Ideal Location Selection for Global Excavator Manufacturing Facilities in North America

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Abstract

The Chinese heavy equipment market and demand are experiencing a considerable increase in North America. It is supported by competitive product prices and better product quality. This paper aims to provide the best results in selecting the ideal location from among the other 50 states in the USA to develop a strategic, effective, and more competitive manufacturing facility. The case study is applied to a multinational Chinese company that already has a manufacturing site in one of the Midwestern states in the USA. The company also brings in material supplies and pre-assembly unit parts from South America, apart from China. Materials shipping from South America to the existing location are still quite far. The company has also set out localization strategies to target new markets in several states with the highest demand at a low cost, so shipping and location placement must be considered. Analytic Hierarchy Process (AHP) is carried out to obtain the best location assessment criteria weights. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is used to get the final score assessing each alternative location. Research obtains six criteria and 29 sub-criteria for selecting one appropriate state. Region Properties and Market Economy (R.M.) hold the priority concerning location selection for a manufacturing facility in one of the U.S. States, followed by Transportation and Optimum Distance (TO) and Cost and Capital Investment (CC). Results depicted state A as the most suitable state for the forthcoming facility location.

Keywords
Location Selection, North America, Analytic Hierarchy Process, Technique for Order of Preference Similarity to Ideal Solution

1. Introduction
The manufacturing industry has faced new challenges related to market globalization and increasing demand. The trade market is increasingly encouraging business players to expand to reach consumers more quickly. Companies can adopt new facilities that cross national borders to target new markets at a low cost. Products can be built and assembled in one country and shipped to other countries and continents for further processing (Eterovic and Özgül 2012).

Strategically, there are many reasons why companies establish manufacturing facilities in other countries, including to face global market risks, namely changes in foreign exchange rates and regimes and trade tariffs and concessions. It also includes cheap and skilled labor, capital subsidies, reductions in costs, and closer proximity to customers and/or suppliers (Ferdows 1997). This expansion needs to be balanced and supported by significant market demand.

One of the heavy equipment products with the best demand in the machinery market is the hydraulic excavator, known for its applications in forestry, agriculture, construction, and mining. The growth in commodity prices impacts the need for hydraulic excavator machines, where over 50 excavator manufacturing enterprises perform worldwide, including the author's research object as one of China's excavator manufacturers.

Excavator sales from 25 leading excavator companies from China are getting more robust, reaching a total of 241,178 excavators as of July 2021. This represents a 27.2% year-over-year increase (China Construction Machinery Association 2021). In detail, a total of 206,029 excavators were sold in the domestic market, up 19.7% year-on-year, while exports jumped 102%, with 35,149 units sold. Thus, on a percentage basis, 85% of excavators are sold in the domestic market, and 15% is the proportion of overseas customers (China Construction Machinery Association 2021).

The respective company already has a manufacturing site in one of the Midwestern states in the USA. The company also brings in material supplies and pre-assembly unit parts from South America, apart from China. Problems occur that are often considered less profitable for the company. The company urges localization because materials shipping from South America to the existing location are still considered quite far. The company has also set out localization strategies to target new markets in several states with the highest demand at a low cost. Shipping and location placement must be considered.

For companies to remain competitive, decision-making regarding the state location selection needs to be considered to identify the relevant factors in selecting manufacturing facilities locations to choose the most appropriate and practical location. Research is required to design the best state location selection strategy to provide the best results. AHP method is used to obtain the weights for the best location assessment criteria, and TOPSIS is also used to get the value of the proximity coefficient, which will be used to assess locations optimally.

1.1 Objectives
This study aims to design the most suitable location selection analytical model to determine the ideal manufacturing facility in one among fifty states in the United States of America to assemble products parts.

2. Literature Review
2.1 Supply Chain Management
Supply chain management is an interconnected network in which all parties are directly or indirectly involved in producing and delivering goods or services to the end-user (Mentzer et al. 2001) through distribution, knowledge and information flow, and finance (Stock and Boyer 2009). SCM can also be translated into a sequence of methods and techniques applied to integrate suppliers, warehouses, and other storage places to produce, deliver and distribute in the correct quantity, location, and time to efficiently diminish expenses and fulfill customer needs (Simchi-Levi 2001). A supply chain consists of all entities fulfilling consumer demands, either directly or indirectly. Supply chain components are manufacturers, freight forwarders, retailers, and even consumers as end-user themselves (Chopra and Meindl 2016).

