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# Including operational costs in warehouse location problems: A case study in USA

## La importancia de incluir los costos operacionales en la localización de centros de distribution: un caso de estudio en USA

Luis Felipe Cardona [1*] Leonardo Rivera-Cadavid [2]

[1] Logistics and Distribution Institute, University of Louisville. 2301 S 3rd. Louisville. KY 40292, United States.
[2] Departamento de Ingeniería Industrial, Universidad del Valle. Calle 13 # 100-00. Cali, Colombia.

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**ABSTRACT:** There is vast research on particular aspects of warehouse design - layout, material handling, order picking, and operating policies - when, in fact, the decisions involved in the process are interrelated. In this paper, we develop an engineering economics framework for warehouse operations that decomposes the cost structure of the operation and lays out the relationships between them. Our framework decomposes operational costs into four exogenous characteristics (wages, leasing costs, cost of capital, and access to technology) that depend on the geographic location of the warehouse and two operational requirements (throughput and storage capacity). Using these six parameters, and publicly available information, practitioners can estimate the total operational cost of the warehouse for potential locations in facility location analysis, which have been traditionally limited to transportation costs. In our case study, we use our framework to establish a rank of preferable warehouse locations in terms of operational costs among logistics clusters in the United States of America.

**RESUMEN:** Existe una amplia literatura sobre elementos del diseño de almacenes (distribución, manejo de materiales, selección de pedidos y políticas operativas) de manera independiente. Sin embargo, las decisiones involucradas en el proceso están interrelacionadas. En este artículo, desarrollamos un marco de ingeniería económica para operaciones de almacén que descompone la estructura de costos de la operación y establece las relaciones entre ellos. Nuestro marco descompone los costos operativos en cuatro características exógenas (salarios, arrendamiento, costo del capital y acceso a la tecnología) que dependen de la ubicación geográfica del almacén y dos requisitos operativos (capacidad de procesamiento y capacidad de almacenamiento). Usando estos seis parámetros e información pública, los profesionales pueden estimar el costo operativo total del almacén para ubicaciones potenciales en el análisis de localización de instalaciones. En nuestro caso de estudio, usamos nuestro marco para establecer un ranking de ubicaciones preferibles en términos de costos operativos entre los clústeres de logística en los EE. UU.

## 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

* Corresponding author: Luis Felipe Cardona
E-mail: luis.cardonaolarte@louisville.edu
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yet fully articulated", and "based on intuition, experience, and judgment, make some initial design decisions about the overall system architecture" [5]. Much of current 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 relative to each other is challenging [21], because the decision factors are subjective, vague, and imprecise [22, 23]. Alternatively, [24] discusses methods aimed at maximizing decision-makers' satisfaction using utility 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]. Speh [27] proposes a cost structure based on functions: handling, storage, operations administration, and general administrative expenses. However, to show the interrelation of design decisions, we find it more convenient to have a cost structure based on cost drivers, because the sources of costs are easier to differentiate for resources with multiple functions. Ackerman [28] provides the most comprehensive framework of warehouse costs up to date based on cost drivers. It brakes down operational costs on *costs of goods at rest* and *costs of goods in motion*. Then, the author establishes the effects of labor, equipment, inventory, and layout on the total operational costs. [28] provides great detail on the cost structure, whereas we focus on the interrelations between these costs drivers. This paper aims to assist practitioners in making warehouse design decisions, considering the trade-offs between critical resources of the operation. We provide a systematic method to assess the total operation cost in terms of four cost drivers: labor, space, working capital, and equipment; and a system dynamics model to describe the interrelation between warehouse design decisions and their impact on the total operational cost. Figure 1 shows the calculation of the total cost presented in the sections below. Here, we color the leaves of the diagram depending on whether they are direct decisions of the warehouse designer (green) or are better modeled as external parameters (gray). All arrows in Figures 1–6 are positive in direction; that is, the higher the salary, the higher the cost per worker, and so on.

Traditional warehouse location problems focus on transportation costs [29, 30] or service level [31–33]. In supply chain network designs, it is common that models include a fixed cost of opening a distribution center in a location [29, 34, 35] or consider just the cost of land [22, 36], but the operational costs of varying the volume among the distribution center are not accounted for. Szeremeta-Spak [37] consider other criteria, such as taxes, land availability, and organizational strategies. And there are some location problems, mono-objective focus on the industry and the product being distributed (such as solid waste management [38]), regardless of costs.

Total operational costs are rarely a criteria in warehouse location problems in the literature [39]. The main contribution of this paper is to highlight the importance of including operational costs in warehouse location decisions in the context of logistics clusters. We decompose the operational costs into two categories of cost drivers. Cost drivers related to the geographic location of the warehouse (wages, leasing costs, cost of capital, and access to technology) and cost drivers associated with the operational requirements (throughput and storage capacity). Warehouse designers require an overall perspective of warehouse costs to optimize the processes within. This with the goal of highlighting the great impact of the warehouse location on the operational costs. Understanding the cost drivers and

