Design and Coordination of a Public Logistics Network

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Public Logistics Networks

- Proposed as alternative to private logistics networks (like UPS) for ground transport of packages.

- **Local transport:** For example, package sent from retail store and then routed through sequence of public distribution centers (DCs) located throughout metropolitan area and then delivered to customer’s home in a matter of hours.

- **Intercity transport:** DCs located at major highway interchanges to reduce loading/unloading time.
<table>
<thead>
<tr>
<th>Public Network</th>
<th>Private Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Each truck and DC can be operated by different firm</td>
<td>Single firm (e.g., UPS) handles package throughout its transport</td>
</tr>
<tr>
<td>Each truck and DC has access to potentially all of network’s demand $\Rightarrow$ scale economies</td>
<td>Each truck and DC has access to only single firm’s portion of demand</td>
</tr>
<tr>
<td>Decentralized control</td>
<td>Centralized control</td>
</tr>
<tr>
<td>Public DCs and open coordination protocols provide low barrier to entry</td>
<td>Private hubs/terminals result in high barrier to entry for parcel and LTL transport</td>
</tr>
</tbody>
</table>
Comparison of Network Alternatives

<table>
<thead>
<tr>
<th>When preferred:</th>
<th>PLN</th>
<th>HUB</th>
<th>P2P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading/unloading time</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Transport demand</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>
Hypothetical Network

- Covers portion of southeastern US
- 36 public DCs
- DCs connected via interstate highways

Public DCs:
- Interstate DCs (shown)
- Local DCs (not shown)
Current Research Issues

I. Design of a Public Logistics Network
II. Design of a Public DC
III. Network Coordination via Bidding
I. Design of a Public Logistics Network

- Two design problems:
  1. Given candidate set of DC locations, determine number of DCs and their location
     - Continental U.S.
     - Each metropolitan area
  2. Given number and location of DCs, determine arcs/lanes in network
     - Subroutine in first design problem
     - 36-DC hypothetical network used
     - Provides insight into economics of PLN and DC design issues

- To implement PLN, neither problem needs to be “solved”
  - Coordination protocols allow network operation to adapt
  - Designs used just to predict performance
  - DCs added incrementally in response to market conditions
Average Transport Time

- Performance criterion to compare designs:

\[
\text{Average Transport Time} = \sum_{i=1}^{36} \sum_{j=1}^{36} w_{ij} t_{ij},
\]

where, \( w_{ij} \) = percentage of total demand from DC \( i \) to DC \( j \)

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

- Proximity factor used to relate demand to distance
- Wait-for-Truck Time estimated by:
  1. Summing total demand along each arc
  2. Dividing by average truck load (80% of its maximum capacity) to get number of truck trips
  3. Using half of headway (average time between trips) as expected waiting time estimate
Example:

US SE: Half Headway: Value

- TrSpeed: 50.00
- LdFac: 0.80
- Hr: 24.00
- TrCap: 2,000.00

<table>
<thead>
<tr>
<th>Iter</th>
<th>tLU</th>
<th>Prox</th>
<th>Pkg</th>
<th>HUB</th>
<th>PLN</th>
<th>PLN+</th>
<th>PLN-</th>
<th>P2P</th>
<th>HUB+</th>
<th>LB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>6</td>
<td>32</td>
<td>1</td>
<td>4.7342</td>
<td>3.6694</td>
<td>3.6787</td>
<td>3.6676</td>
<td>4.7742</td>
<td>-3.6593</td>
</tr>
</tbody>
</table>
II. Design of a Public DC

- Main requirements:
  1. Fast, fully automated loading/unloading
  2. Storage of different size packages
  3. Packages can be redirected any time prior to loading
  4. Low cost to build small DC, allowing many DCs to cover a single metropolitan area
  5. Small exterior footprint to allow locating in urban areas

- Traditional material handling technologies are not adequate with respect to all above requirements
Traditional DC Design

- Conveyors for all transport
- AS/RS for storage
Material Handling Module

- Standardized 8.5-inch square module
- All material handling performed using arrays of modules
- Loads can occupy multiple modules
- Pop-up wheels used to translate load and make series of 90° turns
- Guides on module raised to direct load
Truck Loading and Unloading

- Fully automated loading and unloading
- Truck use same type array used inside DC
- Movable array used to interface between DC and truck
Storage and Retrieval

- Multiple loads can be densely stored on arrays of modules
- To retrieve shaded load:
Storage and Retrieval

- Multiple loads can be densely stored on arrays of modules
- To retrieve shaded load:
  - Other loads move to clear path
Storage and Retrieval

- Multiple loads can be densely stored on arrays of modules
- To retrieve shaded load:
  - Other loads move to clear path
  - Load makes series of 90° turns as it is transported
### Public DC: Top View

