1. Introduction

Warehousing is around 22 percent of logistics costs; therefore, managers are under constant pressure to reduce costs [1].

There are many interdependent decisions in warehouse design, which make the optimization of its process a complex task [2]. In practice, the efforts are often focused on one cost driver regardless of the interrelations between warehousing activities [3]. Traditional approaches “fail to support a joint decision-making process in warehouse location selection.” [4]

"The risk is the tragedy of the commons effect, where a positive return for economic activities in isolation could lead to a negative collective result in the long-term. Therefore, there is a need to elevate the systemic view of logistics to the macroeconomic realm” [3]. In the absence...
of a comprehensive scientific method [5], practitioners "must consider complex trade-offs, many of which are not general administrative expenses. However, to show yet fully articulated", and "based on intuition, experience, the interrelation of design decisions, we find it more and judgment, make some initial design decisions about convenient to have a cost structure based on cost drivers, the overall system architecture" [5]. Much of current because the sources of costs are easier to differentiate for order-picking operations and warehousing practice relies on rules-of-thumb [6–11].

Even if [2] and [12] provide more comprehensive approaches to the warehouse design problem, there are still many complex trade-offs that the designer needs to face. When deciding the number of cross aisles in a traditional warehouse layout, scientific methods focus on minimizing the travel time of pickers [13–15], when, in fact, there is a trade-off between labor costs and space costs. The more cross aisles a warehouse has, the lower the travel times, but also the lower the space utilization. Non-traditional geometries for unit-load warehouses use diagonal aisles to achieve 20% lower travel times [16]; however, their storage density is lower, requiring about 5% more footprint for the same number of storage locations. Slotting strategies are primarily focused on minimizing material handling costs [17]. Allocating high-moving products to prime slots without consideration of dimensional data can create wasted space within slots, which in turn affects the space costs. Warehouse operational costs are already affecting the industrial real estate in Los Angeles, CA [18], where companies moved their warehouse to urban periphery areas, because "the gains from lower land prices and scale operation outweigh the increase in transport costs." Parallel, there are many qualitative factors to consider when choosing a warehouse location in dynamic environments. When there are significant qualitative business drivers, experts resort to multi-criteria decision-making methods [19, 20]. However, assessing the importance of the objectives among the distribution center are not accounted for. Relative to each other is challenging [21], because the Szeremeta-Spak [37] consider other criteria, such as decision factors are subjective, vague, and imprecise as taxes, land availability, and organizational strategies. And [22, 23]. Alternatively, [24] discusses methods aimed at there are some location problems, mono-objective focus maximizing decision-makers’ satisfaction using utility on the industry and the product being distributed [such as functions from qualitative and quantitative factors.

Trade-offs are also common with other functional areas. When procurement responsibilities are independent of warehouse management, it is often the case that purchasing decisions are made regardless of storage capacity. Procurement is interested in reducing costs per unit, buying in bulk without considering holding costs [25]. Another example comes from marketing strategies, where service agreements with clients are changed without consideration for their impacts on inventory levels and throughput requirements of the warehouse [26]. We hope these examples show the pitfalls of focusing on one cost driver, while ignoring the impact on others.

All warehouses incur similar costs, but they are considered differently from company to company [27]. Spehthe great impact of the warehouse location on the [27] proposes a cost structure based on functions: total operational costs. Understanding the cost drivers and
their interrelations helps practitioners to determine the technologies, processes, and equipment that will bring the highest efficiency. This is important for practitioners, because the operational costs are, to a large extent, determined at the design phase [12, 40, 41]. Furthermore, this framework supports managers when interacting with other areas of the organization, so they can show the impact on warehousing costs of purchasing policies, marketing strategies, supplier selection, etc.

2. Operational cost of warehouses

We follow the framework presented by [1], where the operational costs are categorized according to their drivers. In this paper, the annual operational cost of warehouses is based on:

1. Labor: It accounts for the salaries and extra benefits of workers. The main activities that could annualized for our study. Thereafter, we refer to annual require labor in a warehouse are receiving, putting away, replenishment, picking, packing/sorting and returns processing.

2. Space: the cost of space comes twofold. The rental cost and the operational cost - utilities, infrastructure amortizations. The main areas of the warehouse are: receiving, bulk area, picking area, and shipping. There can also be support areas like a battery station for forklifts, returns processing, and maintenance room.

