In *Progress in Material Handling Research: 2004*, R. Meller et al., Eds., MHI, Charlotte, NC, 2004, pp. 181–188
(presented at the Int. Material Handling Res. Colloq., June 13–17, 2004, Graz, Austria).
(Web version of paper revised Jan. 2005)

Protocol Design for a Public Logistics Network

Michael G. Kay

Department of Industrial Engineering
North Carolina State University
Raleigh, NC 27695-7906

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 would be sent from a store and then routed through a sequence of public distribution centers (DCs) located throughput 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. 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.

This paper will describe a proposed design for the package and truck protocols used to coordinate the operation of 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 goal for the decentralized coordination mechanism needed for a public logistics network is to make it possible for packages to maximize their value from transport, and trucks their profit. The proposed solution is to have packages bid for services of the trucks used for their transport and to have the packages 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 protocols 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 [2] proposal to have each packet in the Internet bid for the use of routers when they are congested.

Figure 1 shows the transport of a single package from its pickup at DC1 through to its delivery at DC 6. The package travels on one truck from DC 1 to DC 4. At DC 4, it is unloaded, sorted, and then loaded onto what would usually be a different truck for its transport to DC 6. 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 time is 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. In order to make the transport cost of a single package predicable, some type of insurance mechanism could be used that would pool together the transport of many packages (making transport time more predicable would be more difficult because the bids used to control the behavior of the trucks would have to be included).

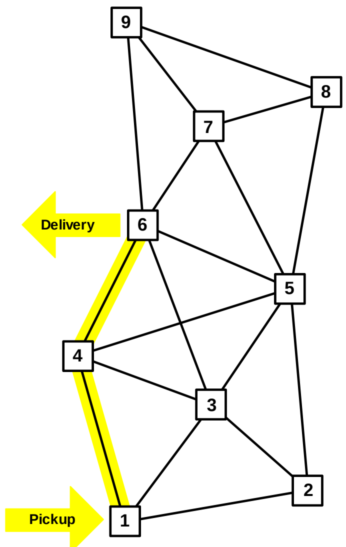

Figure 1. Transport of a single package.

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 DC1	30	2.98		0.06
4	Load	10	2.92		0.02
5	Linehaul to DC4	60	2.90	$1.50	1.50
6	Unload	10	1.40		0.02
7	Wait at DC4	55	1.38		0.18
8	Load	10	1.20		0.02
9	Linehaul to DC6	60	1.18	$1.00	1.00
10	Unload	10	0.18		0.02
11	Delivery				
		255 4.25 hr	$0.16		$2.84

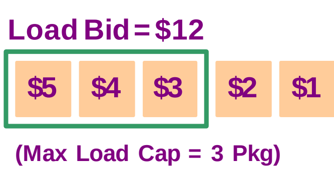

Figure 2. Single load.

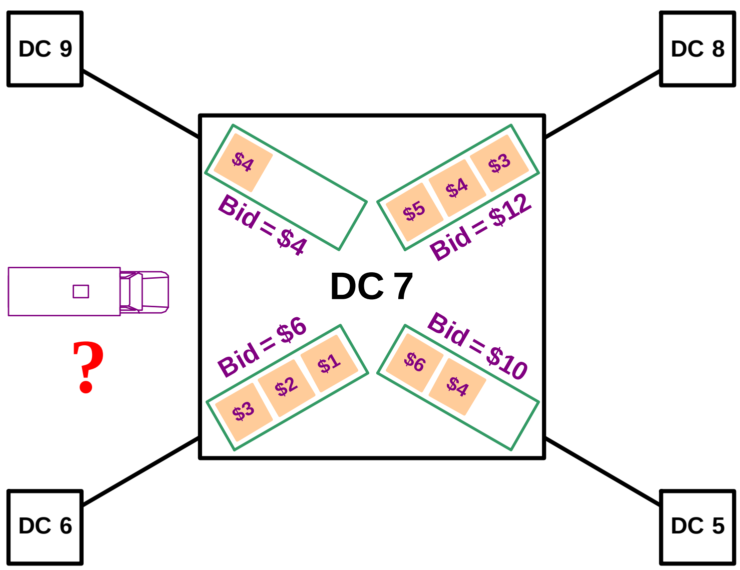

Figure 3. Multiple loads at DC.

