Analyzing Varying Cost Structures of Alternative Warehouse Strategies

Kaan Unnu and Jennifer Pazour

Abstract: Companies have three main alternatives to acquire warehouse and order fulfillment capacities; they can build their own self-distribution facility, outsource using a third-party logistics (3PL) provider, or access on-demand warehousing capabilities. These alternatives have varying benefits but also have varying cost structures. Specifically, on-demand warehousing has high variable costs, but no fixed costs; whereas the self-distribution and 3PL alternatives have high fixed costs, but lower variable costs. This work develops cost expressions for the different alternatives while considering size, capital, equipment, and operational costs. Data from practice is gathered and used to analyze different cost trade-offs. Our cost expressions and data gathering are useful inputs for academic research in facility location and distribution network optimization studies.

Keywords: On-demand, warehouse, distribution, network, cost

1. Introduction
Today’s customers expect fast and free or low-cost delivery of e-commerce orders. 51% of retailers today offer same-day delivery to their customers and 65% plan to achieve this target within two years [1]. This trend has also impacted B2B relations, and 60% of industrial buyers are now expecting to receive their orders within 1-2 days [2]. However, distribution costs such as freight, inbound, outbound logistics, storage, and handling constitute a significant share of overall revenue, leading some retailers to have low or zero profit margins for e-commerce sales [3–5]. Thus, regardless of their industry, in order to increase responsiveness and reduce costs, companies need to align their distribution networks and strategies with today’s customer expectations.

Companies have three main options to increase distribution locations and capabilities. They can build and operate their own self-distribution facility. This option has the longest start-up period and commitment due to its high capital requirements. Alternatively, a company can outsource distribution operations to a third-party logistics (3PL) provider. This requires less initial capital investments, but has monthly recurring and additional variable costs. The final alternative is to access on-demand warehousing capabilities. The on-demand alternative has recently become available in the market [6,7]. On-demand B2B platforms, like Flexe, Ware2Go, and FlowSpace, match companies with underutilized warehouse and distribution center (DC) capacities with customers who need these services [8]. This new model embodies principles of the Physical Internet [9] and open supply webs, as they are open to all supply chain actors, available on-demand and on a per-use basis, and adaptable to demand variabilities [10]. In this option, no fixed costs nor long-term commitments are required, but for this flexibility, companies can face relatively high unit costs per pallet per month. Table 1 presents a basic comparison of these three distribution center options.

Table 1 Comparison of distribution center alternatives

<table>
<thead>
<tr>
<th></th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self Distribution</td>
<td>- Low operational costs per pallet if operated at high capacity utilization.</td>
<td>- High investment costs and the longest commitment</td>
</tr>
<tr>
<td></td>
<td>- Trust, control</td>
<td>- Not adaptable to demand variability and volatility</td>
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<tr>
<td></td>
<td>- More flexible than self- distribution option</td>
<td>- Long start-up period</td>
</tr>
<tr>
<td>3PL</td>
<td>- Shorter start-up period</td>
<td>- Higher operational costs</td>
</tr>
<tr>
<td></td>
<td>- Much lower initial investments</td>
<td>- Startup period required for contract negotiations</td>
</tr>
<tr>
<td></td>
<td>- Commitment with binding contracts</td>
<td>- Potential, trust, quality and performance issues</td>
</tr>
<tr>
<td>On-Demand</td>
<td>- Highest flexibility</td>
<td>- Minimum control</td>
</tr>
<tr>
<td></td>
<td>- No latency between decision and implementation</td>
<td>- Potential, trust, quality and performance issues</td>
</tr>
<tr>
<td></td>
<td>- No initial investments</td>
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</tbody>
</table>

2. Cost expressions and data for the different warehousing options
We develop unit cost expressions to compare the three DC alternatives. Because the alternatives have different cost structures, the introduced expressions can be used to develop an economical comparison of the three alternatives when factors such as capacity utilization, commitment durations, inventory turns, and cost estimates change. The scope of these cost expressions capture DC costs associated with storing and handling of a 40x48 inch standard GMA pallet as...
the smallest stock keeping unit and one month as the smallest storage period. Additionally, in this conference paper, we identify available online references and assumptions focused on the US market.

2.1 Distribution Center Costs
As summarized in Table 2, the three alternatives have different cost structures, which we break into initial (start-up) costs, operational (recurring) costs, holding (storage) costs, and handling costs. Initial costs ($F$) are one-time costs required prior to becoming operational. Operational costs ($R$) are fixed monthly recurring expenses required to keep the DC functioning, regardless of satisfied demand. Holding ($H$) costs are variable costs for storage of each pallet per month. Handling ($G$) costs are per pallet costs every time a pallet is handled for receiving, put-away, picking, and dispatching.