3. Equipment: the amortization and operational cost of equipment like conveyors, industrial trucks, and racks.


We do not consider administrative expenses throughout this work, because they are constant. Also, all expenses here will be given in an annual basis. Costs such as utilities, accounting, and cleaning of the facility are annualized for our study. Therefore, we refer to annual cost as operational costs as operational costs and will do the same for all other expenses. Management can control shipping. Nevertheless, these activities can also be performed by automated equipment. There are also workers, the number of overtime hours, the area, and...
the selection of the material handling equipment. In this section, we analyze the factors that affect the use of these four resources.

Equation 1 shows the labor cost will be given by the salaries, bonuses, and overtime of the workforce.

\[
\text{LaborCost} = \sum_i \sum_p (W_ip(S_ip + B_ip) + O_ip H_ip) \]

where \(i\) represents the activity that workers are assigned to (receiving, putting away, replenishment, picking, packing, sorting, and shipping), \(p\) the period of time, \(W_ip\) the number of workers assigned to activity \(i\) during period \(p\), \(S_ip\) the salary of a worker assigned to activity \(i\) during period \(p\), \(B_ip\) the bonus and other benefits of a worker assigned to activity \(i\) during period \(p\), \(O_ip\) number of overtime hours of a worker assigned to activity \(i\) during period \(p\), and \(H_ip\) the cost of an overtime hour of a worker assigned to activity \(i\) during period \(p\).

In the labor cost, the salaries, bonuses, and cost of an overtime hour are determined mostly by the environment of the warehouse and its location—minimum wage, payroll taxes, and regulations. On the other hand, the number of workers \(W_ip\) and the number of hours of overtime \(O_ip\) are decisions of the warehouse manager. It is typical that warehouse managers have absolute control over labor staffing.

Figure 2 presents the analysis of the most typical activities—receiving, putting away, replenishment, picking, is the cost of product \(j\), and \(P\) is the number of periods packing/sorting, and shipping—that require labor in a warehouse. The activities in dark red require labor hours. In the in the design process of the warehouse.

Equation 3 calculates the equipment cost as the sum of the depreciation \(D_k\) of each equipment \(k\) plus its operational cost \(EO_k\) [e.g., maintenance or charging batteries].

\[
\text{EquipmentCost} = \sum_k (D_k + EO_k) \]

In the equipment cost (Figure 4), the prices of material handling equipment—racks, conveyors, forklifts, cranes, palletizers, etc—are determined by suppliers, but the warehouse designer selects what equipment to use. The selection of the material handling equipment will fully determine the equipment in the warehouse because it is a design decision in and of itself.

The working capital cost accounts for the opportunity cost of holding inventory. Equation 4 calculates it as the average working capital times—the opportunity cost interest rate \(r\) as follows:

\[
\text{WorkingCapital} = \left(\sum_j \sum_p \frac{I_j p C_j}{P}\right) r, \tag{4} \]

The support activities vary depending on the material how the working capital is defined by purchasing policies, handling equipment and level of IT support of the customer orders, and product cost. warehouse. We are referring to activities such as cycle times, counting, handling of returns, inbound inspections and the design decisions (green), external parameters (light gray), maintenance of equipment and work areas. and resources (dark red) to determine the total operational cost. The space cost is fixed, and it depends on the lease and cost of a warehouse.

The operational cost. The lease cost is mostly settled by The customer orders trigger the process and, in general the location of the warehouse but it can also be affected by terms, are out of the control of the warehouse designer, building characteristics such as ceiling height, docks, roof as well as the SKU dimensional data, the cost of structure, etc. Equation 2 calculates the space cost, where \(\text{resources, and the products’ usage requirements (light gray). Considering these parameters, the warehouse the space, BuildingOperational is the fixed operational designer provides labor Staffing, designs the process, cost for using the space per square foot (utilities, taxes, designs the material handling system, selects purchasing cleaning fees, etc), and \(\text{Area}\) is the area of the warehouse. those decisions affect multiple cost factors and should be considered jointly.

\[
\text{SpaceCost} = (\text{Lease} + \text{BuildingOperational}) \text{Area} \tag{2} \]

On the other hand, purchasing policies determine how the warehouse places orders to its suppliers. It will affect the

Figure 2 presents the analysis of the most typical activities—receiving, putting away, replenishment, picking, is the cost of product \(j\), and \(P\) is the number of periods packing/sorting, and shipping—that require labor in a warehouse. The activities in dark red require labor hours. In the in the design process of the warehouse.