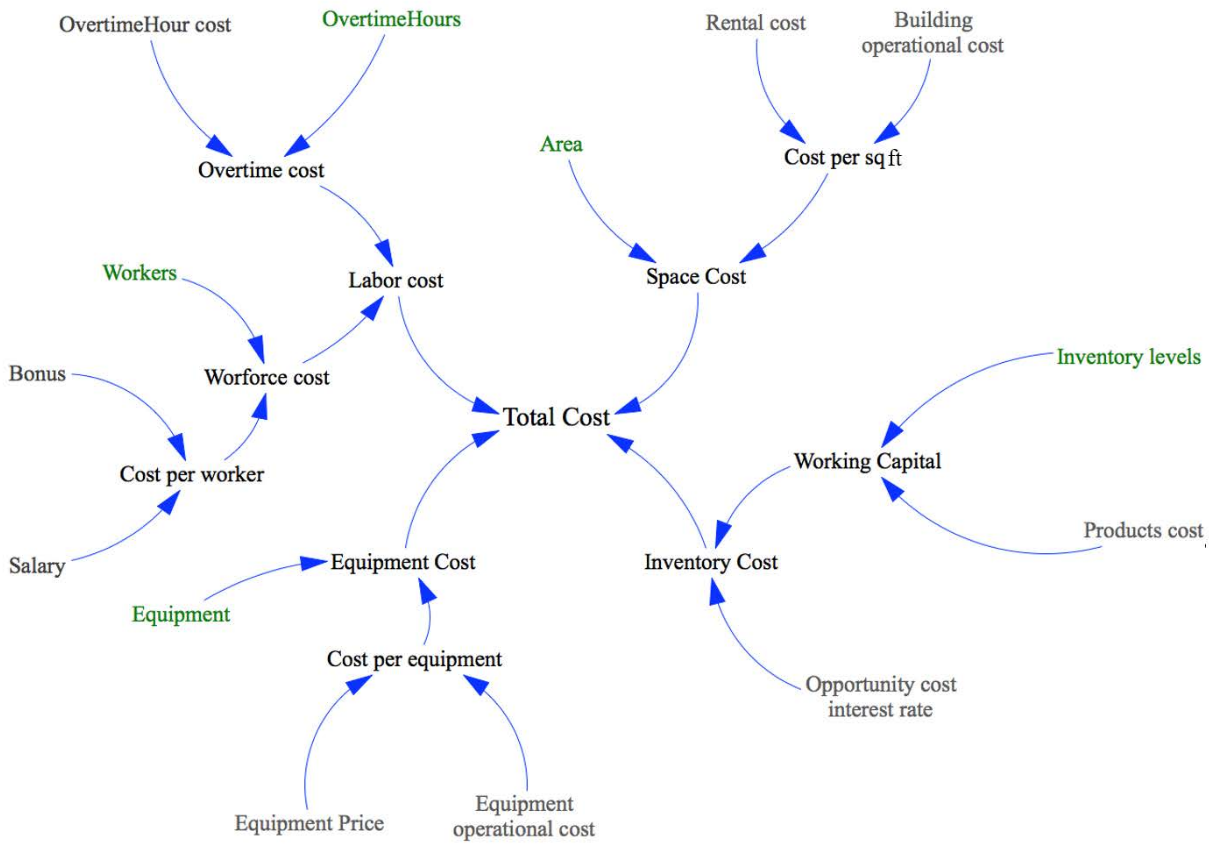


**Figure 1** Total operational cost

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 require labor in a warehouse are receiving, putting away, replenishment, picking, packing/sorting and shipping. Nevertheless, these activities can also be performed by automated equipment. There are also activities that require labor, such as cycle counting 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.
4. Working Capital: The financial cost of the money invested in inventory.

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 operational costs as operational costs and will do the same for all other expenses. Management can control the use of these four resources through the number of 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.

$$LaborCost = \sum_i \sum_p (W_{ip}(S_{ip} + B_{ip}) + O_{ip} H_{ip}) \quad (1)$$

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 ($W_i$) 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, packing/sorting, and shipping - that require labor in a warehouse. The activities in dark red require labor hours. In light gray, we present the process design decisions that will define the labor requirements of these activities and that can be directly controlled by the warehouse manager. And, the factors in green are those that affect the labor hour requirements, but are external to the process decision of the warehouse operation.
The support activities vary depending on the material handling equipment and level of IT support of the warehouse. We are referring to activities such as cycle counting, handling of returns, inbound inspections and the maintenance of equipment and work areas.

The space cost is fixed, and it depends on the lease and the operational cost. The lease cost is mostly settled by the location of the warehouse but it can also be affected by building characteristics such as ceiling height, docks, roof structure, etc. Equation 2 calculates the space cost, where $Lease$ is the marginal cost per square foot for leasing the space, $BuildingOperational$ is the fixed operational cost for using the space per square foot (utilities, taxes, cleaning fees, etc), and $Area$ is the area of the warehouse.

$$SpaceCost = (Lease + BuildingOperational)Area \quad (2)$$

Figure 3 shows the use of space for warehouse operations. The areas that occupy warehouse space are presented in dark red. The warehouse design decisions that affect these areas are light gray. The factors in green are those that affect the labor hour requirements, but that are not defined 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).

$$EquipmmentCost = \sum_k (D_k + EO_k) \quad (3)$$

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:

$$WorkingCapital = \left( \sum_j \sum_p \frac{I_{jp} C_j}{P} \right) r, \quad (4)$$

where $I_{jp}$ is the inventory level of product $j$ in period $p$, $C_j$ is the cost of product $j$, and $P$ is the number of periods considered.

