# Implementing a Pricing Mechanism for Public Logistics Networks

**Michael G. Kay and Ashish Jain**
**Department of Industrial Engineering**
**North Carolina State University**
**Raleigh, NC 27695-7906, USA**

## Abstract

A public logistics network is proposed as an alternative to private logistics networks for the ground transport of packages. A pricing mechanism has been designed for a public logistics network that allows each package to bid to be in the load that will be transported by a truck. This paper describes an implementation of this pricing mechanism. Using a simulation of a public logistics network, weighted average waiting times with and without the use of the protocol were determined and it was found that there was a statistically significant decrease in the waiting time associated with the use of the protocol.

**Keywords:** freight transportation, bidding, pricing, trucking, logistic networks

## 1. Introduction

A public logistics network (PLN) is proposed as an alternative to private logistics networks for the ground transport of parcels [1]. Using the analogy between the packages transported in the network and the packets transmitted through the Internet, a package in a PLN would be sent from a store and then routed through a sequence of public distribution centers (DCs) located throughout a metropolitan area and then delivered to a home in a matter of hours, making a car trip to the store to get the package unnecessary. The DCs, functioning like routers in the Internet, could also be located at major highway interchanges for longer distance transport (see, e.g., Figure 1). Currently, it is common for a single logistics firm like UPS and FedEx to handle a package throughout its transport. In a PLN, the different functions of the network would be separated 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 would make it economical to have many more transshipment points. Each transshipment point, or DC, could be an independently operated facility that serves as both a freight terminal and a public warehouse, and 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.

In [2], package and truck protocols were proposed. These protocols will provide the basis for the development of a decentralized coordination mechanism for a public logistics network. The entities in the network are DCs, trucks, and packages. Since separate firms can own each DC and truck, the coordination of package transport is more difficult than in a private logistics network where a single firm can provide centralized control of the entire network. The overall goal for the design of a decentralized coordination mechanism needed for a public logistics network is to make it possible for packages to try to maximize their value from transport while at the same time allowing trucks to try to maximize their profit. The proposed solution is to use pricing as the decentralized coordination mechanism. In such a pricing mechanism, packages bid for services of the trucks used for their transport and have to pay each DC for the time they spend at the DC and for any other services like loading and unloading. Each package and truck would be controlled by its own software agent, and the agents would interact via a protocol for services provided by each DC. The approach of having each package bid for the services of the resources in the network was inspired by MacKie-Mason and Varian's [3] proposal to have each packet in the Internet bid for the use of routers when they are congested.

In [4], a simulation of a public logistics network was developed. A subset of the proposed package and truck protocols was implemented and then, using the simulation, compared to operation of the network without the use of the protocols. The weighted average waiting time and weighted average transportation time were determined for a series of different experiments using the 36-DC network shown in Figure 1. It was found that there was a statistically significant decrease in both times with the use of the protocol as compared to without the protocol. This paper first summarizes the package and truck protocol as presented in [2] and then summarizes the results of [4].

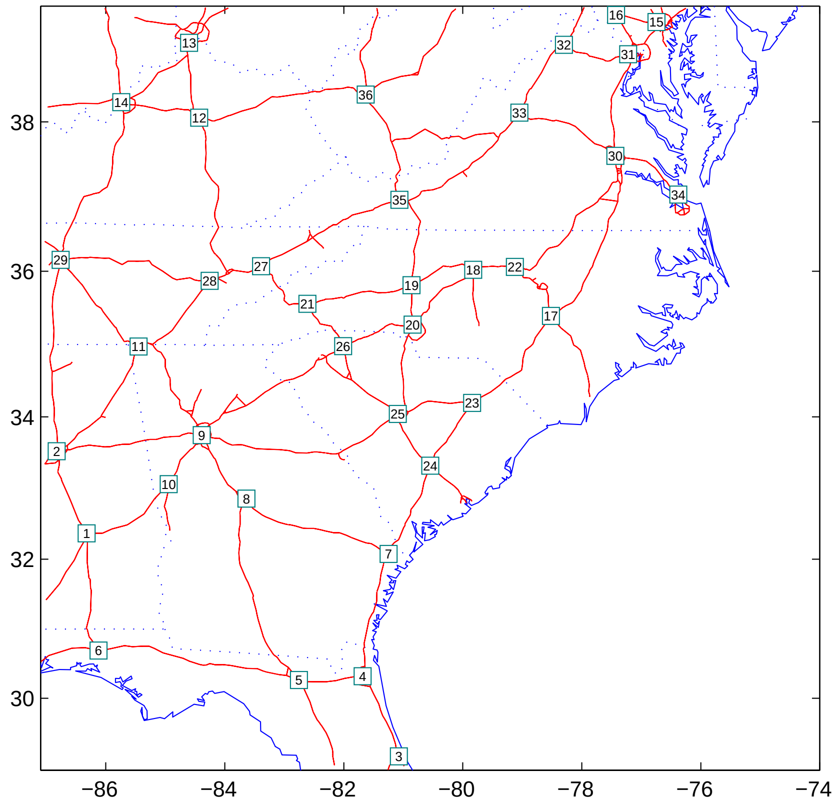


**Figure 1. Hypothetical public logistics network showing 36 public DCs covering the southeastern portion of the USA and connected via interstate highways (Fig. 1 in [1]).**