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\[
\text{SpaceCost} = (\text{Lease} + \text{BuildingOperational}) \text{Area} \tag{2} \]

On the other hand, purchasing policies determine how the warehouse places orders to its suppliers. It will affect the
inventory levels, and it will also define the arrival profile operational cost of a warehouse segregated in resources of products to the receiving area (Figure 3). It is often - which administration is a direct responsibility of the the case that purchasing departments are measured by - warehouse designer - and the cost of resources - out of the prices they can negotiate when purchasing items, and in the control of warehouse designers. thus, acquire inventory without consideration of warehouse capacity or inventory turns, which leads to savings in working capital being paid by space and labor costs, when you consider the overall picture.

The process design is the design of the flow of products in the warehouse and the operation of each functional area. The warehouse designer faces multiple trade-offs. In this section, we highlight how the cost drivers related in selecting the right balance between automation, to the geographic location of the warehouse impact its technology, and labor costs. Depending on the accessibility operational cost. In section 3.1, we illustrate the variability to automation and wages, designers can choose from of operational costs among logistic-intensive regions in labor intensive process to highly automated facilities and the USA. We provide a ranking of metropolitan areas from anything in between.

Table 1 presents all the factors that affect the total costs and real estate costs. The difference in the top 25

3. Operational costs and warehouse location

Figure 2 Labor
metropolitan areas can be up to 50% of total operational costs. Therefore, including operational costs in warehouse location problems is important. In section 3.2, we provide a case study where we use the operational cost as a driver to justify the relocation of a distribution center.

### 3.1 Ranking logistics clusters in the USA

In this section, we use our framework of operational cost of warehouses to rank logistics clusters as desirable locations to operate distribution centers. For that purpose, we build the cost analysis structure for a typical unit load warehouse; then we find the cost parameters of each logistics cluster. Finally, we rank logistics clusters by their total operational cost, with the lower cost signifying a more desirable location.

#### 3.1.1 A typical unit load warehouse

We obtained the data on facility locations from one of the largest commercial real estate companies in the Louisville Greater Area [42]. From this database, we selected 243 unique facilities as current or potential warehouses for distribution purposes. Figure 7 shows a histogram of their footprint. The average warehouse area was 255,764 sq ft. For our typical unit-load warehouse, we assume an area of 250,000 sq ft. From the same database, we were able to extract the building’s clear heights for 194 facilities (Figure 8). The average clear height of the buildings was 25.2’.

<table>
<thead>
<tr>
<th>Resources</th>
<th>Labor hours</th>
<th>Area</th>
<th>Equipment</th>
<th>Working Capital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resources cost</td>
<td>Cost of an Overtime hour</td>
<td>Salaries</td>
<td>Bonuses</td>
<td>Rental cost</td>
</tr>
<tr>
<td>Building operational cost</td>
<td>Equipment prices</td>
<td>Equipment operation costs</td>
<td>Products cost</td>
<td>Opportunity cost interest rate</td>
</tr>
</tbody>
</table>

Table 1 Warehouse operational resources
our typical unit-load warehouse, we assume a clear height of 25′

We assume that pallets are stored in single-deep selective racks with slots with a capacity for two pallets of standard size (40″ by 48″). We assume rack bays have five tiers for a total of 10 storage locations. When two rack bays are back to back to form a double rack bay column, there should be a 6″ flue space between them for fire protection [43].

Considering the uprights’ posts and flue space, the slot exterior dimensions are 100″ and 51″.

A typical layout includes receiving docks, the storage area, shipping docks, and support areas. Each rectangle in the storage area represents a rack bay of 100″ by 51″. For the storage area, we considered an aisle width of 12′, which is the requirement for counterbalanced forklifts. The docks occupy 11.1% of the footprint, and the support areas 9.3%. The layout includes 2,033 rack bays and each rack bay has a capacity for 10 storage locations, which results in 20,330 storage locations in total.

