demand was used because the type of packages handled by UPS (e.g., less than 150 lbs.) is similar to the type of packages envisioned to be handled by the proposed public logistics network. The U.S. Census Bureau publishes a Commodity Flow Survey [9] every five years that tracks all parcel, U.S. Postal Service, and courier shipments. This data was not used because it only includes the tons shipped, not the number of packages shipped.

4.1.2 Proximity Factor

Transport demand to and from each pair of DCs is estimated by using the population percentages of each DC together with a proximity factor that controls the degree to which a DC is more likely to transport packages to nearby DCs as opposed to DCs located further away. The reason for using a proximity factor is twofold:

1. It provides a single, adjustable parameter that can be used to model the effect of distance-related demand; in particular, it could be used to mitigate the "edge effect" associated with transport demand that occurs outside of the region considered in the analysis.
2. It provides a means to model the potential impact of the searching and redirection capabilities associated with the operation of a public logistics network (see Section 2); e.g., an increase the proximity factor could be used to model the effect of being able to find more items at nearby locations.

Let w_i be DC_i's percentage of the total population. Without a proximity factor adjustment, the transport demand between DC_i and DC_j is $w_{ij}^0 \cdot 1.888$ million packages per day, where $w_{ij}^0 = w_i \cdot w_j$ and w_{ii}^0 is the demand within the region covered by DC_i. Given m DCs, $DC_{[1]}, DC_{[2]}, \ldots, DC_{[m]}$, ordered in terms of their increasing great circle distance from DC_i, a proximity factor of p is used in a normalized geometric distribution [10] as follows:

$$w'_{i[j]} = w^0_{i[j]} \cdot \frac{\frac{p}{m}\left(1-\frac{p}{m}\right)^{(j-1)}}{\frac{1}{m}\sum_{k=1}^{m}\frac{p}{m}\left(1-\frac{p}{m}\right)^{(k-1)}} = w^0_{i[j]} \cdot \frac{\left(1-\frac{p}{m}\right)^{(j-1)}}{\frac{1}{m}\sum_{k=1}^{m}\left(1-\frac{p}{m}\right)^{(k-1)}}$$

$$w_{i[j]} = \frac{w'_{i[j]}}{\sum_{k=1}^{m}\sum_{l=1}^{m} w'_{kl}}$$

Both $\sum_{i=1}^{m}\sum_{j=1}^{m} w^0_{i,j} = 1$ and $\sum_{i=1}^{m}\sum_{j=1}^{m} w_{i,j} = 1$. The proximity factor orders DCs in terms of their distance, as opposed to most synthetic trip distribution models [10, Sec. 5.3] that use actual distances. Figure 5 shows the ratio of w_{ij} to w_{ij}^0 for proximity factors of $p = 0$, 1, and 2. The ratios are sorted in terms of increasing distance from the DC. There is no change for a factor of 0, while the maximum increase is 1.58 and 2.30 and the minimum decrease is 0.59 and 0.31 for factors 1 and 2, respectively. Since the maximum occurs at the DC itself, the increase of 1.58 means that there is a 58% increase in the local, non-transported demand at the DC from the base local demand of w_{ii}^0.

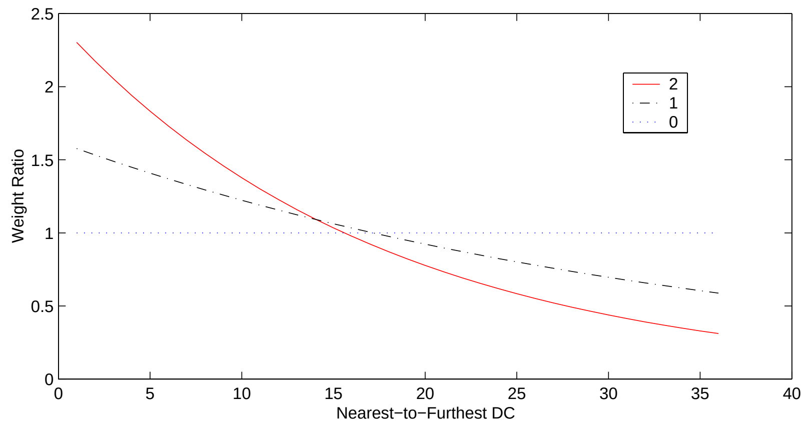

Figure 5: Ratio of w_{ij} to w_{ij}^0 for proximity factors of 0, 1, and 2.

In Table 1, the sum of the total transport demands along each of the links connected to a DC plus the DC's local demand is shown for proximity factors of 0, 1, and 2. Shaded values are used to indicate the hubs in the hub-and-spoke network. The total demand seen across the entire network decreases as the proximity factor increases because, even though the total demand remains the same, items are transported shorter distances.