<table>
<thead>
<tr>
<th>Storage Area</th>
<th>Staging Areas (2)</th>
<th>Elevators (3)</th>
<th>Sortation Area</th>
<th>Storage Area</th>
<th>Staging Areas (2)</th>
<th>S/R Bays (2)</th>
<th>S/R Bays (2)</th>
<th>S/R Bays (2)</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
</tbody>
</table>

**Note:** The diagram illustrates the layout of the Public DC, including storage areas, sortation areas, staging areas, and elevators.
Public DC: Side View

- 4 levels for sortation and truck loading
- 10 levels for long-term storage
III. Network Coordination via Bidding

- Entities in network are DCs, trucks, and packages
- Since separate firms own each DC and truck, coordination of package transport is more difficult than in a private network
- Goal for Coordination Mechanism:
  - Make it possible for packages to maximize their value from transport, and trucks their profit
- Solution:
  - Packages bid for services of the trucks used for their transport
  - Packages pay each DC for time spent at DC and any other services
Transport of a Single Package

- **Total Time** = \( L/U + DC\ Wait + Transit \)
- Since DC Wait time is unknown, total transport time also unknown

⇒ Credit/debit can occur at delivery

### Activity Times Table

<table>
<thead>
<tr>
<th>Activity</th>
<th>Time (min)</th>
<th>Credit</th>
<th>Bid</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Pickup</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Unload</td>
<td>10</td>
<td>$3.00</td>
<td>$0.02</td>
<td></td>
</tr>
<tr>
<td>3 Wait at DC1</td>
<td>30</td>
<td>2.98</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>4 Load</td>
<td>10</td>
<td>2.92</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>5 Linehaul to DC4</td>
<td>60</td>
<td>2.90</td>
<td>$1.50</td>
<td>1.50</td>
</tr>
<tr>
<td>6 Unload</td>
<td>10</td>
<td>1.40</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>7 Wait at DC4</td>
<td>55</td>
<td>1.38</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>8 Load</td>
<td>10</td>
<td>1.20</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>9 Linehaul to DC6</td>
<td>60</td>
<td>1.18</td>
<td>$1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>10 Unload</td>
<td>10</td>
<td>0.18</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>11 Delivery</td>
<td>255</td>
<td>$0.16</td>
<td>$2.84</td>
<td>4.25 hr</td>
</tr>
</tbody>
</table>
Package Bids

Load bid is sum of package bids in load

Packages compete on two levels:
- Packages compete with each other to join a load
- Packages in a load compete with other loads to be selected by a truck for transport

Single Load

Multiple Loads at DC

Load Bid = $12
(Max Load Cap = 3 Pkg)

<table>
<thead>
<tr>
<th>DC 9</th>
<th>DC 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$5</td>
<td>$4</td>
</tr>
<tr>
<td>$3</td>
<td>$2</td>
</tr>
<tr>
<td>$1</td>
<td></td>
</tr>
</tbody>
</table>

Bid = $4

DC 7

<table>
<thead>
<tr>
<th>DC 6</th>
<th>DC 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$3</td>
<td>$2</td>
</tr>
<tr>
<td>$1</td>
<td></td>
</tr>
<tr>
<td>$6</td>
<td>$4</td>
</tr>
</tbody>
</table>

Bid = $6
Bid = $10

Bid = $4
Bid = $12

Bid = $4
Bid = $3
Bid = $1

Bid = $2
Bid = $1

$5 $4 $3 $2 $1

$5 $4 $3 $2 $1

$5 $4 $3 $2 $1

$5 $4 $3 $2 $1

$5 $4 $3 $2 $1

$5 $4 $3 $2 $1

$5 $4 $3 $2 $1

$5 $4 $3 $2 $1

$5 $4 $3 $2 $1

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$5 $4 $3 $2 $1

$5 $4 $3 $2 $1

$5 $4 $3 $2 $1

$5 $4 $3 $2 $1

$5 $4 $3 $2 $1
Truck Protocol

- Determines which truck is used to transport what load at what DC
- **Goal for truck operation:**
  - Try to match the load that values transport the highest with the truck that can provide that transport service at the least cost
- **Protocol:**
  1. **Priority for Accepting Loads:** Opportunity to accept or reject load based on truck’s arrival time at DC
  2. **Reneging:** After reneging, truck cannot again accept same load until all other trucks have rejected it
1. Priority for Accepting Loads

- Opportunity to accept or reject load based on truck’s arrival time at DC
- Truck’s portion of load bid fixed after acceptance
- If all trucks reject load, then it’s posted at DC and available for any truck to accept

Load at DC 7
2. Reneging

After reneging, truck cannot again accept same load until all other trucks have rejected it.

Near and far trucks accept high and low bids, resp.
2. Reneging

- After reneging, truck cannot again accept same load until all other trucks have rejected it.

Near and far trucks accept high and low bids, resp. Low bid now increases beyond high bid.
2. Reneging

- After reneging, truck cannot again accept same load until all other trucks have rejected it.

Near and far trucks accept high and low bids, resp.

Low bid now increases beyond high bid.