In the working capital cost, the cost of products is defined by the manufacturing process and the cost of materials purchased from the suppliers, both out of the purview of the warehouse designer. On the other hand, the inventory levels are, in most cases, under the umbrella of the logistics division of the company, even if they can not be decided solely by the warehouse manager. Figure 5 shows how the working capital is defined by purchasing policies, customer orders, and product cost.
Figure 6 shows the relationships between warehouse design decisions (green), external parameters (light gray), and resources (dark red) to determine the total operational cost of a warehouse.
The customer orders trigger the process and, in general terms, are out of the control of the warehouse designer, as well as the SKU dimensional data, the cost of resources, and the products' care requirements (light gray). Considering these parameters, the warehouse designer provides labor Staffing, designs the process, designs the material handling system, selects purchasing

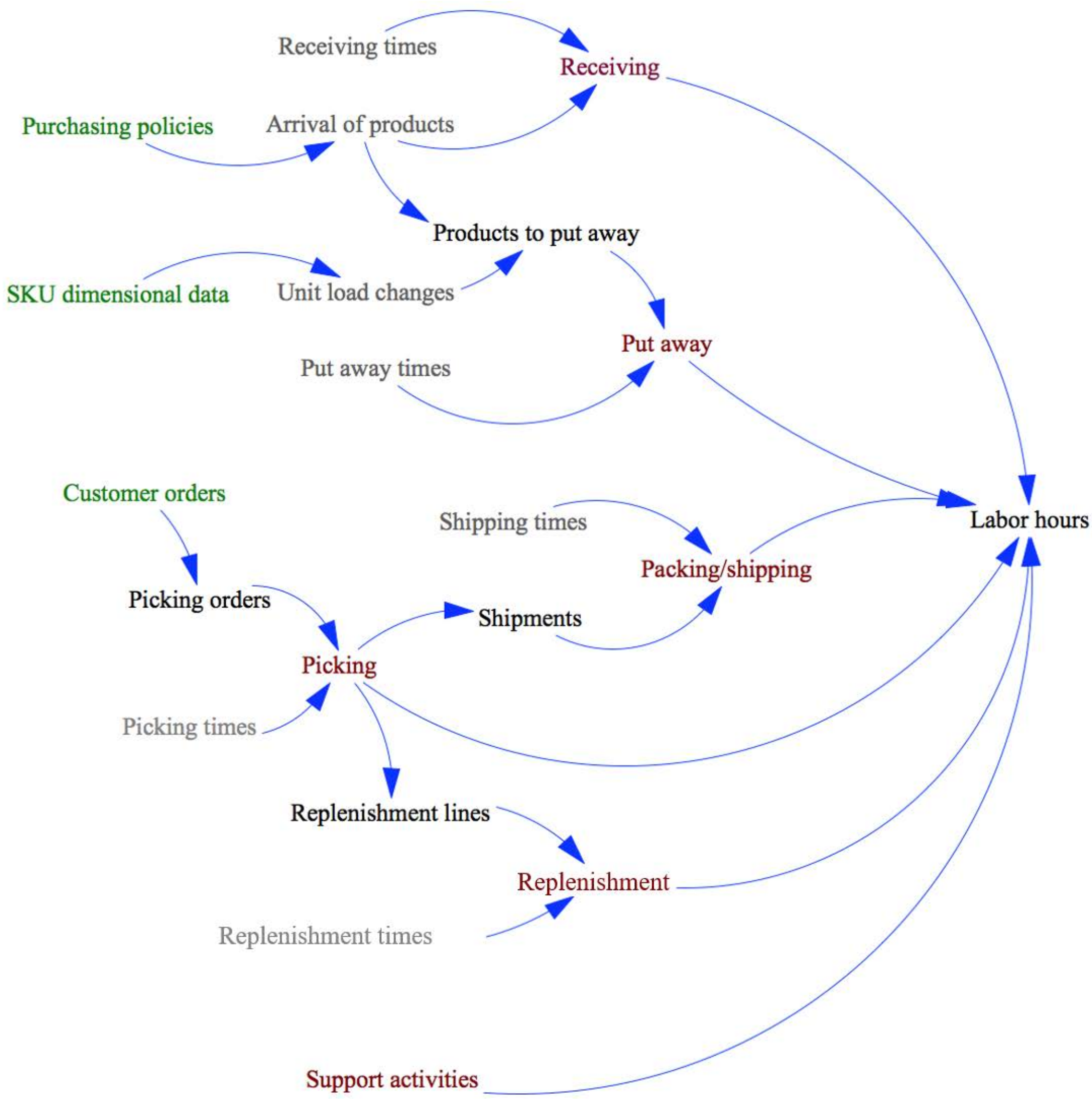


**Figure 2** Labor

policies, and a warehouse layout. As Figure 6 shows, all those decisions affect multiple cost factors and should be considered jointly.

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 of products to the receiving area (Figure 3). It is often the case that purchasing departments are measured by the prices they can negotiate when purchasing items, and 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 selecting the right balance between automation, technology, and labor costs. Depending on the accessibility to automation and wages, designers can choose from labor intensive process to highly automated facilities and anything in between.

Table 1 presents all the factors that affect the total operational cost of a warehouse segregated in resources - which administration is a direct responsibility of the warehouse designer - and the cost of resources - out of the control of warehouse designers.