4.2 Transport Time

The total time taken to transport a package from DC_i to DC_j, t_{ij}, is modeled as the sum of its travel time on each truck, its loading and unloading time at each DC visited, and its time spend waiting for an available truck:

$$t_{ij} = \text{Travel Time} + \text{L/U Time} + \text{Wait-for-Truck Time}.$$

Travel time is assumed to be proportional to the distance of the link. The route selected for transport between DCs is the one that minimizes the sum of the travel and L/U times; wait-for-truck time is not considered (although, after the waiting time has been determined for each link, the route calculation could be repeated, iterating until there is no change in the route selected).

Truck waiting time is estimated by first summing, for each link in the network, the total DC-to-DC demand that is transported over the link and then dividing this by the average truck load to get the average (fractional) number of truck trips needed for the link. Then, assuming that both the trucks and packages arrive at random (i.e., a Poisson process, or exponential interarrival times), the average time between trips is used as the expected waiting time for any package traversing the link (e.g., 3.0 trips per day would imply an 8 hour waiting time). (This approach is based on the "independence assumption" for networks of moderate connectivity used by Kleinrock [12, p. 322] for analyzing the early Internet.)

The average truck load is estimated multiplying the maximum truck capacity by an average load factor (0.80). This corresponds to the assumption that the average truck is 80% full when it traverses a link, which implies that most packages have to wait for a truck. This wait is assumed to be significantly more than any of the other possible delays.

4.3 Results

The average transport time of each network configuration (HUB, PLN, and P2P) was determined for a variety of different parameter values. The parameter values are summarized in Table 2, and the average transport time estimates are shown in Table 3 for all combinations of parameter values, where the minimum time is shaded. The average transport time is determined as follows:

$$\textit{Average Transport Time} = \sum_{i=1}^{m} \sum_{j=1}^{m} w_{ij} t_{ij} ,$$

where $t_{ii} = 0$ (i.e., local demand is ignored).

The results in Table 3 show that loading/unloading time is the most critical factor with respect to the potential utility of using PLN. It supports having the DCs located at interstate highway interchanges (see Figure 2) and the use of highly automated material handling at the DCs (see Figure 3) to reduce these times as much as possible. A savings of as little as five minutes has a significant impact on the performance of PLN relative to HUB and P2P. P2P is increasingly preferred at low truck capacities (60) and longer loading/unloading times, while HUB is only preferred for long loading/unloading times, lower demands (50% and 100%), and larger capacities (120 and 240). Lower truck capacities reduce wait-for-truck times, thereby reducing the negative impact of using P2P.

Note: UPS operates its hub-and-spoke network using a single, overnight sortation delay at the hub [13]. Since this would result in average transport times in excess of 12 hours, wait-for-truck times for HUB were modeled in the same manner as PLN and P2P.

5 Simulation Model

A simulation model was developed in order to verify the model used in Section 4. The data used in the simulation was identical except that, to avoid long run times, a demand of 18,000 packages per day and an average truck load of five were used. Only a proximity factor of zero was considered, and a loading/unloading time of zero was used so that the shortest distance route would also be the shortest time route. The simulation was run for ten days after a warm-up period of two days.

Table 2: Parameter Values Used in the Analysis.

Parameter	Value
UPS daily demand in region	1.888 million packages
Truck speed	60 mph
Average load factor of truck	0.80
Maximum load capacity of truck	60, 120, 240 packages
Proximity factor	0, 1, 2
Percent of UPS demand	50%, 100%, 200%
Loading/unloading time	5, 10, 30 min.

Table 3: Average Transport Time Estimates.