<table>
<thead>
<tr>
<th>DC Alternative</th>
<th>Initial Costs ($F^a$)</th>
<th>Operational Costs ($R^a$)</th>
<th>Holding Costs ($H^a$)</th>
<th>Handling Costs ($G^a$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self Distribution (sd)</td>
<td>- Construction or acquisition - Equipment (handling, storage, etc.) - Closing costs, due diligence</td>
<td>- Labor (direct labor, common, management, etc.) - Equipment rental (e.g. handling, storage) - Other charges (insurance, outsourced services, etc.)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>3PL (tp)</td>
<td>- Security deposit, legal fees (contract review), account setup fees</td>
<td>- Monthly contractual payments - Other charges (insurance, outsourced services, etc.)</td>
<td>None</td>
<td>Per pallet costs</td>
</tr>
<tr>
<td>On-Demand (od)</td>
<td>None</td>
<td>None</td>
<td>Per pallet per month costs</td>
<td>Per pallet costs</td>
</tr>
</tbody>
</table>

In (1)-(3), we create unit cost expressions ($U^a$) of a selected distribution alternative ($a$), which are in $ per pallet per month. Our reference to "per pallet" is based on D, which is the average number of pallets demanded each month.

\[
U^{sd} = \frac{1}{D} \left( \frac{F^{sd}}{N^{sd}} + R^{sd} \right) \tag{1}
\]

\[
U^{tp} = \frac{1}{D} \left( \frac{F^{tp}}{N^{tp}} + R^{tp} \right) + G^{tp} \tag{2}
\]

\[
U^{od} = \left[ \frac{12}{\gamma} \right] * H^{od} + G^{od} \tag{3}
\]

where $N^a$ denotes the commitment duration of alternative $a$, which is the total months of the service duration a company must maintain its decision; and $\gamma$ is the annual inventory turns. Next, we present detailed assumptions and equations for the cost types.

2.1.1 Initial Costs
For self-distribution, building ($IC_{B}^{sd}$), equipment ($IC_{E}^{sd}$) and upfront ($IC_{P}^{sd}$) costs constitute the initial ($F^{sd}$) cost in (4). Whereas, the 3PL alternative’s initial cost ($F^{tp}$) only consists of upfront ($IC_{P}^{tp}$) cost items ($F^{tp} = IC_{P}^{tp}$). The on-demand alternative has a negligible contract review cost as the only upfront cost. One customer contract covers all suppliers matched through the on-demand platform regardless the number of suppliers used or pallets stored.

\[
F^{sd} = IC_{B}^{sd} + IC_{E}^{sd} + IC_{P}^{sd} \tag{4}
\]

Building Costs: The main factors affecting the acquisition or construction cost of a warehouse are its size, type, location (state, city, and proximity to transportation and dense population areas), and design options (wiring, lighting, office space, dock doors). In this paper, commitment durations ($N^{sd}$) studied for self-distribution are shorter than the building’s economic useful life. Thus, we consider a resale value at the end of the commitment period. We calculate the initial cost of the building ($IC_{B}^{sd}$) with (5), which captures the total building and land cost ($C_{B}$) and the net present value of the resale income of the building and land ($PV_{SB}$) at the end of the commitment period ($N^{sd}$).

\[
IC_{B}^{sd} = C_{B} - PV_{SB} \tag{5}
\]

In (6), we estimate $C_{B}$ as a function of $A$, the warehouse space in square feet, and $C_{e}$, the land acquisition and building construction costs per square foot. $C_{e}$ can be estimated depending on location through references and calculations [11-14] or commercial real estate web sites, such as LoopNet, Costar and Cityfeet.

\[
C_{B} = C_{e} * A \tag{6}
\]

Equation (7) can estimate the warehouse space ($A$) for a projected number of monthly pallet-demand ($D'$), annual inventory turns, warehouse floor space in sq ft per pallet ($\theta$) and additional space required other than the dedicated
storage area (e.g. cafeteria, office, docks) in square feet \((g)\). The Peerless Research Group survey [15] reports average annual inventory turn for warehouses and DCs, 8.5 for 2017 and 9.2 for 2016. The warehouse floor space estimate coefficient \(\theta\) is a simplified solution of warehouse dimensioning, which converts the pallet capacity into floor space \([16]\). The space required for a pallet is affected by the storage equipment (layout, rack types, height, storage depth) and handling equipment decisions (aisle width, # of intersections, aisle length, max height etc.). Further details and related academic literature can be found in the survey paper by Gu et al. [16] and approximate calculations for different storage layouts are addressed in [17,18]. Space estimate per pallet coefficients \((\theta)\) might include the additional spaces like office, administrative spaces (dining, lockers, etc.), docks or pick pack areas. However, if such floor spaces are not considered in \(\theta\), then they should be added to the gross space calculation with \(g\).