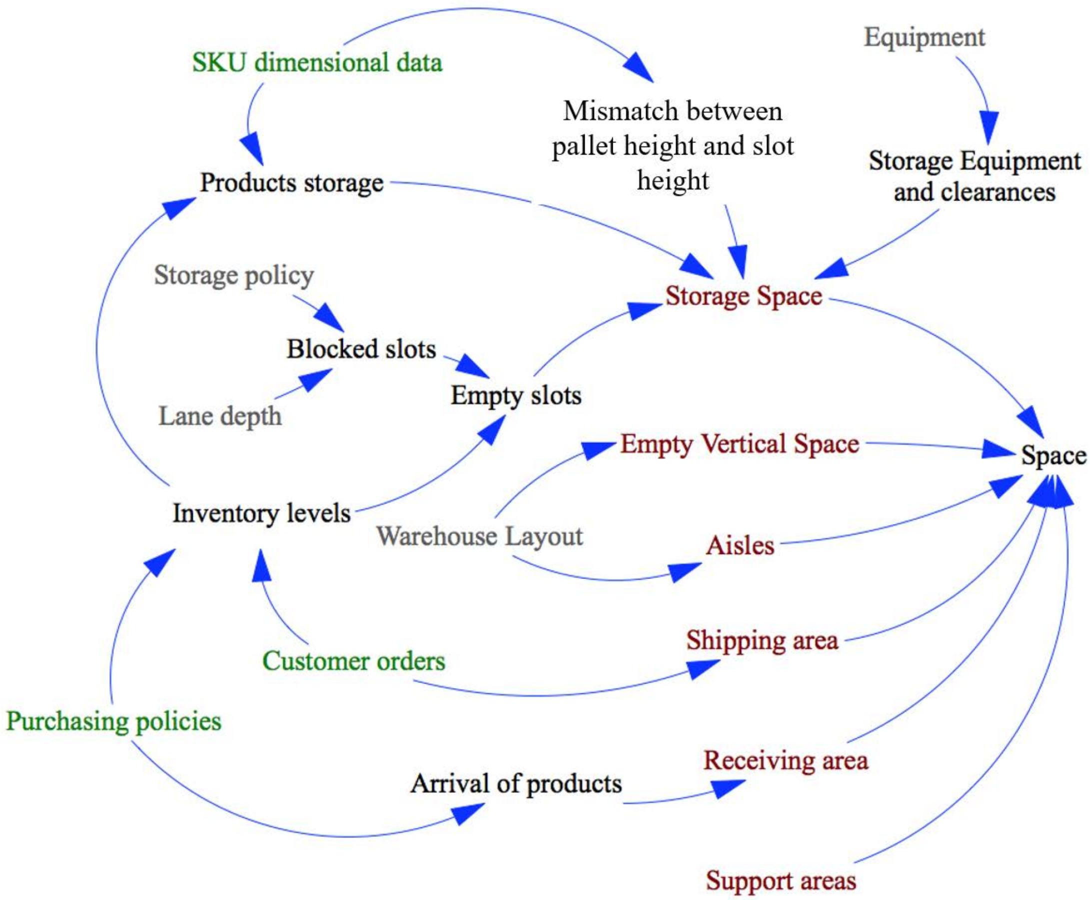


**Figure 3** Space Use

# 3. Operational costs and warehouse location

In this section, we highlight how the cost drivers related to the geographic location of the warehouse impact its operational cost. In section 3.1, we illustrate the variability of operational costs among logistic-intensive regions in the USA. We provide a ranking of metropolitan areas from low to high operational costs, mainly driven by their labor costs and real estate costs. The difference in the top 25 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.

### 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 $\mathrm{sq\,ft}$. For our typical unit-load warehouse, we assume an area of 250,000 $\mathrm{sq\,ft}$. 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′. For 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

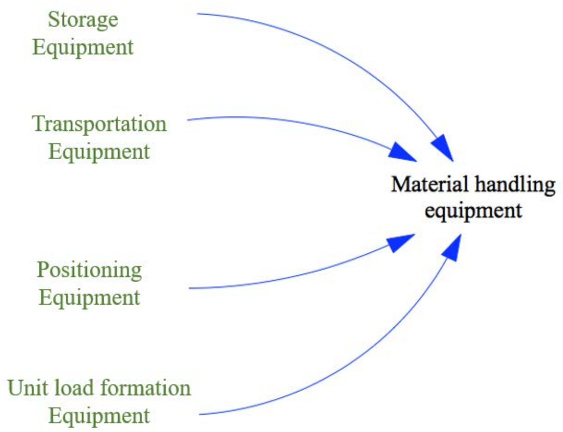


**Figure 4** Equipment

**Table 1** Warehouse operational resources

| | |
|---|---|
| Resources | Labor hours<br>Area<br>Equipment<br>Working Capital |
| Resources cost | Cost of an Overtime hour<br>Salaries<br>Bonuses<br>Rental cost<br>Building operational cost<br>Equipment prices<br>Equipment operation costs<br>Products cost<br>Opportunity cost interest rate |

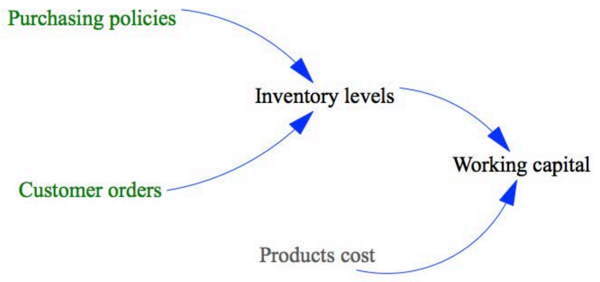


**Figure 5** Working capital

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.

## 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.
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 $/ $\mathrm{sq\,ft}$ 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.

