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An Engineered Approach to Site Selection: Determining where Facilities Should be Located

Kerry Melton
University of Arkansas, Fayetteville

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ENGINEERING AND OPERATIONS MANAGEMENT
LUNCH & LEARN WEBINAR SERIES

April 25, 2019
# Online Degree Options

<table>
<thead>
<tr>
<th>Expand breadth and depth of engineering knowledge</th>
<th>Provide leadership and business skills to manage technology teams</th>
<th>Improve effectiveness and efficiency of operations</th>
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<tbody>
<tr>
<td><strong>M.S. in Engineering</strong></td>
<td><strong>M.S. in Engineering Management</strong></td>
<td><strong>M.S. in Operations Management</strong></td>
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<td>MSE Comprehensive Exam</td>
<td>MSEM Comprehensive Exam</td>
<td>MSOM Comprehensive Exam</td>
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<td>6 Electives chosen from OMGT and MSEM courses</td>
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<td>OMGT 5003 Intro to Operations Mgt</td>
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<td>OMGT 5783 Project Management</td>
<td>OMGT 5123 Finance or 5463 Economic Decision Making</td>
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<td>OMGT 4333 Statistics</td>
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<td>OMGT 4313 Law and Ethics</td>
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<td><strong>Approved 3 course engineering sequence</strong></td>
<td><strong>Any Regionally Accredited Bachelors Degree</strong></td>
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</table>
Dr. Kerry Melton
Instructor – M.S. in Operations Management

- Dr. Kerry Melton earned his Ph.D. in Industrial Engineering and Management from Oklahoma State University in 2012, with a concentration in supply chain management and logistics.

- Since then, he's taught Operations Management, Transportation Strategies, Advanced Forecasting and Inventory Management, Engineering and Business Statistics, and Goods and Services at the undergraduate and graduate levels at the University of Arkansas.

- He's been teaching online since 2015, and joined the Arkansas faculty as an adjunct professor in 2013.

- He has industry experience working at J.B. Hunt Transport for 12 years and at Walmart for 6 years. He currently works for J.B. Hunt Transport in Engineering and Technology in Lowell, Arkansas.
Brief Bio

Current:

• Adjunct Professor- University of Arkansas
• J.B. Hunt Transport

Past:

• Walmart Logistics
• FM Corporation

Education:

• Ph.D. Industrial Engineering, Oklahoma State University
• Master’s/Bachelor’s Industrial Engineering, University of Arkansas
An Engineered Approach to Site Selection: Determining Where Facilities Should Be Located

By

Kerry Melton
Outline

▶ The Strategic Importance of Location
▶ Factors That Affect Location Decisions
▶ Methods for Evaluating Location Alternatives
The Strategic Importance of Location

- One of the most important decisions a firm makes
- Increasingly global in nature
- Significant impact on fixed and variable costs
- Decisions made relatively infrequently
- Long-term decisions
- Once committed to a location, many resource and cost issues are difficult to change
The Strategic Importance of Location

The key objective of location strategy is to maximize the benefit of location to the firm.

Options include:

1. Expanding existing facilities
2. Maintain existing and adding sites
3. Closing existing and relocating
The Strategic Importance of Location

- Location decisions based on low cost require careful consideration
- Once in place, location-related costs are fixed in place and difficult to reduce
- Determining optimal facility location is a good investment
  - Requires good customer demand planning and forecasting
  - Real estate experts must weigh in
  - Cost factors are critical—land, building, etc.
Factors That Affect Location Decisions
Factors That Affect Location Decisions

Globalization adds to complexity
- Market economics
- Communication and systems
- Rapid, reliable transportation
- Ease of capital flow
- Differing labor costs

Identify key success factors (KSFs)
- Country, region, site
Factors That Affect Location Decisions

Country Decision | Key Success Factors
--- | ---
1. Political risks, government rules, **incentives**
2. Cultural and economic issues
3. Location of markets
4. Labor talent, attitudes, **productivity**, labor turnover/absenteeism culture
5. Availability of supplies, communications, energy
6. Exchange rates and currency risks
Factors That Affect Location Decisions