## 2. Truck and Package Protocol

A pricing mechanism has been designed for a PLN that allows each package to bid to be in a load that will be transported by a truck. A package bids for transport between each distribution center (DC) visited along its path through the network to its destination. At each DC, the loads to adjacent DCs are competing with each other to be selected by a truck as the next load to be transported and packages are competing with each other to be selected to be in that next load. In addition, the trucks themselves can be competing with each other for the right to select the next load for transport.

**Table 1. Costs for Transport of a Single Package**

| | Activity | Time (min) | Credit | Bid | Cost |
|---|---|---|---|---|---|
| 1 | Pickup | | | | |
| 2 | Unload | 10 | $3.00 | | $0.02 |
| 3 | Wait at DC 3 | 30 | 2.98 | | 0.06 |
| 4 | Load | 10 | 2.92 | | 0.02 |
| 5 | Linehaul to DC 4 | 60 | 2.90 | $1.50 | 1.50 |
| 6 | Unload | 10 | 1.40 | | 0.02 |
| 7 | Wait at DC 4 | 55 | 1.38 | | 0.18 |
| 8 | Load | 10 | 1.20 | | 0.02 |
| 9 | Linehaul to DC 7 | 60 | 1.18 | $1.00 | 1.00 |
| 10 | Unload | 10 | 0.18 | | 0.02 |
| 11 | Delivery | | | | |
| | | 4.25 hrs | $0.16 | | $2.84 |

Referring to Figure 1, the transport of a single package from its pickup at DC 3 (near Jacksonville, FL) through to its delivery at DC 7 would include at stop at DC 4 where it is unloaded, sorted, and then loaded onto what would usually be a different truck for its transport to DC 7. As listed in Table 1, the total time required for the transport of the package is the sum of (1) the loading/unloading (L/U) times at each DC, (2) the time spent waiting at each DC for arrival of a truck to transport the package to its next DC, and (3) the time spent in transit onboard each truck. Since the DC waiting times are unknown (because the arrival of the trucks is not scheduled or otherwise controlled), the total transport time and cost is unknown until the package arrives at its destination.

### 2.1. Truck Protocol

The truck protocol consists of two rules and is used to determine which truck is used to transport what load at what DC. The goal for truck operation is to try to match the load that values transport the highest with the truck that can provide that transport service at the least cost (e.g., the truck closest to the DC).

1. **Priority for Accepting Loads.** *Opportunity to accept or reject load based on truck's arrival time at DC:* Priority for accepting or rejecting an available load at a DC is first given to trucks already at the DC based on their order of arrival, earliest first, and then to trucks not at the DC based on their expected time of arrival at the DC along their intended path to the DC.

2. **Reneging.** *After reneging, a truck cannot again accept the same load until all other trucks have rejected it:* A truck can renege on its acceptance of a load at anytime, but it will not be able to accept the same load until all other trucks have been offered the load and have rejected it. Reneging can be used by trucks to capture all of an increase in a load bid as long there are few other trucks nearby; with many trucks nearby, all of the increase is given to the original packages in the load (see Package Protocol Rule 2).

### 2.2. Package Protocol

The package protocol consists of three rules and is used to determine which packages are selected to join a load. The goal for package selection is to encourage a package to submit a bid that represents its true value for transport as soon possible, thereby allowing trucks to be more responsive and discouraging multiple-bid auction-like behavior.

1. **Load Formation.** *Packages assigned to load that maximizes resulting load bid:* Packages at and inbound to a DC are assigned to the load that will create the maximum possible total load bid as a result of the inclusion of their bids, and any packages that, as a result, are dropped from the load are assigned to other loads (where the load bid for a single load is the sum of its package bids).

2. **Allocation of Load Bid.** *Truck's portion of a load bid does not increase after acceptance:* The portion of a load bid given to the truck that accepted the load is equal to the amount of the load bid at the time of acceptance; all subsequent increases in the load bid are given to the packages that were in the load at the time of acceptance (and remain in the load) in proportion to their bid amounts.