Now, the number of lift trucks depends on the nature of the business. Pearless Research Group (PRG) conducts an annual survey on behalf of Modern Materials Handling (MMH) on lift truck fleets and maintenance. Figure 9 shows the distribution of fleet sizes for the 2017 survey, which included 144 facilities from the pool of subscribers of the magazine. The average fleet size was 21 vehicles. For our typical unit-load warehouse, we will assume a fleet size of 20 vehicles.

### 3.1.2 Outline of the cost analysis

Table 2 shows the outline of our cost analysis, where the operational costs of the warehouse are the sum of the space, rack, labor, and lift truck costs. In this way, we need eight parameters to calculate the operational costs of a unit-load warehouse: four cost parameters and four characteristics of the warehouse. The characteristics of the warehouse were given in Section 3.1.1.

In Table 3, we itemized the cost parameters. However, there are several ways in which companies incur each of the seven cost items depending on the ownership of the assets, leasing terms, and contractual relationship with employees. In the following, we detail each of the seven cost items in Table 3 and how they are incurred in our typical unit-load warehouse.

- **Land costs**: Companies can own or lease the space. We assume that the company leases the space in a triple net lease agreement, which is extensively used in commercial real estate [44]. In triple net leases, tenants are responsible for operating expenses on top of the base rent. When we talk about land costs, we refer only to the base rent. It is given in $/ sq ft and depends on the location of the warehouse.

- **Land operating expenses**: In triple net leases, operating expenses include the building maintenance, insurance, and property taxes that must be covered by the tenant. We estimated these costs as a fixed percentage of the land costs.

- **Racking costs**: we assume that the racks are owned by the company. Therefore, we consider their annual cost as their depreciation. It is given directly in $ per storage location.

- **Operators’ salary**: We assume that operators are direct employees of the company and that all of them have the same base salary. It is given in $ per operator per year and depends on the location of the warehouse.

- **Operators’ salary overhead**: Besides base salaries, companies have to pay for health insurance benefits, Social Security taxes, state insurances, incentives, and benefits for their employees. We estimate the overhead as a fixed percentage of the operators’ salaries.

- **Lift trucks costs**: We assume that the company owns electric lift trucks. Therefore, we consider their...
3.1.3 Logistics-intensive regions

To identify logistics-intensive regions in the US, we resort to the theory on logistics agglomerations laid out by [45]. A logistics cluster is a geographically concentrated set of logistics-related activities, where members enjoy the benefits of agglomeration economies: combined transport capacity, sharing of resources, infrastructure, labor availability and governmental incentives [46–48].

Here, we replicate the method laid out in [49] to annual cost as their depreciation. It is given directly in $ per lift truck.

- Lift truck operating costs: Electric lift trucks require mechanical maintenance and electrical maintenance for their batteries and charging stations, electricity consumption, and supplies. It is given directly in $ per lift truck.
Table 2 Outline of the cost analysis of a unit-load warehouse.

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost per unit</th>
<th>No. units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space costs</td>
<td>Cost per sq ft</td>
<td>Area</td>
</tr>
<tr>
<td>Rack costs</td>
<td>Cost per storage location</td>
<td>No. storage locations</td>
</tr>
<tr>
<td>Labor costs</td>
<td>Cost per lift truck operator</td>
<td>No. Operators</td>
</tr>
<tr>
<td>Lift truck costs</td>
<td>Cost per lift truck</td>
<td>No. lift trucks</td>
</tr>
</tbody>
</table>

Table 3 Cost parameters in a unit-load warehouse.

- **Cost per sq ft**
  - Land costs
  - Land operating expenses

- **Cost of racks per storage location**
  - Racking costs
  - Operators salary
  - Salary overhead

- **Cost per lift truck operator**
  - Lift truck costs
  - Lift truck maintenance

We use the commercial real estate marketplace [51] for the 25 logistics clusters identified in Section 3.1.3 to estimate the average cost per square foot of a leased warehouse. We consider locations in the periphery of the city in the country regions, given that warehouses are generally located in those areas [52]. We looked for warehouses with a minimum of 50,000 sq ft and with industrial purposes and surveyed 289 facilities. Multiple surveys and case studies [53–57] estimate that the leasing operating expenses represent between 25 and 50% of the base leasing cost. Here, we assume them to be 40% for all county regions.