Region/Community Decision

Key Success Factors

1. Corporate desires
2. Attractiveness of region
3. Labor availability and wage costs
4. Utilities cost and availability
5. Environmental regulations
6. State government incentives, taxes
7. Proximity to raw materials and customers (i.e. perishable goods, JIT, transportation costs)
8. Land/construction costs
Factors That Affect Location Decisions

Site Decision

Key Success Factors

1. Site size and cost
2. Air, rail, highway, and waterway systems
3. Zoning restrictions
4. Proximity of services/supplies needed
5. Environmental impact issues, pollution, ethics
6. Life quality (i.e. crime, cost)
7. Public transportation
8. Education
Factors That Affect Location Decisions

Labor productivity example

- Wage rates are not the only cost
- Lower productivity may increase total cost

\[
\text{Labor cost per day} \quad = \quad \frac{\text{Cost per unit}}{\text{Productivity (units per day)}}
\]

**South Carolina**

- \( \frac{\$70}{60 \text{ units}} = \$1.17 \text{ per unit} \)

**Mexico**

- \( \frac{\$25}{20 \text{ units}} = \$1.25 \text{ per unit} \)
Methods for Evaluating Location Alternatives

- Factor-Rating Method
- Locational Cost-Volume Analysis
- Center-of-Gravity
- Load Distance Method
- Transportation Model (Linear Program)
- Mixed Integer Quadratic Program
Factor-Rating Method

▶ Popular because a wide variety of factors can be included in the analysis (subjective/qualitative)

▶ Six steps in the method

1. Develop a list of key success factors
2. Assign a weight to each key success factor
3. Develop a scale for each key success factor
4. Score each location for each key success factor
5. Multiply score by weights for each key success factor for each location and then sum the weights for each location
6. Make a recommendation based on the highest point score or lowest score (i.e. if cost related, risk related)
## Factor-Rating Example

The goal is to determine the best location (China or Sweden) for locating a plant facility based on maximizing the weighted score given the key success factors.

<table>
<thead>
<tr>
<th>Key Success Factor</th>
<th>Weight</th>
<th>Scores out of 100</th>
<th>Weighted Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>China</td>
<td>Sweden</td>
</tr>
<tr>
<td>Labor availability</td>
<td>30%</td>
<td>65</td>
<td>75</td>
</tr>
<tr>
<td>Incentives</td>
<td>25%</td>
<td>70</td>
<td>60</td>
</tr>
<tr>
<td>Labor wages</td>
<td>20%</td>
<td>80</td>
<td>85</td>
</tr>
<tr>
<td>Education</td>
<td>15%</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>Taxes</td>
<td>10%</td>
<td>80</td>
<td>55</td>
</tr>
<tr>
<td>Totals</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Highest score is the best, so China is the best location option based on this method.

Subjective: Weights, Scoring, Key Success Factors
Locational Cost-Volume Analysis

- An economic comparison of location alternatives
- Three steps in the method
  1. Determine fixed and variable costs for each location
  2. Plot the cost for each location based on production volume
  3. Select location with lowest total cost for expected production volume
Locational Cost-Volume Analysis
Example

Three locations: Clinton, MS; Akron, OH; Oakland, CA

Expected volume = 2,000 units

Which city would be the best location?

<table>
<thead>
<tr>
<th>City</th>
<th>Fixed Cost</th>
<th>Variable Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinton, MS</td>
<td>$30,000</td>
<td>$75</td>
<td>$180,000</td>
</tr>
<tr>
<td>Akron, OH</td>
<td>$60,000</td>
<td>$45</td>
<td>$150,000</td>
</tr>
<tr>
<td>Oakland, CA</td>
<td>$110,000</td>
<td>$25</td>
<td>$160,000</td>
</tr>
</tbody>
</table>

Total Cost = Fixed Cost + (Variable Cost x Volume)
Locational Cost-Volume Analysis Example