Pct. of UPS	Proximity	Truck Capacity	Loading/Unloading Time (min)											
			5				10				30			
				HUB	PLN	P2P		HUB	PLN	P2P		HUB	PLN	P2P
50	0	60	1	8.34	**7.47**	8.39	28	8.68	**8.11**	8.55	55	10.04	10.61	**9.19**
50	0	120	2	8.49	**7.62**	9.93	29	8.83	**8.25**	10.09	56	**10.19**	10.75	10.73
50	0	240	3	8.80	**7.91**	13.00	30	9.14	**8.54**	13.16	57	**10.50**	11.04	13.80
50	1	60	4	7.37	**6.45**	7.45	31	7.69	**6.99**	7.60	58	8.97	9.15	**8.23**
50	1	120	5	7.53	**6.59**	8.98	32	7.85	**7.13**	9.14	59	**9.12**	9.29	9.77
50	1	240	6	7.83	**6.88**	12.06	33	8.15	**7.42**	12.21	60	**9.43**	9.58	12.84
50	2	60	7	6.43	**5.46**	6.54	34	6.72	**5.92**	6.69	61	7.91	7.75	**7.29**
50	2	120	8	6.58	**5.60**	8.07	35	6.88	**6.06**	8.22	62	8.06	**7.89**	8.83
50	2	240	9	6.89	**5.89**	11.15	36	7.18	**6.35**	11.30	63	8.37	**8.18**	11.91
100	0	60	10	8.26	**7.40**	7.62	37	8.60	8.03	**7.78**	64	9.96	10.54	**8.42**
100	0	120	11	8.34	**7.47**	8.39	38	8.68	**8.11**	8.55	65	10.04	10.61	**9.19**
100	0	240	12	8.49	**7.62**	9.93	39	8.83	**8.25**	10.09	66	**10.19**	10.75	10.73
100	1	60	13	7.30	**6.37**	6.68	40	7.62	6.92	**6.83**	67	8.89	9.08	**7.46**
100	1	120	14	7.37	**6.45**	7.45	41	7.69	**6.99**	7.60	68	8.97	9.15	**8.23**
100	1	240	15	7.53	**6.59**	8.98	42	7.85	**7.13**	9.14	69	**9.12**	9.29	9.77
100	2	60	16	6.35	**5.38**	5.77	43	6.65	**5.85**	5.92	70	7.83	7.68	**6.53**
100	2	120	17	6.43	**5.46**	6.54	44	6.72	**5.92**	6.69	71	7.91	7.75	**7.29**
100	2	240	18	6.58	**5.60**	8.07	45	6.88	**6.06**	8.22	72	8.06	**7.89**	8.83
200	0	60	19	8.22	7.37	**7.24**	46	8.56	8.00	**7.40**	73	9.92	10.50	**8.04**
200	0	120	20	8.26	**7.40**	7.62	47	8.60	8.03	**7.78**	74	9.96	10.54	**8.42**
200	0	240	21	8.34	**7.47**	8.39	48	8.68	**8.11**	8.55	75	10.04	10.61	**9.19**
200	1	60	22	7.26	6.34	**6.29**	49	7.58	6.88	**6.45**	76	8.85	9.04	**7.08**
200	1	120	23	7.30	**6.37**	6.68	50	7.62	6.92	**6.83**	77	8.89	9.08	**7.46**
200	1	240	24	7.37	**6.45**	7.45	51	7.69	**6.99**	7.60	78	8.97	9.15	**8.23**
200	2	60	25	6.31	**5.35**	5.38	52	6.61	5.81	**5.53**	79	7.79	7.64	**6.14**
200	2	120	26	6.35	**5.38**	5.77	53	6.65	**5.85**	5.92	80	7.83	7.68	**6.53**
200	2	240	27	6.43	**5.46**	6.54	54	6.72	**5.92**	6.69	81	7.91	7.75	**7.29**

The analysis of Section 4 was repeated for just PLN, not HUB or P2P. It was found that the difference in average transport time estimates between the Section 4 and simulation models was approximately 3.8% (7.4731 vs. 7.1994 hours, respectively), while the difference in the estimates of the total number of trucks needed was approximately 1.6% (2,008 vs. 1,976 trucks per day, respectively).

Another simulation model was developed in order to model the operation of a public logistics network in finer detail. In addition to the data used above, it was assumed that 20% of the total demand has a higher priority. Waiting time consists of (a) grouping of items for an average truck load, (b) waiting for the availability of a truck, and (c) waiting for the availability of a shipping/receiving bay at the DC. Items having higher priority are pushed to the front of the queue while waiting for trucks. To avoid long run times, each demand entity in the simulation was assumed to represent four packages. The average number of trucks operating out of each DC and the number of loading/unloading bays at each DC were calculated by running the simulation without any constraints on the number of trucks and bays. Then, the number of bays at each DC was restricted to be 20% more than the average number of bays required. Data collection and analysis was performed for the priority items. The performance of the network was analyzed with respect to sensitivity to distance, truck capacity, and demand. The time required for grouping of items for an average truck load was found to be 25 minutes, one hour waiting for the availability of a truck, and the time required for waiting for a shipping/receiving bay at the DC was found to be insignificant. Overall, the simulation results confirm that the time required to wait for the availability of a truck is the most significant delay. Additional information can be found in [14].

6 Conclusion and Future Work

The most significant result of the material flow analysis presented in this paper is that the potential utility of a public logistics network is critically dependant on the time required for loading/unloading at a DC, and thus the need in such a network for highly automated DCs located at interstate highway interchanges. In the analysis, the number of DCs required for the public logistics network (36) and the average number of sorts per route (2.76) is much greater than the numbers for the hub-and-spoke network (5 DCs and 1.22 sorts) and the point-to-point network (0 DCs and 0 sorts). For the public logistics network, any of the advantages associated with a lower average transport time would have to be offset with the increase in cost associated with the additional number of DCs and sorts.

Future work will include implementing the model presented in this paper as a distributed, agent-based simulation. Intelligent agents representing each package will negotiate with agents representing each manufacturer, customer, truck, and distribution center. A major assumption used in the analysis is that the only difference between multiple items of the same type is the difference in cost associated with transporting the items to their destinations. This makes it possible to focus on the pure transport-related arbitrage opportunities that a public logistics network can provide. In particular, it will be determined whether, in equilibrium, the logistics network does operate in a least cost manner and, most importantly, whether the network can re-optimize through self organization after being subject to a variety of disturbances, ranging from the simple breakdown of a truck to the logistical challenges associated with a major natural disaster (e.g., a hurricane).

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