The load bid for a single load is the sum of its package bids (see Figure 2). Packages compete on two levels: (1) the packages compete with each other to join a load, and (2) the packages in a load compete with other loads to be selected by a truck for transport (see Figure 3).

The topology of the logistics network is defined by the adjacency relationships between the DCs, where adjacency between a pair of DCs refers to having an established lane (i.e., a single direct link or arc) between each DC. New lanes can be established between any pair of DCs as long as each DC is in agreement. The need for new lane could, for example, result from an increase in demand for direct transport between the DCs or the construction of a new road between the DCs. In Figure 4, a new lane could be established between DCs 1 and 7 that would eliminate the need for intermediate stops at DCs 4 and 6. Lane change is envisioned to be an infrequent event in order to allow for more efficient implementation of the protocol and agent procedures.

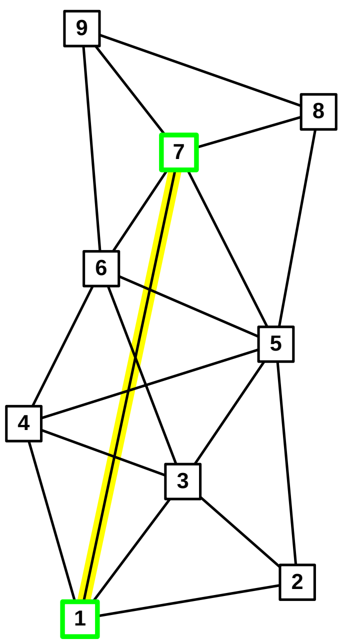

Figure 4. New lane from DC 1 to DC 7 added to network.

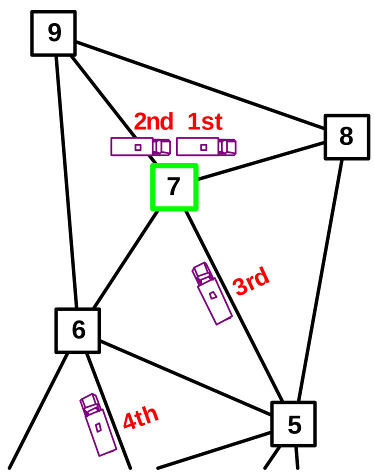

Figure 5. Priority for accepting a load at DC 7.

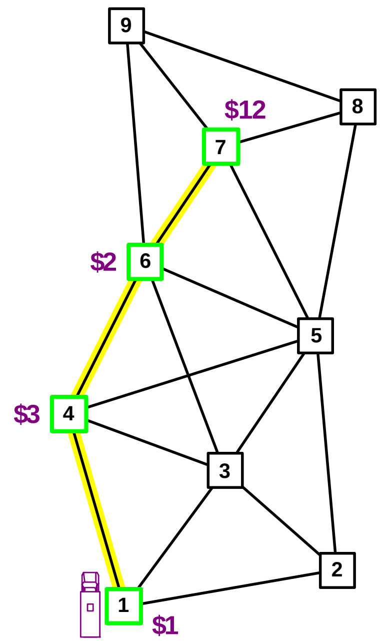

Figure 6. Intended path from DC 1 to DC 7.

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. (See Figure 5.)

- If all trucks reject a load, then it is posted at the DC and is then available for any truck to accept.
- The expected time of arrival of each truck is posted at the DC.
- Although the intended path chosen by a truck does not have to be the quickest path to the DC, a late expected arrival at the DC can affect the truck's priority for being able to accept the load.

- A truck's portion of the load bid is fixed after acceptance.
- Each truck's current location is assumed to be known at all times.