Figure 1. Cost-Volume graph [1]
Center-of-Gravity Method

- Finds the facility location that minimizes distribution costs
- Does not consider topography or direction
- Considers
  - Location of markets
  - Volume of goods shipped to those markets
  - Shipping cost or distance
- 2 methods:
  - Method 1 excludes transportation rates
  - Method 2 includes transportation rates
Center-of-Gravity Method

- Place existing locations on a coordinate grid
  - Latitude and longitude coordinates are often used
  - An arbitrary grid can be used
- Calculate (latitude, longitude) or other (x,y) coordinates for the center of gravity location
Center-of-Gravity Method

Method 1:

\[
\begin{align*}
\text{latitude coordinate of the center of gravity} & = \frac{\sum_{i} d_{ix} Q_i}{\sum_{i} Q_i} \\
\text{longitude coordinate of the center of gravity} & = \frac{\sum_{i} d_{iy} Q_i}{\sum_{i} Q_i}
\end{align*}
\]

where

- \(d_{ix}\) = latitude coordinate of location \(i\)
- \(d_{iy}\) = longitude coordinate of location \(i\)
- \(Q_i\) = Quantity of goods moved to or from location \(i\)
Center-of-Gravity Method

Method 1:
Example- Determine where a warehouse should be located to support 4 large stores located in the Dallas metro-plex. Information about each of the 4 locations is given below. The warehouse will provide same day service so it should be located strategically.

<table>
<thead>
<tr>
<th>Store Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Annual Loads</th>
<th>Latitude Weight</th>
<th>Longitude Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fort Worth, TX</td>
<td>32.82</td>
<td>-97.35</td>
<td>1,200</td>
<td>32.82*1200/4200</td>
<td>-27.81</td>
</tr>
<tr>
<td>Tyler, TX</td>
<td>32.35</td>
<td>-95.30</td>
<td>1,100</td>
<td>32.35*1100/4200</td>
<td>-24.96</td>
</tr>
<tr>
<td>Plano, TX</td>
<td>33.02</td>
<td>-96.68</td>
<td>900</td>
<td>33.02*900/4200</td>
<td>-20.72</td>
</tr>
<tr>
<td>Denton, TX</td>
<td>32.25</td>
<td>-99.53</td>
<td>1,000</td>
<td>32.25*1000/4200</td>
<td>-23.70</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4,200</strong></td>
<td><strong>32.60</strong></td>
<td></td>
<td></td>
<td><strong>-97.19</strong></td>
</tr>
</tbody>
</table>

Warehouse should be located at **latitude 32.60 & longitude -97.19**

Use [http://www.latlong.net/Show-Latitude-Longitude.html](http://www.latlong.net/Show-Latitude-Longitude.html) to find the actual city/state

(32.60, -97.19) is Mansfield, TX
Center-of-Gravity Method

Method 2:
Includes transportation rates

\[ X \text{ coordinate: } \frac{\sum (r_i W_i d_{ix})}{\sum (r_i W_i)} \]

\[ Y \text{ coordinate: } \frac{\sum (r_i W_i d_{iy})}{\sum (r_i W_i)} \]

- \( r_i \) ~ shipping rate (\$ per unit distance) for location \( i \)
- \( W_i \) ~ weight (or volume) shipped for location \( i \)
- \( d_{ix} \) ~ \( x \)-coordinate for location \( i \)
- \( d_{iy} \) ~ \( y \)-coordinate for location \( i \)
## Center-of-Gravity Method

**Method 2:**
Where should the DC be located to minimize transportation costs?

<table>
<thead>
<tr>
<th>Source / Market</th>
<th>Rate ($/ton-mile)</th>
<th>Tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buffalo</td>
<td>$0.90</td>
<td>500</td>
</tr>
<tr>
<td>Memphis</td>
<td>$0.95</td>
<td>300</td>
</tr>
<tr>
<td>St. Louis</td>
<td>$0.85</td>
<td>700</td>
</tr>
<tr>
<td>Atlanta</td>
<td>$1.50</td>
<td>225</td>
</tr>
<tr>
<td>Boston</td>
<td>$1.50</td>
<td>150</td>
</tr>
<tr>
<td>Jacksonville</td>
<td>$1.50</td>
<td>250</td>
</tr>
<tr>
<td>Philadelphia</td>
<td>$1.50</td>
<td>175</td>
</tr>
<tr>
<td>New York</td>
<td>$1.50</td>
<td>300</td>
</tr>
</tbody>
</table>