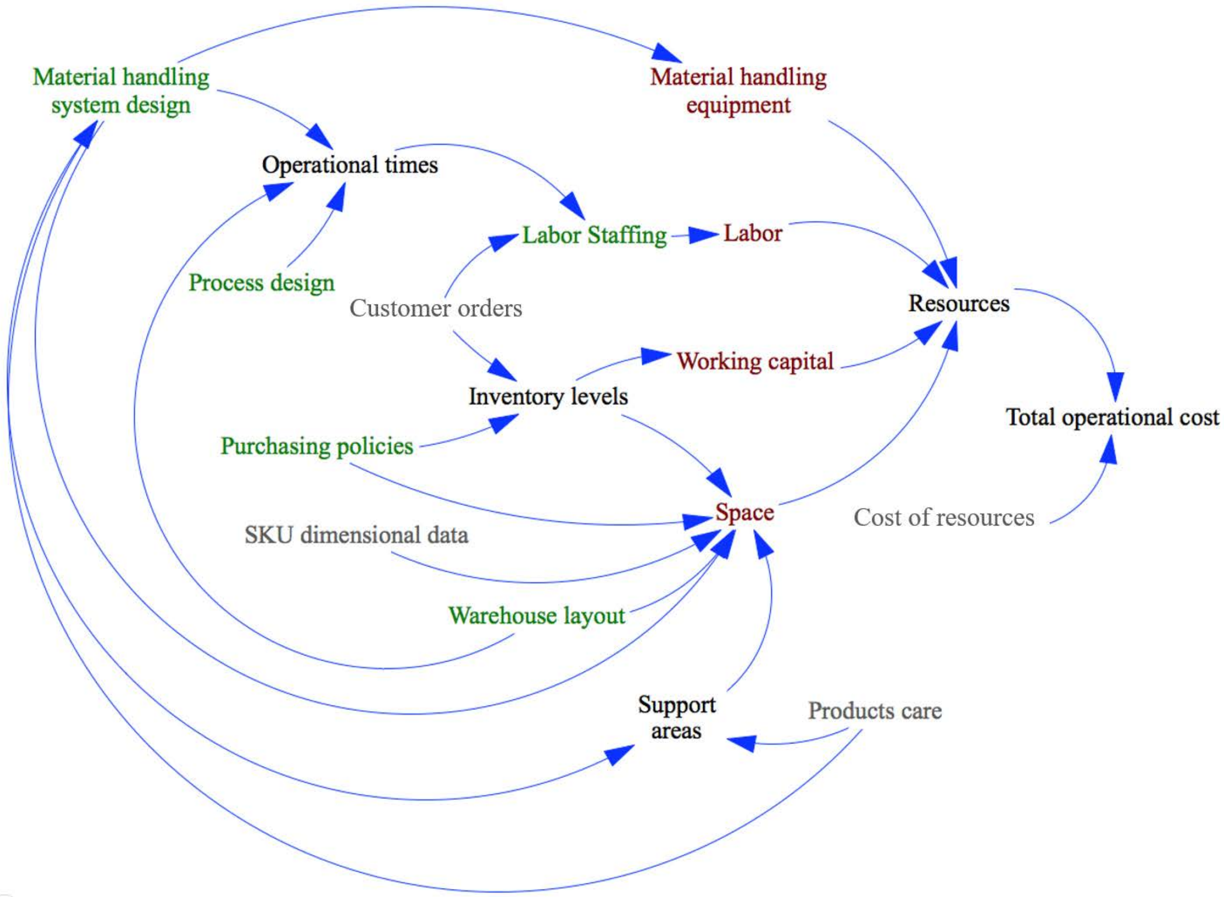


**Figure 6** Impact of warehouse decisions

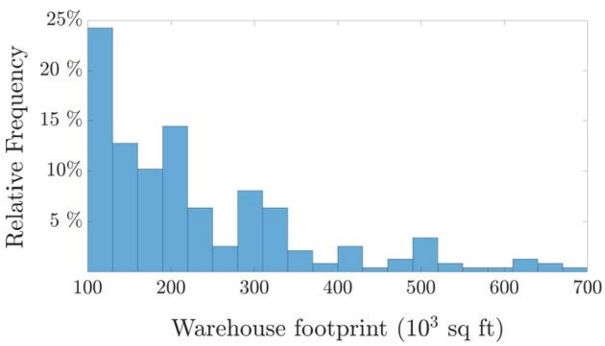


**Figure 7** Warehouse Footprint

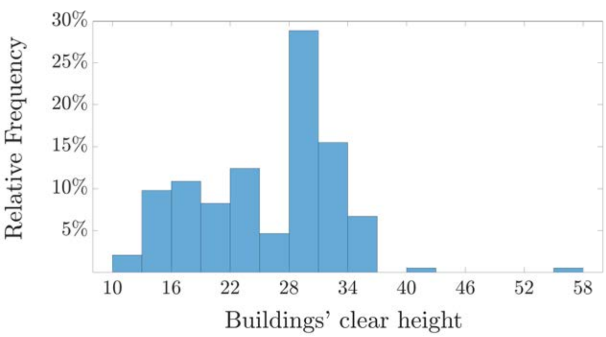


**Figure 8** Buildings' clear height

- 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 Securities 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 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

**Table 2** Outline of the cost analysis of a unit-load warehouse

| **Component** | **Cost per unit** | **No. units** |
|---|---|---|
| Space costs | Cost per $\mathrm{sq\,ft}$ | Area |
| Rack costs | Cost per storage location | No. storage locations |
| Labor costs | Cost per lift truck operator | No. Operators |
| Lift truck costs | Cost per lift truck | No. lift trucks |