Trucks agree to reneg (since far truck’s portion fixed at $50).
2. Reneging

- After reneging, truck cannot again accept same load until all other trucks have rejected it.

Near and far trucks accept high and low bids, resp.

Low bid now increases beyond high bid.

Trucks agree to reneging (since far truck’s portion fixed at $50).

Near truck accepts $200 bid and far truck $100 bid.
Package Protocol

- Determines which packages selected to join load
- Goal for package selection:
  - 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

- Protocol:
  1. **Load Formation:** Packages assigned to load that maximizes resulting load bid
  2. **Allocation of Load Bid:** Truck’s portion of load bid does not increase after acceptance
  3. **Withdrawal and Rebidding:** Packages that withdraw or rejoin load are charged previous bid amounts
1. Load Formation

- Packages assigned to load that maximizes resulting load bid
- Packages can bid as soon as they are at or inbound to DC

<table>
<thead>
<tr>
<th>Time Index</th>
<th>Load Bid</th>
<th>First Load</th>
<th>Second Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$3</td>
<td>$2 $1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>$9</td>
<td>$4 $3 $2</td>
<td>$1</td>
</tr>
<tr>
<td>2</td>
<td>$12</td>
<td>$5 $4 $3</td>
<td>$2 $1</td>
</tr>
</tbody>
</table>
2. Allocation of Load Bid

- Truck’s portion of load bid fixed after acceptance
- Subsequent increases in bid allocated to packages in load (and remain in load) at time of acceptance

<table>
<thead>
<tr>
<th>Package Event</th>
<th>Truck Response</th>
<th>Load Bid</th>
<th>Truck Portion</th>
<th>Allocated Portion</th>
<th>Load (Bid / Cost)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bid &amp; Join</td>
<td>Reject</td>
<td>8</td>
<td>8</td>
<td>0</td>
<td>8 / 8</td>
</tr>
<tr>
<td>Bid &amp; Join</td>
<td>Accept</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>8 / 8 2 / 2</td>
</tr>
<tr>
<td>Bid &amp; Join</td>
<td>—</td>
<td>15</td>
<td>10</td>
<td>5</td>
<td>8 / 4 5 / 5 2 / 1</td>
</tr>
<tr>
<td>Bid, Join, &amp; Drop</td>
<td>—</td>
<td>16</td>
<td>10</td>
<td>6</td>
<td>8 / 2 5 / 5 3 / 3 2 / 0</td>
</tr>
</tbody>
</table>
3. Withdrawal and Rebidding

Packages that withdraw or rejoin load are charged previous bid amounts

<table>
<thead>
<tr>
<th>Package Event</th>
<th>Truck Response</th>
<th>Load Bid</th>
<th>Truck Portion</th>
<th>Allocated Portion</th>
<th>Load (Bid / Cost)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bid &amp; Join Reject</td>
<td>8</td>
<td>8</td>
<td>0</td>
<td></td>
<td>8 / 8</td>
</tr>
<tr>
<td>Bid &amp; Join Accept</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td></td>
<td>8 / 8 2 / 2</td>
</tr>
<tr>
<td>Bid &amp; Join —</td>
<td>15</td>
<td>10</td>
<td>5</td>
<td></td>
<td>8 / 4 5 / 5 2 / 1</td>
</tr>
<tr>
<td>Bid, Join, &amp; Drop —</td>
<td>16</td>
<td>10</td>
<td>6</td>
<td></td>
<td>8 / 2 5 / 5 3 / 3</td>
</tr>
<tr>
<td>Rebid, Rejoin, &amp; Drop—</td>
<td>19</td>
<td>10</td>
<td>9</td>
<td></td>
<td>8 /-1 5 / 5 4 / 6</td>
</tr>
<tr>
<td>Rebid, Rejoin, &amp; Drop—</td>
<td>24</td>
<td>10</td>
<td>14</td>
<td></td>
<td>8 /-6 6 / 9 5 / 5</td>
</tr>
<tr>
<td>Withdraw &amp; Rejoin —</td>
<td>28</td>
<td>10</td>
<td>18</td>
<td></td>
<td>8 /-10 6 / 9 4 / 6</td>
</tr>
<tr>
<td>Renege —</td>
<td>28</td>
<td>28</td>
<td>0</td>
<td></td>
<td>8 / 8 6 / 9 4 / 6</td>
</tr>
</tbody>
</table>
Agent-based Coordination

- Each package and each truck controlled by a software agent
- Agents:
  - provided with all load bids at DC and all truck locations
  - can make side payments with each other
  - can be located at DC, off-site via Internet, or in package or truck
Current and Future Work

- Specify DC Services to run at each DC to efficiently support protocol, thereby making larger-scale simulations feasible
- Implement more intelligent (i.e., non-greedy) truck and package software agents
- Explore issues like
  - Dynamic inventory positioning
    - saving on transport cost since it’s possible for packages to get “free ride” ($0 bid, only paying for storage)
  - In-transit trading
Contact

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