The primary purpose that a business desires to accomplish by enforcing SCM is to raise its revenue, productivity, and efficient acquisition of raw materials (Daugherty et al. 2005). SCM also supports constructing a more rapid turnover of goods that resemble consumers. SCM is also valuable in reducing inventory stored goods and stock carrying costs. It reduces the stock frequency from running out, curtailing the demand cycle, decreasing costs, and advancing product availability in the market (Leonard et al. 2009).

2.2 Location Selection
Location of production facilities is an essential aspect of a manufacturing company's strategic decision-making and logistics. The optimal location can offer a competitive advantage and contribute to the company's success (Maccarthy 2003). Determining the factory's location is helpful to obtain an effective and maximum economic operation. As a component in operations management, the location of a new facility optimizes a single objective such as cost and profit, distance, service, or waiting time. A global decision-maker will consider qualitative and quantitative factors when deciding which country to place a new manufacturing facility in. Its application can be used in various fields, including public and private facilities, military environment, national and international scope (Zanjirani et al. 2010).

Location problems refer to the modeling, formulation, and solution of placing facilities in a defined area. The choice of facility location plays an essential role in designing the company's strategic value (Melo et al. 2009). This is a broad and enduring topic, as it influences several operational and logistical decisions and generally involves long-term investments. Therefore, a successful facility location process will certainly provide an advantage for the company (Kodali & Routroy 2006).

On the other hand, many companies do not exploit the full potential of their foreign plants. These facilities are managed solely to benefit from tariffs and trade concessions, cheap labor, capital subsidies, and reduced logistics costs (Ferdows 1997). The work, responsibilities, and resources channeled to the factory are limited. Mistakes in facility location selection can be challenging and expensive to change, especially in extensive facilities. The decision-maker must choose the facilities that perform well for the current situation and the facilities that will benefit the company.

2.3 Analytical Hierarchy Process

Analytical Hierarchy Process (AHP) is an approach to facilitate decrypting multi-criteria decision-making (MCDM) issues by creating a scale and ranking consisting of objectives, criteria, sub-criteria, and alternatives for each judgment. AHP is operated to uncover the weight of the criteria by accomplishing a pairwise for the thought and statements of experts (Dachyar and Purnomo 2018). AHP is used to express complex and undeveloped conditions. Multi-criteria must be settled into several elements, and the author will sort these elements into a hierarchy.

2.4 Technique for Order of Preference by Similarity to Ideal Solutions

TOPSIS is a ranking multi-criteria decision-making (MCDM) method that yields alternative ranking founded on the resemblance from an ideal solution (Dachyar and Maharani 2019). The concept of TOPSIS is to specify a solution based on the distance to positive and negative ideal solutions.

3. Methods

3.1 Criteria Assessment

In identifying criteria, the author gathered the data by conducting in-depth virtual interviews with five experts directly from China and USA from each office. It is also supported by extensive literature reviews from journals, references, supporting libraries, and theoretical sources for the writing process related to the location selection of a manufacturing facility.

The authors performed a literature study on the criteria used in selecting a location. Survey questionnaires are being raised based on the criteria obtained from the literature review. Seven criteria influencing location selection are carried out: cost and capital investment (CC), region properties and market economy (RM), environmental and social effects (ES), transportation and optimum distance (TO), availability, accessibility, and land potential (AL), and labor and workforces (LW).

Each sub-criterion is equipped with a Likert scale response from 1-5 (1 for a less critical statement and 5 for an upmost critical statement). The geometric mean and Cronbach's alpha statistical test are carried out in this research. The geometric mean is used to find a compromise between the data sets provided, giving comparable results. At the same time, Cronbach's alpha calculates the consistency between items in a test that is the test's internal consistency (Christmann & Van Aelst 2006).