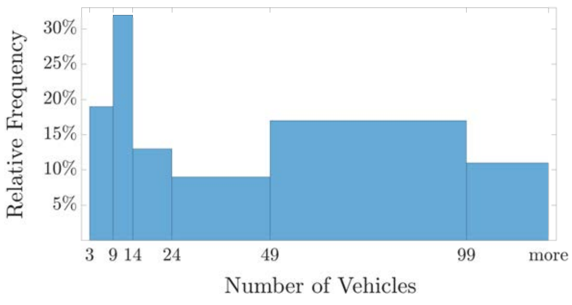


**Figure 9** 2017 survey on the size of lift truck fleets by PRG and MMH.

**Table 3** Cost parameters in a unit-load warehouse

| | |
|---|---|
| Cost per $\mathrm{sq\,ft}$ | Land costs |
| | Land operating expenses |
| Cost of racks per storage location | Racking costs |
| Cost per lift truck operator | Operators salary |
| | Salary overhead |
| Cost per lift truck | Lift truck costs |
| | Lift truck maintenance |

consumption, and supplies. It is given directly in $ per lift truck.

## 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 identify logistics clusters in the US using the County Business Patterns Report of the United States Census Bureau [50]. There are two major characteristics of logistics clusters [49]: high employment levels and high number of establishments in the logistics sector. In the County Business Patterns, the employment level and number of establishments data is segregated by economic sector at a county level — county or county equivalent. With this data, we filtered the list from 3,193 to 400 locations by establishing thresholds for a location to be considered a logistics-intensive agglomeration, according to [49]. Additionally, we considered that clusters are not necessarily contained within one county; therefore, we established a radius of 35 miles for each county and called it a county region — making sure that county regions do not overlap.

We use the commercial real estate marketplace [51] for the 25 logistics clusters identified in Section 3.1 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 $\mathrm{sq\,ft}$ 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 location $63.32. The U.S. Bureau of Economic Analysis [59] considers the depreciation rate of material handling equipment to be 0.1072, i.e., the equipment will be fully depreciated in 9.32 years. Therefore, we estimate the racking costs to be $6.79 per storage location per year.

We survey the average annual salary of lift truck operators using the career website [60] for the 25 logistics-intensive regions identified in Section 3.1. We take the largest city in the corresponding county region as a reference and look for the average annual salary of lift truck operators in that city, which is provided directly by the website. The overhead typically represents between 18 to 26% of the worker's salary [61]. Here, we considered a fixed overhead of 20% for all regions.

Finally, Table 4 shows the top 25 county regions in the continental US ordered by logistics employment, also illustrated in Figure 10.

Now, the estimated price for an electric reach truck is between $35,000 USD and $55,000 [62]; Consequently, we assume a price of $45,000. Under IRS guidelines for depreciation of assets, lift trucks are under the category "Other Property Used for Transportation", which means that their depreciation rate is 0.2. Therefore, we estimate the lift truck costs to be $9,000 per lift truck per year. Manufacturers estimate that lift truck operating costs range from $1 to $4 per hour, depending on the age of the vehicle. Their general assumption is 1,500 hours per year, which results in $1,500 to $6,000 per year. We assume a lift truck operating cost of $2,000 per year.

With the estimated values for the cost parameters and 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 of the distribution center and the re-assignment of the manufacturing of the products for the North American market across 4 sites. The objective of the projects was to decrease the logistics costs of the company, which include inbound transportation, distribution center operation, and outbound transportation. Given the robustness of the facility location when only considering transpiration costs, we use the operational costs as the focus of the decision in the context of logistics clusters.

Before the project, the company had a manufacturing plant in China for most of the volume, and small production sites in Florida, Texas, and California for specific product lines. The distribution for the North American market occurred mostly from Massachusetts (85%). The rest of volume was shipped to customers directly from the manufacturing sites. We visited the distribution center in Massachusetts and gathered data to analyze their operation. We gathered process flows, dimensional data, layouts, operational times, inventory snapshots, storage utilization, and labor staffing.

Figure 11 shows the layout of the warehouse, and an overview of the process is presented in Figure 12. It has two docks which are used both for receiving and shipping. Trucks park in the dock, and the receiver helps unload products - which usually come in pallets - and receives the documentation of the delivery. The receiver gives the product to put away or quality control if the product requires inspection. Put away workers unwrap the pallets and put the cartons away, prioritizing primary locations - bins and totes. They also have to dispose of extra packaging and register the movement of products in their information system.

The pickers pick multiple orders at the time on their carts. This group of orders is called a cluster of orders. Picking one cluster usually takes one picker about 20 minutes. Once they complete a cluster, they deliver the outbound cartons to a packer, each box with the items picked and the paperwork associated with it. Packers take the cartons, scan the items, print the shipping label, pack the items again in the box, and put the cartons in the outbound conveyor. When the outbound conveyor is full, packers put the cartons in a staging area, waiting to be picked up by the transportation carrier.