\[
A = \left( D' \times \frac{12}{\gamma} \times \theta \right) + g 
\]  

We calculate the present value of the building and land resale income \((PV_{SB})\) with (8). We estimate the resale value by linearly prorating the building’s remaining useful life \([19]\). This is \((L - (N^{rd}/12))/L\), in which \(L\) represents the useful life of the building in years. A way to define \(L\) is to use the official depreciation figures. Commercial buildings are depreciated over 39 years; and commercial land is not depreciated \([20]\). By incorporating the ratio of the land over total initial cost \((l)\), the depreciation differences are also reflected in (8). If the land value is not known, a ratio between 20% to 40% is widely used to estimate \(l\).

\[
P_{SVB} = \frac{(1 - l) \left( \frac{L - (N^{rd}/12)}{L} + l \right) \times C_B \times (1 + i)^{(N^{rd}/12)}}{(1 + j)^{(N^{rd}/12)}} 
\]  

**Equipment Costs:** For the self-distribution alternative, initial equipment costs include purchasing cost of storage equipment (racks, shelves, cabinets), handling equipment (forklifts, conveyors), picking equipment, dock equipment, and warehouse management software. Equipment’s initial costs \((IC_{Ed})\) can be calculated with an adapted version of equations (5) - (8) as shown in (9), where \(FV_e\) denotes the salvage or resale value of the equipment at the end of the commitment duration \((N^{rd})\).

\[
IC_{Ed} = \sum_{e \in E} \left( C_e - \frac{FV_e}{(1 + j)^{(N^{rd}/12)}} \right) \times q_e 
\]  

The one-time total cost of warehouse equipment is the sum product of the average unit cost of a specific equipment \((C_e)\) and equipment quantity needed \((q_e)\), where \(E\) denotes the set of all equipment indexed by \(e\). Equipment cost estimates \((C_e)\) can be gathered from equipment manufacturers, consultants and online resources \([17, 24-26]\). As an example, cost estimates for double deep pallet racks are $55-$105 and selective racking are $46-$95, and additional cost estimates for other rack types such as pushback, narrow aisle, drive-in can be found in \([17, 24-26]\). Equipment quantity \((q_e)\), which is pallet locations for this example, can be calculated by \((D' \times 12/\gamma)\).

Other equipment’s required quantity is related to operational rates. For example, the number of reach trucks \((q_e)\) can be calculated with an operation rate of 8-20 pallets per hour. Operational rates and cost estimates of equipment can be gathered from equipment manufacturers, consultants and supply chain related organizations \([17, 27-29]\). These rates depend on warehouse layout (parallel with \((\theta)\) space estimate per pallet coefficient), equipment technology, storage and retrieval policies and warehouse management decisions. Alternatively, if equipment is rented, equipment costs become monthly operational costs. For the 3PL and on-demand alternatives, equipment costs are assumed to be included in operational, holding, and handling costs.

**Upfront Costs:** For self-distribution, the broker, closing and inspection costs, or project and permit costs form the upfront costs \(IC_{Up}\) \([30]\). Those depend on the various factors, but some figures such as broker costs are typically 6%-10 and closing costs are 2-5 of the sales price. For the 3PL alternative, legal fees for contract review, and account set-up fees (regarding the integration of a new customer) together create the initial upfront costs \(IC_{Up}\). The contract cost depending on the risk and complexity can rise up to $50,000 \([31]\) and different account setup costs offered by 3PLs can vary between $100 to more than $1000 \([32]\).
2.1.2 Operational Costs

We consider three operational costs for the self-distribution alternative’s total operational cost \( R^{sd} \) in equation (10), labor \( (OC^{L}_{L}) \), overhead \( (OC^{O}_{L}) \) and equipment rental \( (OC^{R}_{L}) \) costs, which all are estimated in $ per month.

\[
R^{sd} = OC^{L}_{L} + OC^{O}_{L} + OC^{R}_{L} \tag{10}
\]

Monthly labor costs \( (OC^{L}_{L}) \) include salaries, benefits, and other costs for warehouse employees who conduct day to day operations and for management. The operational costs for labor can be written as equation (11), or (12).

\[
OC^{L}_{L} = \left( q_h * w_h * t \right) + \left( q_a * \frac{w_a}{12} \right) * \delta * \rho \tag{11}
\]

\[
OC^{L}_{L} = \frac{A}{aq_h} \left( w_h * t + \frac{w_a}{12 + \tau} \right) * \delta * \rho \tag{12}
\]