3.2 Weighting Criteria

The weighting enumeration by the AHP method demonstrates the level of significance of each criterion and sub-criteria used in this analysis by developing a pairwise comparison questionnaire filled out by each expert. The weighting assessment by more than one expert requires calculating the combined weight so that the author can obtain the final weight for each criterion and sub-criteria. AHP method is also operated to construct pairwise comparisons reckoned by experts using Equation (1) derived from Giovanni et al. (2021),

$$D_k = \begin{pmatrix} b_{11k} & \cdots & b_{1mk} \\ \vdots & b_{ijk} & \vdots \\ b_{n1k} & \cdots & b_{nmk} \end{pmatrix} \tag{1}$$

k = 1, …, *K*; *i* = 1, …, *n*; *j* = 1, …, *n*. D_k is the pairwise comparison matrix for *K* is the number of experts, *k* is the expert index, and b_{ijk} is the degree of influence for *i*-criteria on *j*-element of the *k*-expert judgment. Calculation of the geometric mean from the expert's judgments are resulted using Equation (2) and (3).

$$D = \begin{pmatrix} d_{11} & \cdots & d_{1m} \\ \vdots & \ddots & \vdots \\ d_{n1} & \cdots & d_{nm} \end{pmatrix}$$

(2)

$$d_{ij} = \sqrt[k]{\prod_{k=1}^{K} b_{ijk}} = \frac{1}{d_{ji}} \forall\, i,j \tag{3}$$

D is the geometric mean of the expert's opinion that proceeds with normalizing the pairwise comparison matrix using Equation (4).

$$r_{ij} = \frac{d_{ij}}{\sqrt{\sum_{i=1}^{n} d^2{}_{ij}}} \forall\, i,j \tag{4}$$

r_{ij} is the value of a normalized matrix that calculates the weights for each criterion with Equation (5) as follows.

$$W_i = \frac{\sum_{j=1}^{n} r_{ij}}{\sum_{i=1}^{n} \sum_{j=1}^{n} r_{ij}} \forall\, i \tag{5}$$

CR is the inconsistency factor, *CI* is the consistency index, and *RI* is the consistency index of the mutual matrix erratically chosen. All of the analysis phases are being enforced on all criteria and sub-criteria. The final results acquired from the analysis are the local weights and global weights for all criteria.

3.3 States Location Selection and Evaluation

The location assessment calculation will use the TOPSIS method based on the location selection assessment questionnaire filled out by experts and use the value of each sub-criteria global weight starting from a decision matrix with the following Equation (6).

$$A = (a_{ij})_{mxn} = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{pmatrix} \tag{6}$$

a_{ij} is the value for *j*-criterion from *i*-alternative; *i* = 1, 2, …, *m* and *j* = 1, 2, …, *n*, proceeds with a normalized decision matrix created with the following Equation (7).

$$b_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}{}^2}} \tag{7}$$

a_{ij} conveys the value of *j*-criterion for *i*-alternative; b_{ij} is the normalization value of *j*-criterion for *i*-alternative. The normalized decision matrix can be yielded in Equation (8) as follows.

$$B = (b_{ij})_{mxn} = \begin{pmatrix} b_{11} & \cdots & b_{1n} \\ \vdots & \ddots & \vdots \\ b_{m1} & \cdots & b_{mn} \end{pmatrix} \tag{8}$$

The author completes a weighted normalized decision matrix with the following Equation (9).

$$C = (c_{ij})_{mxn} = \begin{pmatrix} W_1 x b_{11} & \cdots & W_n x b_{1n} \\ \vdots & \ddots & \vdots \\ W_1 x b_{m1} & \cdots & W_n x b_{mn} \end{pmatrix}$$

(9)

c_{ij} is the weighted normalization value of j-criterion for i-alternative. The author then proceeds to determine the positive ideal (C^+) and the ideal negative resolution (C^-) using Equation (10).

$$C^+ = \left(c_j{}^+\right) = \left\{\left(\max c_{ij} \middle| j \in J_1\right), \left(\min c_{ij} \middle| j \in J_2\right)\right\}$$
$$C^- = \left(c_j{}^-\right) = \left\{\left(\min c_{ij} \middle| j \in J_1\right), \left(\max c_{ij} \middle| j \in J_2\right)\right\} \quad (10)$$