Then, we evaluated the distribution center in terms of area cost and labor cost for a required throughput. The warehouse has 17K ft$^2$ and the annual cost per square feet

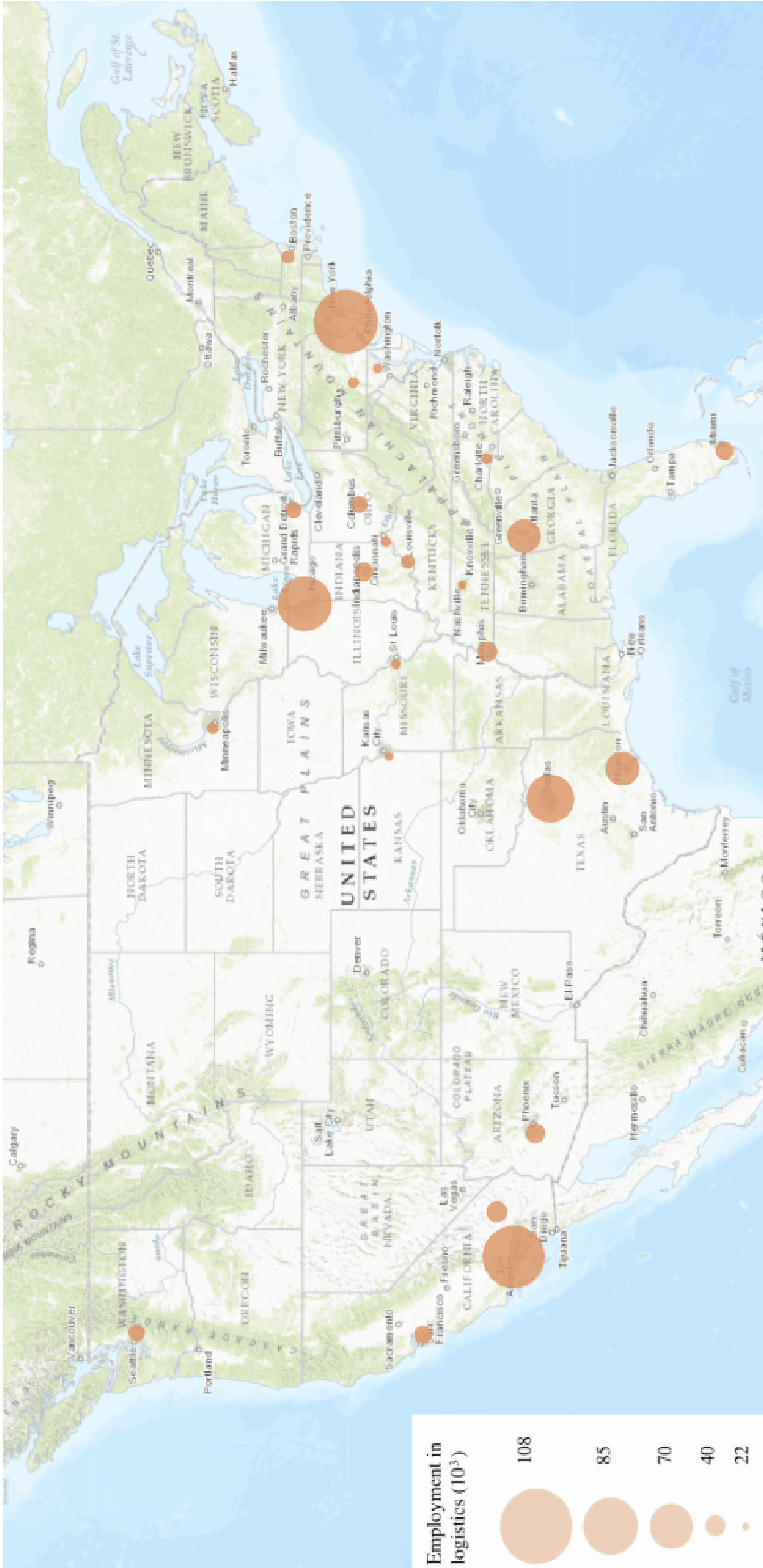


**Figure 10** Top 25 regions in the continental US with intensive logistics activities, 2013.

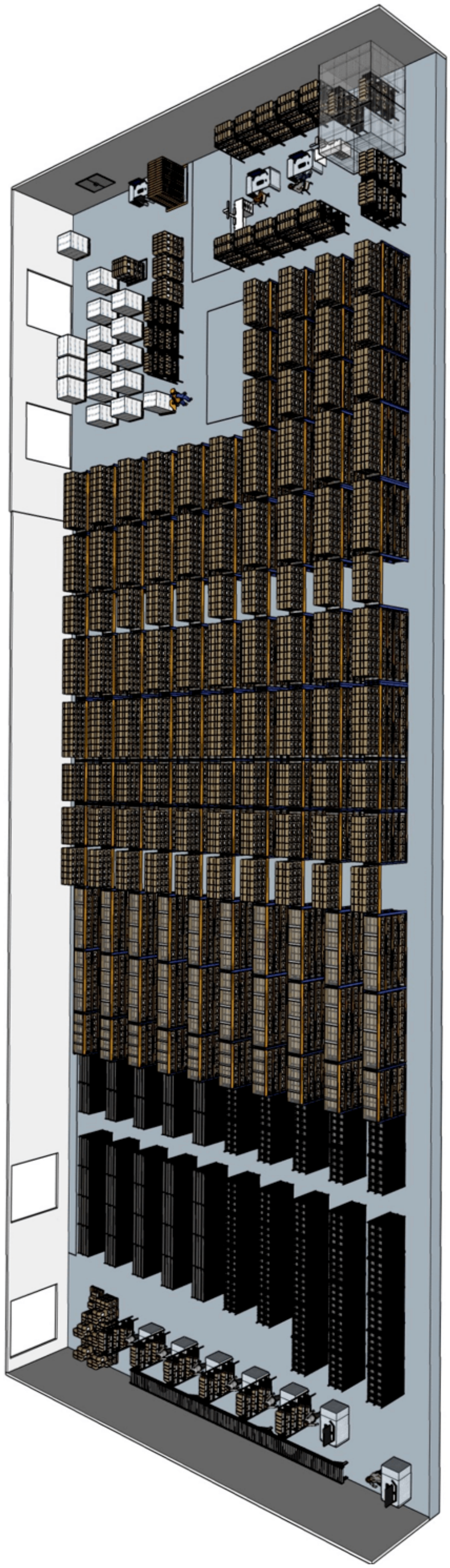

**Figure 11** Warehouse Layout

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

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

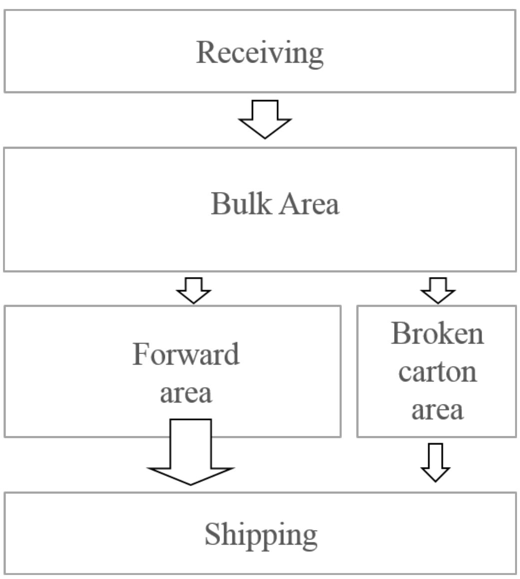


**Figure 12** Warehouse process

is $14, therefore the annual area cost is $238K.

Figure 13 shows the headcount of the warehouse segregated by area. The average salary for warehouse associates in the area was $34K and with 22% of overhead, the labor cost per associate was $41K. Therefore, the annual labor cost was $753K. Finally, the total operation cost of the warehouse was $991K (Table 6).

During the project, we identified several opportunities for 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 locations for the distribution center.

For the purpose of this analysis, we will keep constant the warehouse footprint and labor staffing. We also considered that relocating the distribution center was going to impact the transportation cost. Therefore, any proposal would have to come with a balance of both cost drivers. Finally, the alternative presented included moving the manufacturing sites from Florida, Texas, and California to Mexico and the distribution to be centralized in Arizona. In this way, the distribution center in Arizona receives products from China and Mexico, and serves most of the North American market.

**Table 5** Operational costs rank of logistics-intensive regions

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

**Table 6** Warehouse operational cost in Massachusetts

| **Area** ($ft^2$) | **17,000** |
|---|---|
| Area Cost ($/year) | $ 238,000 |
| Labor head count | 18 |
| Labor Cost ($/year) | $ 753,250 |
| Total operational cost ($/year) | $ 991,250 |

**Table 7** Warehouse operational cost in Arizona

| **Area** ($ft^2$) | **17,000** |
|---|---|
| Area Cost ($/year) | $ 112,200 |
| Labor head count | 18 |
| Labor Cost ($/year) | $ 629,066 |
| Total operational cost ($/year) | $ 741,266 |