Salaries for both (11) and (12) can be estimated from the U.S. Bureau of Labor Statistics [33]. In this report, October 2018 average earning of production and nonsupervisory employees is listed as $18.00 per hour \( (w_h -$/hour) and mean average annual salary \( (w_a - $/year) of distribution managers is listed as $94,780. The September 2018 report for employer costs of BLS reflects $20.10 wage and $8.53 total benefits, for a total $28.63 cost per hour for the private transportation industry [34], which leads to a 140% net salary to gross labor cost coefficient \( (\delta) \). To incorporate regional differences, costs can be arranged with an additional coefficient \( (\rho) \) representing the ratio of state minimum wage [35] over the US average minimum wage. In equation (11) the human resource requirements for hourly staff \( (q_h) \), and annually waged staff \( (q_a) \) can be calculated using the operational rates approach in section 2.1.1. Revisiting the same example (3 reach trucks for 2 shifts), we need 6 drivers for the reach trucks, and if we estimate additional 2 operators for handling and other operations for each reach truck each shift, \( q_h \) becomes 18. For calculating the total monthly cost, \( (t) \) is defined as the monthly working hours per hourly staff. The alternative equation (12) uses the average sq feet one operator can serve \( (aq_h) \). According to recent research [15], the average square feet of the total DC networks was 539,000 for 2016 and 473,400 for 2017 with an average number of employees 278 and 228 and annual inventory turns of 9.2 and 8.5 respectively. This returns an average one employee for each 2000 sq ft (2076-1938 sq ft) of distribution space for an average annual inventory turn of 9. Similar averages can be calculated from [36]. The average number of supervisors \( (aq_{s}) \), can be estimated by 12-15 employee to supervisor ratio \( (\tau) \) [37].

Monthly overhead costs \( (OC^{O}_{O}) \), which include utilities, insurance, taxes, etc., as a function of warehouse size and square foot monthly overhead costs \( (c_{o}) \) can be calculated with \( (OC^{O}_{O} = c_{o} * A). \) According to the [38], \( c_{o} \) can be estimated between $0.167 and $0.25. Finally, the total cost of the rented equipment can be calculated as the sum product of each equipment quantity \( (q_{e}) \) with each equipment’s monthly rent \( OC^{R}_{R} = \sum_{e \in E} (q_{e} * c_{e}). \)

For the 3PL alternative, operational costs \( R^{up} \) are the contractual costs per month \( (OC^{L}_{L}) \) fixed ahead of time for an agreed number of pallet locations and can be calculated by (13).

\[
R^{up} = OC^{L}_{L} = D' * \frac{12}{y} * c_{DC} \tag{13}
\]

Many 3PL contractual agreements’ costs are based on average per pallet per month costs \( (c_{DC}) \) and the contracted pallet positions. According to [39] the average 3PL pallet storage fee \( (c_{DC}) \) is $13.02, and as an example RedStag fulfillment charges $15 per pallet per month [40]. However, for an on-demand alternative the only operational costs are the average labor time spent managing the on-demand distribution network, and similar to the initial cost calculation, this cost is considered negligible.

2.1.3 Holding and Handling Costs

In most 3PL options, holding costs are considered as fixed dwell costs and defined in the contract regardless of real usage, which we calculated as \( R^{up} \) in (13). However, pallet handling operations are typically charged separately. Average handling cost \( (G^{up}) \) for both inbound operations and outbound operations is between $4-$10 per pallet [32].

For the on-demand alternative handling costs are charged only once for each pallet that enters the facility, regardless of the storage duration. Holding costs \( (H^{up}) \) are charged as per pallet per month even if the pallet is stored less than a month, which is incorporated to equation (3) by the ceiling function. To estimate these costs, one alternative is to use Flexe’s 2016 on-demand warehousing summary report [41], which presents $9.98 as the Q4 average holding cost paid for three different pallet storage options. The report does not provide handling costs, but currently approximate handling costs are listed on Flexe’s webpage as “labor from $7.80 per pallet” for multiple available locations [42]. On average on-demand rates can be assumed as $10-16 for storage and $8-13 for handling.
3. Conclusion

In Figure 1, we apply our cost expressions and assumptions to present on the y-axis the unit cost $U^a$ of the distribution alternatives in $ per pallet for the number of pallets demanded each month $(D)$ on the x-axis. Depending on an alternative’s capacity utilization, the best economical alternative is changing. Similarly, commitment durations, inventory turns, and cost estimates also affect which alternative is best.

![Cost comparison of different distribution alternatives](image)

Figure 1 Cost comparison of different distribution alternatives

In this paper, we present different warehousing alternatives and details of their cost structures. These cost calculations require assumptions and up-to-date cost data that should be used for an accurate cost estimate. However, we believe our approach to the cost structure expressions will be valuable to researchers and industry professionals interested in understanding the cost trade-off between warehousing alternatives and for inputs into optimization problems.

References