In Figure 6, a high load bid at DC 7 results in the truck accepting low bids at DCs 1, 4, and 6. As a result of a truck accepting very low load bids at intermediate DCs due to a high load bid at a DC further along the path, it possible for some packages to get a "free ride" (i.e., paying almost nothing for transport and paying only for storage), thus making it possible to achieve "dynamic inventory positioning" where, at almost no cost for transport, a package representing finished goods inventory held in stock could be send to a region where, based on past sales records, it is most likely to be purchased; once purchased, it could then be quickly sent the short distance to the customer at very little cost, as opposed to the long delay or expedited shipping that would have been required if the inventory had been stored at the factory or at a centralized distribution center.

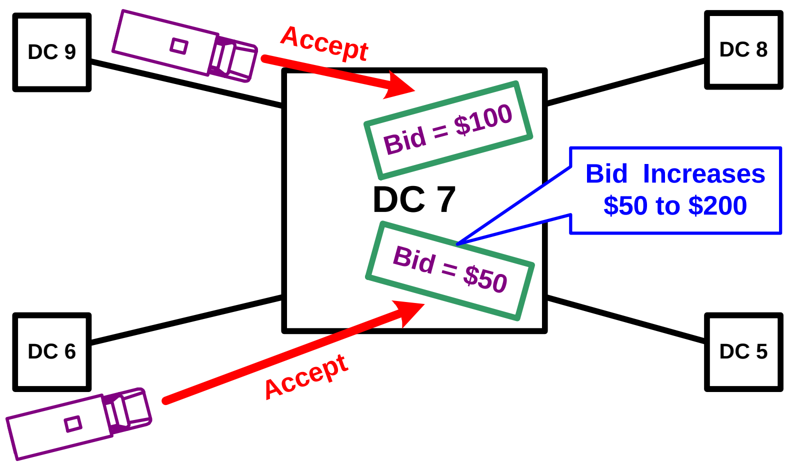

Figure 7. After bid increases from $50 to $200, the trucks renege their current accepted loads so that they can increase their profit; as a result, the load with the higher ($200) bid that values transport the highest will now be transported sooner by the truck closest to the DC.

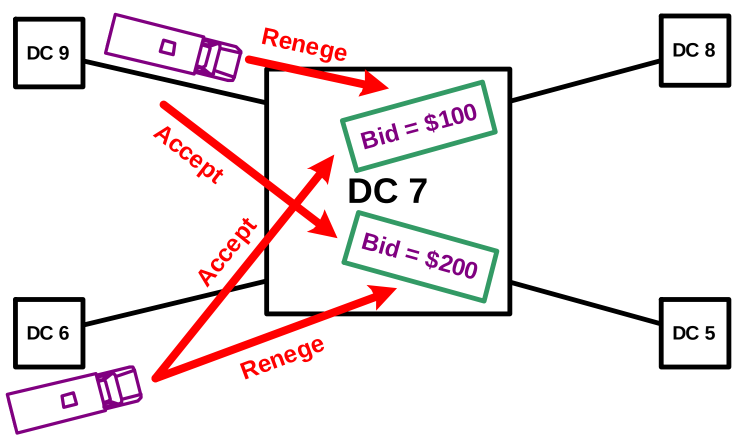

Figure 8. After reneging, the closer truck (coming from DC 9) can accept the $200 bid (an increase of $100 over its original load) and the truck that is farther away can now accept the $100 bid (an increase of $50, since its acceptance of the original bid for the other load fixed its portion of the new $200 bid at $50).

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. Figure 7 and Figure 8 present an example of how two trucks can both renege on their loads in order to capture all of the increase in a load bid.

- All loads beyond the reneged load along a truck's intended path are also reneged.
- Trucks can make agreements with each other to simultaneously renege their current loads.

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 bid, and any packages that, as a result, are dropped from the load are assigned to other loads. (See Figure 9 and Table 2, where the $2- and $1-bid packages will be dropped from first load after the expected arrival of the higher-bid packages that are inbound to DC 7.)