The main components of selective racks are beams and uprights. The first rack bay of a row will have two uprights and a pair of beams for each tier; the other rack bays of the row will have only one upright. We assume rows of 15 rack bays in average and each rack bay has 5 tiers. In consequence, a rack bay has on average 16/15 uprights and 10 beams.

The estimated price for a beam is $31.69 [58]. The estimated price for an upright 240” high is $237.42 [58]; we assume that uprights 300” high cost $296.78. In this way, a rack bay costs on average $633.38 and a storage
We survey the average annual salary of lift truck operators times, inventory snapshots, storage utilization, and labor using the career website for the 25 logistics-intensive regions identified in Section 3.1.3. We take the largest Figure 11 shows the layout of the warehouse, and an city in the corresponding region county as a reference and an overview of the process is presented in Figure 12. It has look for the average annual salary of lift truck operators two docks which are used both for receiving and shipping. in that city, which is provided directly by the website. The Trucks park in the dock, and the receiver helps unload overhead typically represents between 18 to 26% of the lift truck operating cost of $2,000 per year. We assume a worker’s salary [61]. Here, we considered a fixed overhead as the documentation of the delivery. The receiver gives of 20% for all regions. the product to put away or quality control if the product Finally, Table 4 shows the top 25 county regions in the requires inspection. Put away workers unwrap the pallets continental US ordered by logistics employment, also and put the cartons away, prioritizing primary locations illustrated in Figure 10. Now, the estimated price for an electric reach truck is packaging and register the movement of products in their between $35,000 USD and $55,000 [62]; Consequently, a information system. we assume a price of $45,000. Under IRS guidelines for The pickers pick multiple orders at the time on their carts. depreciation of assets, lift trucks are under the category This group of orders is called a cluster of orders. Picking “Other Property Used for Transportation”, which means one cluster usually takes one picker about 20 minutes. that their depreciation rate is 0.2. Therefore, we estimate Once they complete a cluster, they deliver the outbound the lift truck costs to be $9,000 per lift truck per year. cartons to a packer, each box with the items picked and the Manufacturers estimate that lift truck operating costs paperwork associated with it. Packers take the cartons, range from $1 to $4 per hour, depending on the age of the scan the items, print the shipping label, pack the items vehicle. Their general assumption is 1,500 hours per year, again in the box, and put the cartons in the outbound which results in $1,500 to $6,000 per year. We assume a conveyor. When the outbound conveyor is full, packers put lift truck operating cost of $2,000 per year.

With the estimated values for the cost parameters and a transportation carrier.

The characteristics of a typical unit-load warehouse, we calculated the space costs and handling costs for a typical unit-load as if it was located in each of the 25 logistics-intensive regions. Finally, Table 5 ranks the logistics-intensive regions according to their operational costs, the first being the one with the lowest costs.

3.2 Case Study

We used the insights presented in this paper in a consulting project to redesign the supply chain of an electronics company. The project involved the relocation and re-assignment of the distribution center and the manufacturing of the products for the North American market across 4 sites. The objective of the projects was to locations for the distribution center.

Despite the logistics costs of the company, which include inbound transportation, distribution center operation, and the warehouse footprint and labor staffing. We also considered that relocating the distribution center was an improvement in the operation, but our basic observation was that the annual cost per square foot of $14 and the annual wage of $30K were high and that there were better market opportunities at lower costs. For the purpose of this analysis, we will keep constant inbound transportation, distribution center operation, and the warehouse footprint and labor staffing. We also considered that relocating the distribution center was an improvement in the operation, but our basic observation was that the annual cost per square foot of $14 and the annual wage of $30K were high and that there were better market opportunities at lower costs.
Figure 10 Top 25 regions in the continental US with intensive logistics activities, 2013.
Figure 11 Warehouse Layout
The annual cost per square foot was $6.6, therefore, the annual area cost would be $112K. The average salary for warehouse associates in the area was $28K, and with 22% of overhead, the labor cost per associate was $35K. Therefore, the annual labor cost was $629K. Finally, the total operation cost of the warehouse was $741K (see breakdown in Table 7).