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 break down 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 of the importance of balancing warehouse operational costs and transportation costs when making location decisions.

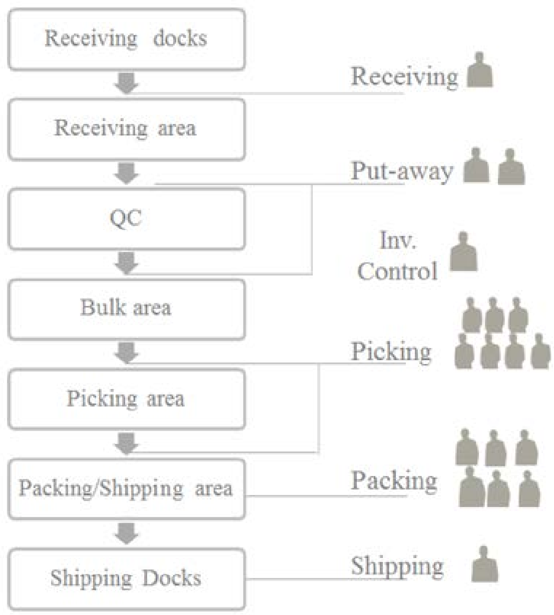


**Figure 13** Labor Staffing

## 4. Conclusions

Most literature on warehouse location problems focus on minimizing transportation costs. This paper advocates 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 here could be easily applied to any other market of interest: Large emerging countries such as the BRIC (Brazil, Russia, India, and China), and integrated regional economies such as the European Union come to mind.

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 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 proposal requires adaptation to be of use. to consider the infrastructure required to cover the last mile. However, manufacturers and distributors of products that do not have such expectations of availability and lead times could apply this framework to their operations. Distributors of electronics, auto parts, rare or hard-to-find items, industrial products, and in general items over which there is no expectation of immediate response (and that probably do not have regular supply runs in order to take advantage of vehicle routing) can use these analyses to configure their supply chains in the most efficient (total-cost-wise) manner.

The framework for logistics decisions presented in this paper is useful for companies that have adopted an integrated outlook towards the manufacturing vs. logistics separation that used to be the norm. Even though it has been known for many years that what counts for the company is the total cost of logistics [63], it is still common to observe companies that treat procurement, manufacturing, and distribution as separate business units. Adopting an operations management perspective that integrates manufacturing, procurement, logistics and distribution would make the implementation of this framework that much easier and more productive, opening the door to the re-consideration of production localization, customer service, and lead-time demands and constraints.

## 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.

## 6. Funding

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## 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.

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