3. **Withdrawal and Rebidding.** *Packages that withdraw or rejoin load are charged previous bid amounts:* If a package wants to withdraw from a load, then it is charged the amount of its bid. If a package that was dropped from a load because of a low bid submits a new bid to try to rejoin the load, then it is charged the amount equal to all of its previous bids even if it is not selected or is later dropped from the load. In both cases, the charged amounts are added to the load bid.

## 3. Implementation and Experimental Results

A simulation of a public logistics network consisting of the 36 DCs shown in Figure 1 was used in [4] to investigate the effectiveness of the protocols described in the previous section. A subset of the proposed package and truck protocols was implemented and then, using the simulation, compared to operation of the network without the use of the protocols. The weighted average waiting time at DCs of packages transported through the network was used as the criterion to demonstrate the effectiveness of the pricing mechanism.

### 3.1. Weighted Average Waiting Time and Package Bids

In an implementation of the full package protocol, the monetary value that a package places in each hour required for its transport from its origin to its destination provides an upper limit on the amount that the package would bid in order to try to reduce its transport time by one hour; but, if there are few other packages and lots of trucks at a DC, then a package may be able to bid less than its value and still be able to reduce its transport time by one hour. In the implementation of a subset of the package protocol describe here, the simplifying assumption is made that a package's bid always equals its value. As a result, the weighted average waiting time is determined by weighing the hours of delay that each package incurs waiting for a truck at each DC it visits along the path from its origin to its destination by its total value/bid as a percentage of the total values/bids of all packages transported during each run of the simulation. The total value/bid of each package is determined by randomly generating from a beta distribution a value/bid in terms of $/mile and then multiplying this by shortest distance (in miles) from its origin to its destination. A beta distribution was chosen because it gives only non-negative values, which is required for package values/bids, and because, by using proper parameters, the shape of beta distribution can be altered to get different combinations of package values/bids.

### 3.2. Implementing the Protocols

Without the protocols, trucks make decisions only when they are at DCs. At a DC, a truck picks the load in the queue with the maximum number of packages and packages are loaded on the truck in order of their arrival at the DC, earliest first. With the protocols, only Truck Protocol Rule 1 and Package Protocol Rules 1 and 2 were implemented because, in the simulation, packages do not have software agents to make decisions on their behalf and the truck agents have a very simple greedy behavior. In order to keep the behavior of a truck agent simple, trucks do not wait at a DC if there is a load available and the load bid exceeds the variable cost of transporting the load (to cover fuel cost and the labor cost of the truck driver). Shortest paths for packages and trucks are determined in terms of distance instead of time or other measure of cost.

In the simulation, since a software agent is not available to make decisions on behalf of a package, it cannot renege (Package Protocol Rule 3) from a reservation. Once a package is assigned to a truck, it can not be assigned to any other truck unless the first truck reneges the load that the package is in. This could result in a load not assigned to the truck nearest to the DC even though the load offers the highest amount at the DC. To avoid this problem in the simulation, every time a load bid changes at a DC, all the loads associated with that DC are reassigned to the trucks such that the highest value load should be assigned to the nearest truck.

### 3.3. Experimental Setup

Each simulation run was started by putting packages corresponding to one day of demand at each of the 36 DCs in proportion to their surrounding population, and no demand was generated after that. This was done to try to duplicate the effects of a sudden surge in demand. Each simulation was run for 50 hours of simulation time. All packages that had not reached their destination at the end of 50 hours were assigned a transport time of 50 hours. The profit received by a truck is equal to the package's value minus the transportation cost.

Results were obtained for the following set of parameters:

- Number of DCs: 36
- Package demand per day: 10,000 and 20,000
- Number of trucks: 36 and 72
- Truck capacity: 10 and 20
- Transportation cost: $2 per mile
- Package values: Derived from beta distributions with large, zero, and small variance
- Number of replications: 25

### 3.4. Results

**Large Variance:** Package values were derived from Beta (2,5) with a mean of $3 per mile. Table 2 shows the average weighted waiting time obtained from simulation with and without the protocols using a large variance in package values for different demands, numbers of trucks, and truck capacities.

**Table 2. Weighted Waiting Time With and Without Protocol for a Large Variance**

| Packages per Day | Number of Trucks | Truck Capacity | Weighted Waiting Time (in hrs) | | % Change |
|---|---|---|---|---|---|
| | | | With Protocol | Without Protocol | |
| 10,000 | 36 | 10 | 42.71 | 48.58 | –12.08 |
| | | 20 | 33.26 | 44.50 | –25.26 |
| | 72 | 10 | 32.27 | 44.37 | –27.27 |
| | | 20 | 18.85 | 25.67 | –26.57 |
| 20,000 | 36 | 10 | 47.00 | 49.47 | –4.99 |
| | | 20 | 42.55 | 48.49 | –12.25 |
| | 72 | 10 | 42.07 | 48.47 | –13.20 |
| | | 20 | 31.81 | 43.91 | –27.56 |

**Zero Variance:** All the packages in the simulation have same value, i.e., $3 per mile. Table 3 shows the average weighted waiting time obtained from simulation with and without the protocols for a demand of 20,000 packages per day with different numbers of trucks and truck capacities.