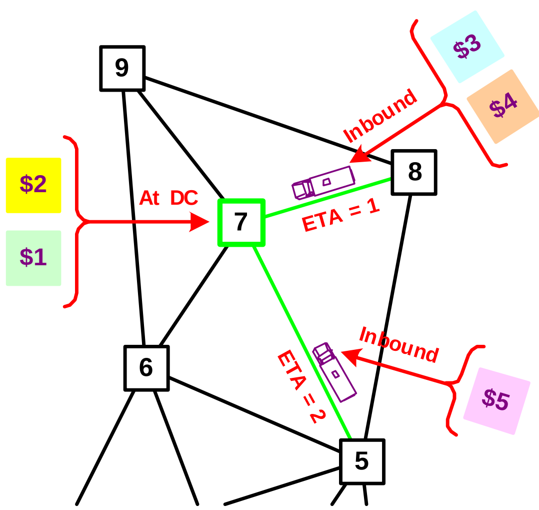

Figure 9. Packages at and inbound to DC 7.

Table 2. Load Formation at Times 0, 1, and 2

Time Index	Load Bid	First Load	Load Bid	Second Load
0	$3	$2 $1		
1	$9	$4 $3 $2	$1	$1
2	$12	$5 $4 $3	$3	$2 $1

- All loads are assumed to have the same capacity (i.e., maximum size).
- Both the bid amount and the size of a package determine whether it will selected for a load.
- A load is indexed based on the latest arrival time of its packages.
- When necessary, equivalent package bids are selected based on the elapsed time a package has spent in the network.

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.

- Once a load has been accepted, no further increase in the amount given to the truck is needed to change its behavior, while giving the increase to the original packages encourages them to submit their bids early, thus increasing the load bid while it can still influence truck behavior.
- Once a truck has accepted a load at a DC, it has no incentive to delay its departure to wait for additional packages, thus resulting in predictable departure times.
- A truck can renege on an accepted load in order to try to capture all of the incease in a load bid, but it must take into account that all other trucks will first be given the opportunity to accept the load.

Table 3 shows a sequence of package bids and truck responses. The $8 load bid consisting of a single package is rejected by the truck(s). The load is accepted after a second package bids $2 so that the load bid increases to $10. At this point, the truck's portion of the load bid remains fixed at $10 as a $5-bid and a $3-bid package are added to the load and the total load bid increases to $16. The additional $15 – $10 = $5 of the load bid that occurs when the $5-bid packages is added to the load is allocated to the packages that were in the load at the time of its acceptance, the $8- and $2-bid packages, based on their respective 80% and 20% portions of the original load bid so that their costs are now $4 and $1, respectively. When the $3-bid package is added to the load, the $2-bid package is dropped and all of the additional $6 of load bid is allocated to the $8-bid package so that its cost is now $2.

Table 3. Allocation of Load Bid

Package Event	Truck Response	Load Bid	Truck Portion	Allocated Portion	Load (Bid / Cost)			
Bid & Join	Reject	8	8	0	8 / 8			
Bid & Join	Accept	10	10	0	8 / 8	2 / 2		
Bid & Join	—	15	10	5	8 / 4	5 / 5	2 / 1	
Bid, Join, & Drop	—	16	10	6	8 / 2	5 / 5	3 / 3	2 / 0

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.

- Only the current bid is used during rebidding to determine if the package can rejoin the load and subsequently remain in the load.

- Previous bid charges are meant to discourage use of frequent bid changes just to extract information but still allow changes to occur if a package's circumstances have changes (e.g., if it has been redirected to a new destination).
- If all of the packages withdraw from a load, then the amount they are charged for their previous bid amounts is given to the DC.

Table 4 shows a sequence of package events and truck responses that continues Table 3. The \$2-bid package that was dropped from the load rebids \$4 as is now able to rejoin the load, while the \$3-bid package is dropped. Although the bid of the package that rejoined is now \$4, its cost is \$6 because it is charged the \$2 of its initial bid in addition to its current \$4 bid. The \$9 – \$6 = \$3 increase in the allocated portion of the load bid is due to the \$4 bid and \$2 charge from the new \$4-bid package minus the \$3 lost when the \$3-bid package is dropped from the load. The cost for the \$8-bid package is now –\$1, which represents a profit of \$1 to the package. Next, the \$3-bid package that was just dropped from the load increases its bid to \$6 and rejoins the load, but its costs is \$9 due to the \$3 charge for its initial bid. Next, the \$5-bid package withdraws from the load and is charged its \$5 bid, which is added to the allocated portion of the load bid. Finally, when the truck reneges, the entire total load bid of \$28 is now available to use to attract a different truck to accept the load (since the truck that just reneged is not able to accept the load again).