With the proposal, the operational cost would decrease $250K, which was about 25%. However, the transportation cost increased by 7%, and there were about $80K of investment to do the relocation, which diminished the return on the investment, but it still was a financially justifiable decision.

Management decided to implement the proposal for the strength of the business case and other reasons related to the consolidation of manufacturing sites. We believe that the relocation of the distribution center from Massachusetts to Arizona showcases the importance of balancing warehouse operational costs and transportation costs when making location decisions.

### Table 4  Top 25 regions in continental US with intensive logistics activities, 2013.

<table>
<thead>
<tr>
<th>County Region</th>
<th>State</th>
<th>Employment</th>
<th>Establishments</th>
<th>annual $ / sq.ft.</th>
<th>lift truck Operator Annual salary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middlesex</td>
<td>NJ</td>
<td>107,757</td>
<td>6,370</td>
<td>7.62</td>
<td>30,418</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>CA</td>
<td>104,917</td>
<td>5,514</td>
<td>8.35</td>
<td>31,116</td>
</tr>
<tr>
<td>Cook</td>
<td>IL</td>
<td>92,511</td>
<td>7,087</td>
<td>6.93</td>
<td>31,484</td>
</tr>
<tr>
<td>Dallas</td>
<td>TX</td>
<td>82,889</td>
<td>2,738</td>
<td>3.81</td>
<td>30,020</td>
</tr>
<tr>
<td>Harris</td>
<td>TX</td>
<td>61,040</td>
<td>2,804</td>
<td>6.5</td>
<td>31,057</td>
</tr>
<tr>
<td>Fulton</td>
<td>GA</td>
<td>60,789</td>
<td>2,573</td>
<td>4.19</td>
<td>28,365</td>
</tr>
<tr>
<td>San Bernardino</td>
<td>CA</td>
<td>42,049</td>
<td>1,344</td>
<td>6.36</td>
<td>28,940</td>
</tr>
<tr>
<td>Shelby</td>
<td>TN</td>
<td>40,104</td>
<td>1,105</td>
<td>3.16</td>
<td>27,769</td>
</tr>
<tr>
<td>Maricopa</td>
<td>AZ</td>
<td>39,868</td>
<td>1,471</td>
<td>5.79</td>
<td>28,646</td>
</tr>
<tr>
<td>Marion</td>
<td>IN</td>
<td>38,556</td>
<td>1,188</td>
<td>3.36</td>
<td>29,633</td>
</tr>
<tr>
<td>Miami-Dade</td>
<td>FL</td>
<td>37,205</td>
<td>2,851</td>
<td>8.17</td>
<td>31,229</td>
</tr>
<tr>
<td>Alameda</td>
<td>CA</td>
<td>37,084</td>
<td>1,955</td>
<td>8.53</td>
<td>38,086</td>
</tr>
<tr>
<td>Wayne</td>
<td>MI</td>
<td>34,882</td>
<td>2,310</td>
<td>5.26</td>
<td>31,261</td>
</tr>
<tr>
<td>Franklin</td>
<td>OH</td>
<td>34,881</td>
<td>1,015</td>
<td>4.07</td>
<td>29,127</td>
</tr>
<tr>
<td>King</td>
<td>WA</td>
<td>34,865</td>
<td>1,711</td>
<td>6.44</td>
<td>34,263</td>
</tr>
<tr>
<td>Jefferson</td>
<td>KY</td>
<td>30,871</td>
<td>769</td>
<td>3.84</td>
<td>29,781</td>
</tr>
<tr>
<td>Middlesex</td>
<td>MA</td>
<td>29,359</td>
<td>1,669</td>
<td>9.56</td>
<td>34,301</td>
</tr>
<tr>
<td>Hennepin</td>
<td>MN</td>
<td>26,762</td>
<td>1,659</td>
<td>6.45</td>
<td>32,385</td>
</tr>
<tr>
<td>Mecklenburg</td>
<td>NC</td>
<td>26,196</td>
<td>1,233</td>
<td>5.42</td>
<td>27,343</td>
</tr>
<tr>
<td>Cumberland</td>
<td>PA</td>
<td>25,434</td>
<td>693</td>
<td>3.87</td>
<td>31,218</td>
</tr>
<tr>
<td>Boone</td>
<td>KY</td>
<td>25,217</td>
<td>1,015</td>
<td>4.2</td>
<td>28,600</td>
</tr>
<tr>
<td>Baltimore city</td>
<td>MD</td>
<td>24,817</td>
<td>1,583</td>
<td>5.76</td>
<td>32,153</td>
</tr>
<tr>
<td>St. Louis</td>
<td>MO</td>
<td>24,523</td>
<td>1,341</td>
<td>4.22</td>
<td>29,363</td>
</tr>
<tr>
<td>Johnson</td>
<td>KS</td>
<td>23,175</td>
<td>987</td>
<td>4.42</td>
<td>31,736</td>
</tr>
<tr>
<td>Davidson</td>
<td>TN</td>
<td>22,723</td>
<td>781</td>
<td>4.77</td>
<td>30,609</td>
</tr>
</tbody>
</table>