**Figure 2. Center-of-Gravity illustration [2]**

Best location to minimize transportation costs.
Load Distance Method

Load distance- quick method for determining a location based on volume (i.e. shipments, demand, etc.) and potential site locations and existing facilities along with distance

A Load Distance Model Steps:
• Calculate the distance between each potential site and existing facility where an existing facility can be a supplier or destination (DC, store, etc.)
• Multiply the distance by the volume between each potential site and each existing facility to obtain the load distances
• Sum the load distances for each potential site
• The potential site with the smallest (minimum) load distance is the best choice option
Load Distance Method

A Load-Distance Model Example: Matrix Manufacturing is considering where to locate its warehouse in order to service its four Ohio stores located in Cleveland, Cincinnati, Columbus, Dayton. Two sites are being considered—Mansfield and Springfield, Ohio. Use the load-distance model to make the decision.
The load distance (Id) score for Mansfield is higher than for Springfield. The warehouse should be located in Springfield.

The goal is to minimize load distance.
Transportation Model

- Finds amount to be shipped from several points of supply to several points of demand
- Solution will minimize total production and shipping costs
- A special class of linear programming problems
Transportation Model

Determine how many product cases to ship from each supplier to each processing plant based on the supplier and plant volume constraints with the goal of minimizing distance. Use a linear program (LP).

Transportation flow diagram:

Figure 3. Transportation model illustration [2]
Transportation Model

LP Decision variables:

\[ X_{ij} = \# \text{ of cases shipped from node } i \text{ to node } j \]

Specifically, the nine decision variables are:

\[ X_{14} = \# \text{ of cases shipped from Mt. Dora (node 1) to Ocala (node 4)} \]
\[ X_{15} = \# \text{ of cases shipped from Mt. Dora (node 1) to Orlando (node 5)} \]
\[ X_{16} = \# \text{ of cases shipped from Mt. Dora (node 1) to Leesburg (node 6)} \]
\[ X_{24} = \# \text{ of cases shipped from Eustis (node 2) to Ocala (node 4)} \]
\[ X_{25} = \# \text{ of cases shipped from Eustis (node 2) to Orlando (node 5)} \]
\[ X_{26} = \# \text{ of cases shipped from Eustis (node 2) to Leesburg (node 6)} \]
\[ X_{34} = \# \text{ of cases shipped from Clermont (node 3) to Ocala (node 4)} \]
\[ X_{35} = \# \text{ of cases shipped from Clermont (node 3) to Orlando (node 5)} \]
\[ X_{36} = \# \text{ of cases shipped from Clermont (node 3) to Leesburg (node 6)} \]
Transportation Model

LP Objective:

Minimize the total number of case miles.

\[ \text{MIN: } 21X_{14} + 50X_{15} + 40X_{16} + \\
35X_{24} + 30X_{25} + 22X_{26} + \\
55X_{34} + 20X_{35} + 25X_{36} \]
Transportation Model

LP Constraints:

- **Capacity constraints**
  
  \[ X_{14} + X_{24} + X_{34} \leq 200,000 \] Ocala
  \[ X_{15} + X_{25} + X_{35} \leq 600,000 \] Orlando
  \[ X_{16} + X_{26} + X_{36} \leq 225,000 \] Leesburg

- **Supply constraints**
  
  \[ X_{14} + X_{15} + X_{16} = 275,000 \] Mt. Dora
  \[ X_{24} + X_{25} + X_{26} = 400,000 \] Eustis
  \[ X_{34} + X_{35} + X_{36} = 300,000 \] Clermont