Table 4. Withdrawal and Rebidding

Package Event	Truck Response	Load Bid	Truck Portion	Allocated Portion	Load (Bid / Cost)			
Bid & Join	Reject	8	8	0	8 / 8			
Bid & Join	Accept	10	10	0	8 / 8	2 / 2		
Bid & Join	—	15	10	5	8 / 4	5 / 5	2 / 1	
Bid, Join, & Drop	—	16	10	6	8 / 2	5 / 5	3 / 3	2 / 0
Rebid, Rejoin, & Drop	—	19	10	9	8 /-1	5 / 5	4 / 6	3 / 0
Rebid, Rejoin, & Drop	—	24	10	14	8 /-6	6 / 9	5 / 5	4 / 2
Withdraw & Rejoin	—	28	10	18	8 /-10	6 / 9	4 / 6	0 / 5
—	Renege	28	28	0	8 / 8	6 / 9	4 / 6	0 / 5

Agent-Based Coordination

Each package and each truck is controlled by a software agent. The agents interact with each DC via the services provided by the DC (see Figure 10). Each agent is provided with all of the active load bids and all truck expected arrival times as part of the data maintained by the DC. The DC determines and maintains all of the load bids and tracks all of the truck paths in order determine the expected arrival times of the trucks at the DC. For each new load bid, the DC determines the order in which trucks are offered the opportunity to accept the load; if all of the trucks reject the load, then its bid is posted with other active load bids at the DC. The package and truck agents can make side agreements with each other in order to be able to coordinate their actions. A single firm that owns multiple packages or trucks could such agreements to coordinate the transport of the packages or the operation of the trucks to, potentially, achieve better results than would be possible if each agent were operating independently. Each actual software code running each agent can be located either (1) on servers at the DC (moving to adjacent DCs as the package moves); (2) off-site at servers operated by the owner of the package or truck, and communicating with each DC via the Internet; or (3) in portable computers located either on the package or in each truck, and communicating with each DC via a wireless connection.

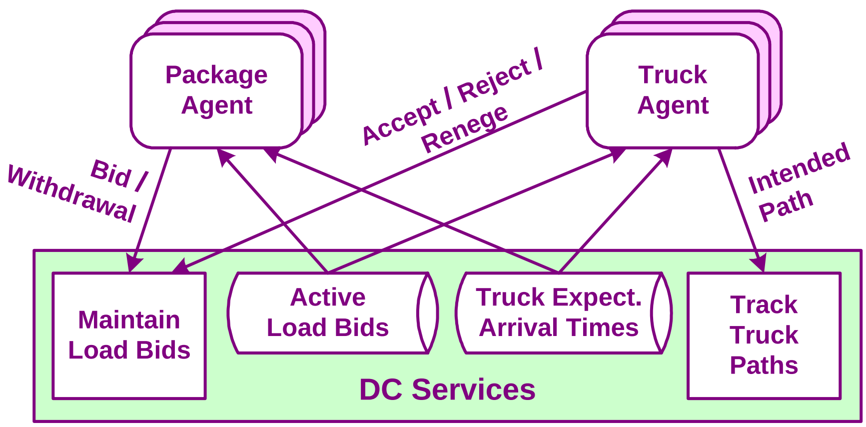

Figure 10. Framework for agent-based coordination.

References

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

2. J.K. MacKie-Mason and H.R. Varian, “Pricing the Internet,” in *Public Access to the Internet*, JFK School of Government, May 26–27, 1993.

Acknowledgement

This research is supported, in part, by the National Science Foundation under Grant CMS-0229720 (NSF/USDOT).