**Figure 12** Warehouse process

4. Conclusions

Most literature on warehouse location problems focus on minimizing transportation costs. This paper advocates...
Table 5 Operational costs rank of logistics-intensive regions.

<table>
<thead>
<tr>
<th>Rank</th>
<th>County Region</th>
<th>State</th>
<th>Largest city</th>
<th>Operational costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shelby</td>
<td>TN</td>
<td>Memphis</td>
<td>2,130,497</td>
</tr>
<tr>
<td>2</td>
<td>Marion</td>
<td>IN</td>
<td>Indianapolis</td>
<td>2,245,233</td>
</tr>
<tr>
<td>3</td>
<td>Dallas</td>
<td>TX</td>
<td>Dallas</td>
<td>2,412,021</td>
</tr>
<tr>
<td>4</td>
<td>Jefferson</td>
<td>KY</td>
<td>Louisville</td>
<td>2,416,785</td>
</tr>
<tr>
<td>5</td>
<td>Cumberland</td>
<td>PA</td>
<td>Harrisburg</td>
<td>2,461,773</td>
</tr>
<tr>
<td>6</td>
<td>Franklin</td>
<td>OH</td>
<td>Columbus</td>
<td>2,481,589</td>
</tr>
<tr>
<td>7</td>
<td>Fulton</td>
<td>GA</td>
<td>Atlanta</td>
<td>2,505,301</td>
</tr>
<tr>
<td>8</td>
<td>Boone</td>
<td>KY</td>
<td>Cincinnati</td>
<td>2,514,441</td>
</tr>
<tr>
<td>9</td>
<td>St. Louis</td>
<td>MO</td>
<td>St. Louis</td>
<td>2,539,753</td>
</tr>
<tr>
<td>10</td>
<td>Johnson</td>
<td>KS</td>
<td>Kansas City</td>
<td>2,666,705</td>
</tr>
<tr>
<td>11</td>
<td>Davidson</td>
<td>TN</td>
<td>Nashville</td>
<td>2,762,157</td>
</tr>
<tr>
<td>12</td>
<td>Mecklenburg</td>
<td>NC</td>
<td>Charlotte</td>
<td>2,911,273</td>
</tr>
<tr>
<td>13</td>
<td>Wayne</td>
<td>MI</td>
<td>Detroit</td>
<td>2,949,305</td>
</tr>
<tr>
<td>14</td>
<td>Maricopa</td>
<td>AZ</td>
<td>Phoenix</td>
<td>3,072,045</td>
</tr>
<tr>
<td>15</td>
<td>Baltimore city</td>
<td>MD</td>
<td>Baltimore</td>
<td>3,145,713</td>
</tr>
<tr>
<td>16</td>
<td>San Bernardino</td>
<td>CA</td>
<td>Riverside</td>
<td>3,278,601</td>
</tr>
<tr>
<td>17</td>
<td>Harris</td>
<td>TX</td>
<td>Houston</td>
<td>3,378,409</td>
</tr>
<tr>
<td>18</td>
<td>Hennepin</td>
<td>MN</td>
<td>Minneapolis</td>
<td>3,392,781</td>
</tr>
<tr>
<td>19</td>
<td>King</td>
<td>WA</td>
<td>Seattle</td>
<td>3,434,353</td>
</tr>
<tr>
<td>20</td>
<td>Cook</td>
<td>IL</td>
<td>Chicago</td>
<td>3,539,157</td>
</tr>
<tr>
<td>21</td>
<td>Middlesex</td>
<td>NJ</td>
<td>New York City</td>
<td>3,755,073</td>
</tr>
<tr>
<td>22</td>
<td>Miami Dade</td>
<td>FL</td>
<td>Miami</td>
<td>3,967,037</td>
</tr>
<tr>
<td>23</td>
<td>Los Angeles</td>
<td>CA</td>
<td>Los Angeles</td>
<td>4,027,325</td>
</tr>
<tr>
<td>24</td>
<td>Alameda</td>
<td>CA</td>
<td>San Francisco</td>
<td>4,257,605</td>
</tr>
<tr>
<td>25</td>
<td>Middlesex</td>
<td>MA</td>
<td>Boston</td>
<td>4,527,265</td>
</tr>
</tbody>
</table>