- **Non-negativity conditions**
  \[ X_{ij} \geq 0 \text{ for all } i \text{ and } j \]
Transportation Model

LP Solution using Microsoft Excel Solver:

<table>
<thead>
<tr>
<th>Decision variables</th>
<th>minimize objective</th>
<th>24,000,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>X14 200,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X15 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X16 75,000</td>
<td>200,000 ≤ 200,000</td>
<td></td>
</tr>
<tr>
<td>X24 0</td>
<td>550,000 ≤ 600,000</td>
<td></td>
</tr>
<tr>
<td>X25 250,000</td>
<td>225,000 ≤ 225,000</td>
<td></td>
</tr>
<tr>
<td>X26 150,000</td>
<td>275,000 = 275,000</td>
<td></td>
</tr>
<tr>
<td>X34 0</td>
<td>400,000 = 400,000</td>
<td></td>
</tr>
<tr>
<td>X35 300,000</td>
<td>300,000 = 300,000</td>
<td></td>
</tr>
<tr>
<td>X36 0</td>
<td>200,000 ≥ 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>75,000 ≥ 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>250,000 ≥ 0</td>
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<td></td>
<td>150,000 ≥ 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>300,000 ≥ 0</td>
<td></td>
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</tbody>
</table>

$X_{14}$ = # of cases shipped from Mt. Dora to Ocala
$X_{15}$ = # of cases shipped from Mt. Dora to Orlando
$X_{16}$ = # of cases shipped from Mt. Dora to Leesburg
$X_{24}$ = # of cases shipped from Eustis to Ocala
$X_{25}$ = # of cases shipped from Eustis to Orlando
$X_{26}$ = # of cases shipped from Eustis to Leesburg
$X_{34}$ = # of cases shipped from Clermont to Ocala
$X_{35}$ = # of cases shipped from Clermont to Orlando
$X_{36}$ = # of cases shipped from Clermont to Leesburg
Mixed Integer Quadratic Program

Mixed Integer Quadratic Program can be used to determine locations

- Models include an objective and constraints
- Models are often complex and timely and computationally difficult to solve
Mixed Integer Quadratic Program

Melton & Ingalls [3]; Method to improve driver home time:
• Determines locations where truck drivers can relay trailer equipment to increase driver home time and to reduce driver driving distances
  o Location points established using mathematical programming-mixed integer quadratic program
• Method to improve the truckload driving job but not at the expense of the transportation carrier and customer

Mathematical Program Includes:
1. Driver home time
2. Driver turnover costs based on historical data for avg. weekly driving distances
3. Equipment maintenance and depreciation costs
4. Driver hiring charges/labor costs for areas of the country
5. Miles driven per week
6. Relay setup cost
7. Driver wages
**Mixed Integer Quadratic Program**

Melton & Ingalls [3]; Mathematical Program

| Objective: |
| Minimize |
| (1) \( \sum_{(ij) \in P} f_{ij} \sum_{k \in \{i,j\}} d_{ij}^{ik} y_{ki} + \) |
| (2) \( \sum_{k \in N} a_k z_k + \) |
| (3) \( \tau \cdot u \cdot q + \) |
| (4) \( b \cdot q \) |