**Table 3. Weighted Waiting Time With and Without Protocol for Zero Variance**

| Packages per day | Number of Trucks | Truck Capacity | Weighted Waiting Time (in hrs) | | % Change |
|---|---|---|---|---|---|
| | | | With Protocol | Without Protocol | |
| 20,000 | 36 | 10 | 49.05 | 49.47 | –0.85 |
| | | 20 | 46.99 | 48.49 | –3.09 |
| | 72 | 10 | 46.92 | 48.47 | –3.20 |

**Small Variance:** Package values were derived from Beta (5,5) with a mean of $3 per mile. Table 4 shows the average weighted waiting time obtained from simulation with and without the protocols for demand of 20,000 packages per day with different numbers of trucks and truck capacities.

**Table 4. Weighted Waiting Time With and Without Protocol for Small Variance**

| Packages per day | Number of Trucks | Truck Capacity | Weighted Waiting Time (in hrs) | | % Change |
|---|---|---|---|---|---|
| | | | With Protocol | Without Protocol | |
| 20,000 | 36 | 10 | 48.35 | 49.47 | –2.26 |
| | | 20 | 45.74 | 48.49 | –5.67 |
| | 72 | 10 | 45.55 | 48.48 | –6.04 |

A test was performed for each set of "demand of packages per day," "number of trucks," and "truck capacity" values to see if there is a statistically significant difference between weighted waiting times with and without the protocols. It was found that for each set of values there is a significant difference ($\alpha = 0.05$) between weighted waiting times with and without the protocols.

### 3.5. Analysis

From the above results, it can be seen that a public logistics network performs better with the protocols. But difference in the performance of a PLN with and without the protocols is significantly larger with a large variance in package values (in terms of $ per mile) as compared to a small variance or zero variance. The protocols have been designed such that trucks pick first those packages that value transportation the highest. As a result, in the simulation with the protocols, the higher value packages reach their destinations before lower value packages, which results in a lower weighted waiting time as compared to the weighted waiting time in simulation without the protocols. This difference in the weighted waiting time is significant when the variation in the package values is large. When the variation in the package values is small, the difference between the weighted waiting time with and without the protocols is small because all packages value transportation nearly the same.

When all packages have the same value per mile, there is still a statistically significant difference in the times with and without the protocols. The reason for this is due the difference in how loads are selected: without the protocols, a truck selects its next load based on the queue with the maximum number of packages in it, while, with the protocols, a truck selects the load that has the maximum value, where the load value is determined by the value per mile times the distance to the destination DC. In order to make the load selection methods more similar, a test was performed where, without the protocols, load selection was based on the number of packages in each queue times the distance to their next DC. Based on the preliminary results, it was found that their was no statistically significant difference in the weighted average waiting times as compared to the results for the original method of load selection without the protocols.

## 4. Conclusions

This paper described an implementation of a pricing mechanism that can be used to coordinate the operation of a public logistics network. Although the goal of this work is to determine the minimal package and truck behaviors necessary to match the load whose packages place the greatest value in reaching their destinations with the truck that can transport the load at the lowest cost, the current implementation reported in this paper used no dynamic package behaviors and only simple greedy truck behaviors. As a result, the truck reneging and package withdrawal and rebidding aspects of the protocols were never needed. Future work will include a full implementation of the protocols. This will require the use of a more complex criterion than weighted average waiting time, and will provide the basis for developing more complex software agents that will control the transport of each package and operation of each truck in the network.

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## References

1. Kay, M.G., and Parlikad, A.N. , 2002, “Material flow analysis of public logistics networks,” in *Progress in Material Handling Research: 2002*, Meller, R., Ogle, M.K., Peters, B.A., Taylor, G.D., and Usher, J., Eds., Charlotte, NC: The Material Handling Institute, pp. 205–218.

2. Kay, M.G., 2004, “Protocol Design for a Public Logistics Network,” in *International Material Handling Research Colloquium*, Graz, Austria, June 13–17.

3. MacKie-Mason, J.K., and Varian, H.R., 1995, “Pricing the Internet,” in *Public Access to the Internet*, Kahin, B., and Keller, J., Eds., MIT Press, Cambridge, MA, pp. 269–314.

4. Jain, A., 2004, *Protocol Design for a Public Logistics Network*, Master’s Thesis, Dept. of Industrial Eng., North Carolina State Univ., Raleigh, NC.