Table 6 Warehouse operational cost in Massachusetts

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (ft$^2$)</td>
<td>17,000</td>
</tr>
<tr>
<td>Area Cost ($/year)</td>
<td>$238,000</td>
</tr>
<tr>
<td>Labor head count</td>
<td>18</td>
</tr>
<tr>
<td>Labor Cost ($/year)</td>
<td>$753,250</td>
</tr>
<tr>
<td>Total operational cost ($/year)</td>
<td>$991,250</td>
</tr>
</tbody>
</table>

Figure 13 Labor Staffing

The importance of considering total costs in location problems, where the operational costs of the facility are also a significant cost driver. We found that there are location problems in practice, where factors such as labor availability and leasing costs play a critical role in where warehouses should be located.

The decision framework explained in this paper could be used by a company that desires to distribute products throughout the continental United States. This country is a special case in worldwide distribution, due to its sheer size and close-to-continuous nature in terms of highway availability and space. However, the procedure followed...
the company is the total cost of logistics \[63\], it is still
has been known for many years that what counts for
separation that used to be the norm. Even though it
integrated outlook toward the manufacturing vs. logistics
paper is useful for companies that have adopted an
their supply chains in the most efficient (total-cost-wise)
don’t have regular supply runs in order to take advantage
the characteristic that stores will not be willing to wait
several days to have their inventories re-stocked. These
types of supply chains will need an additional echelon
closer to big centers of demand, in order to rationalize
transportation costs and expedite delivery. For them, this
the framework presented in this work. In particular, different
types of products require different lead times and service
levels facing the end customer. For example, massive
consumption products such as paper cleaning products
(toilet paper, paper towels, paper napkins and so on) have
the characteristic that stores will not be willing to wait
several days to have their inventories re-stocked. These
types of supply chains will need an additional echelon
closer to big centers of demand, in order to rationalize
transportation costs and expedite delivery. For them, this
Not all types of supply chains could directly apply the
framework presented in this work. In particular, different
types of products require different lead times and service
levels facing the end customer. For example, massive
consumption products such as paper cleaning products
(toilet paper, paper towels, paper napkins and so on) have
the characteristic that stores will not be willing to wait
several days to have their inventories re-stocked. These

4.5. Declaration of competing interest

We declare that we have no significant competing interests,
including financial or non-financial, professional, or
personal interests interfering with the full and objective
presentation of the work described in this manuscript.

4.6. Funding

This work was supported by Fulbright Colombia and the
Logistics and Distribution Institute in Louisville, KY, USA.

7. Author contributions

Luis F. Cardona and Leonardo Rivera developed the
Engineering Framework and wrote the paper together.
Luis F. Cardona was the manager of the project presented
in the case study.

8. Data availability statement

All the data associated with a paper is contained within.

References


<table>
<thead>
<tr>
<th>Area (ft²)</th>
<th>17,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area Cost ($/year)</td>
<td>$112,200</td>
</tr>
<tr>
<td>Labor head count</td>
<td>18</td>
</tr>
<tr>
<td>Labor Cost ($/year)</td>
<td>$629,066</td>
</tr>
<tr>
<td>Total operational cost ($/year)</td>
<td>$741,266</td>
</tr>
</tbody>
</table>

Table 7 Warehouse operational cost in Arizona


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