| Constraints: |
| (1) \( \sum_{i \in P \cup j < k} d_{ij}^{ik} y_{ki} = z_k \) for all \( (ij) \in P \) and \( k \in P \setminus \{i,j\} \) |
| (2) \( \sum_{i \in P \cup j < k} d_{ij}^{ik} y_{ki} = z_k \) for all \( (ij) \in P \) and \( k \in P \setminus \{i,j\} \) |
| (3) \( \sum_{i \in P \cup j \leq i} d_{ij}^{ik} y_{ki} = 1 \) for all \( (ij) \in P \) |
| (4) \( \sum_{i \in P \cup j \leq i} d_{ij}^{ik} y_{ki} = 1 \) for all \( (ij) \in P \) |
| (5) \( \sum_{d=0}^{\infty} \lambda_d m_d = (1/[2 \sum_{(ij) \in P} f_{ij} d_{ij}^{ij}]) \sum_{(ij) \in P} [(2 \sum_{k \in \{i,j\}} y_{ki} d_{ij}^{ik} f_{ij} + (\rho_{ij} \cdot w \cdot h) + (2* f_{ij} / (w+h)) + (\sum_{(ij) \in P} f_{ij} \sum_{k \in \{i,j\}} e_k z_k \psi / (w+h))] \) |
| (6) \( \sum_{i=0}^{r} \lambda_i = 1, \lambda_i \geq 0, i = 0, ..., r \) |
| (7) \( \sum_{i=1}^{r} \delta_i = 1, \delta_i \in \{0,1\}, i = 0, ..., r \) |
| (8) \( \lambda_0 \leq \delta_1 \) |
| (9) \( \lambda_i \leq \delta_i + \delta_{i+1}, i = 1, ..., r-1 \) |
| (10) \( \lambda_r \leq \delta_r \) |
| (11) \( \tau = \sum_{i=0}^{r} \lambda_i \) |
| (12) \( q = \sum_{(ij) \in P} [(2 \sum_{k \in \{i,j\}} y_{ki} d_{ij}^{ik} f_{ij} + (\rho_{ij} \cdot w \cdot h) + (2* f_{ij} / (w+h)) + (\sum_{(ij) \in P} f_{ij} \sum_{k \in \{i,j\}} e_k z_k \psi / (w+h))] \) |
| (13) \( y_{ij} \in \{0,1\} \) for all \( k \in P \) and all \( (ij) \in P \) |
| (14) \( z_k \in \{0,1\} \) for all \( k \in N \) |
Mixed Integer Quadratic Program

Melton & Ingalls [3]- Driver route using relay points

- Luling, LA to Foxfield, CO path
- Relay points picked in: Alexandria, LA; Tyler, TX; Henrietta, TX; Amarillo, TX; Raton, NM (each driving loop ranges from 210 miles to 244 miles)

<table>
<thead>
<tr>
<th>Origin Location</th>
<th>Relay Location 1</th>
<th>Relay Location 2</th>
<th>Relay Location 3</th>
<th>Relay Location 4</th>
<th>Relay Location 5</th>
<th>Dest. Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luling, LA</td>
<td>212 miles</td>
<td>213 miles</td>
<td>217 miles</td>
<td>244 miles</td>
<td>215 miles</td>
<td>210 miles</td>
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<tr>
<td>Alexandria, LA</td>
<td></td>
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</tr>
<tr>
<td>Tyler, TX</td>
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<td>Henrietta, TX</td>
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<tr>
<td>Amarillo, TX</td>
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Determined locations
Site Selection Location Tools Used in Industry

- LLamasoft Supply Chain Guru
- Maptitude
- Accruent
- Microsoft Excel
Comments

► Site selection software- few options in the market
► Site selection location is important for long-term solutions (e.g. new DC needed in 5 years based on projected customer demand growth)
► Locations are often locked in for a period of years and are not mobile
  • Once a 3M square feet DC is built for $60M, the company is locked to the location and cost.
  • Long-term building leases can be costly to terminate
References


M.S. in Operations Management
At a Glance:

- Online and Live Course Options
- 30 Credit Hours (10 Graduate Courses)
  - With up to 4 pre-requisite classes
- Five 8-week Sessions Per Year
- No GRE/GMAT required with 3.0 Bachelor's GPA
- Total Program Cost is $12,000 to $15,000 (depending on pre-reqs needed)
- Can be completed in one year, but you have up to six years to complete

Master of Science in Operations Management | http://operations-management.uark.edu
PROJECT MANAGEMENT GRADUATE CERTIFICATE AT A GLANCE:

- Online and Live Course Options
- 12 Credit Hours (4 Graduate Courses)
- 8-week sessions
- Five Enrollment Periods: Aug, Oct, Jan, Mar, May
- Entire Program Cost: Approximately $5,000
- 2.5 GPA with a Bachelor’s Degree required for admission
- Certificate courses can also count toward MSOM degree