$c_j{}^+$ shows the positive ideal solution from j-criteria; $c_j{}^-$ shows the negative ideal solution from j-criteria; max c_{ij} $\left[max\left(w_j \times b_{ij}\right)\right]$; min c_{ij} $\left[min\left(w_j \times b_{ij}\right)\right]$; $i = 1, 2, \ldots, m$; and $j = 1, 2, \ldots, n$. J_1 shows a set of benefit type criteria and J_2 shows a set of cost type criteria. Equations (11) and (12) are used to figure the distance between each alternative with the positive and negative ideal solutions.

$$d_i^+ = \sqrt{\sum_{j=1}^{n}(c_{ij} - cj^+)^2} \quad (11)$$

$$d_i^- = \sqrt{\sum_{j=1}^{n}(c_{ij} - cj^-)^2} \quad (12)$$

The d_i^+ is an equation for the distance of i-alternative from the positive ideal solution, and d_i^- is an equation for the distance of i-alternative from the negative one. Step to figure the correspondence coefficient for all alternatives using Equation (13) below.

$$CC_i = \frac{d_i^-}{(di^+ - di^-)} \quad (13)$$

The value of CC_i needs to be normalized first before classifying the other options to produce the value of CC_{ni}, using Equation (14) to rank the alternatives.

$$CC_{ni} = \frac{CC_i}{Max\ (CC_i)} \quad (14)$$

4. Data Collection

The research acquired seven criteria with 66 sub-criteria through various literature analyses. Calculation continues by validating the criteria by distributing questionnaires to the five selected experts responsible for selecting and evaluating the suitable location. The validation outcomes of the prerequisites were the finding of 6 criteria and 29 utmost critical sub-criteria to be used, shown in Table 1; (see Table 1).

Table 1. Criteria and sub-criteria for manufacturing facilities location selection assessment

Manufacturing facilities location selection	
Criteria	Sub-criteria
Cost and Capital Investment (CC)	Land acquisition cost (C1)
	Labour cost (C2)
	Procurement cost of machinery (C3)
	Transportation cost from China to US port (C4)
	Lowest operational costs (C5)
Region Properties and Market Economy (RM)	The economic status of the region (R1)
	Proximity to suppliers (R2)
	Proximity to airport/sea port/railways or other shipyard zones (R3)
	Central to major markets (R4)
	Low tax (R5)
Environmental and Social Effects (ES)	Environmental Effects of Waste (E1)
	Far from disaster area (E2)
	Adequacy of energy resources (E3)
Transportation and Optimum Distance (TO)	Maximum coverage and minimize the travel distance (T1)
	Access to roads for loading/unloading (T2)
	Distance from residential areas (T3)
Availability, Accessibility and Land Potential (AL)	Expectations of Future Demand (A1)
	Level of Increasing Capacity (A2)
	Availability of Skilled labours (A3)
	Availability of utilities (A4)
	Availability of multi modes of transportation (A5)
	Relatively cheap land sites (A6)
	Present and Planning Status Around The Area (A7)
	Highway, Airport, Seaport and Rail Link Distance (A8)
	Material handling flexibility (A9)
Labor and Workforces (LW)	Income level (L1)
	Skilled manpower availability (L2)
	Tax incentive (L3)
	Proximity to the Ministry/Govt. offices for quick execution of plans and awareness of new rules & regulations (L4)

Selected and preferred criteria and sub-criteria were later used to analyze applicable states based on states' economic stability and potential. The states' economies were ranked by the business environment, employment, and growth. The data were collected from the Best States, an interactive platform developed by U.S. News & World Report L.P. (2022) to rank 50 U.S. states. However, the calculation is adjusted to the needs of the research. Not all metrics are used and considered in this study.

The business environment subcategory evaluates the business birth rate and overall tax burden. This research also factored in venture capital investment and the number of top businesses headquartered in a state. The employment subcategory evaluates unemployment, job growth, and labor force participation rates, indicating employment and economic prospects. The last subcategory states' growth measures the financial future. It can be a strong indicator of up-and-coming locations for businesses through the young population's growth and GDP growth rate. The results of the states' ranking can be seen in Table 2 below; (see Table 2).

Table 2. Top 10 Best U.S. States based on Economy Rankings

States	Business Environment	Employment	Growth	Overall Rank
Utah	12	2	1	1
Colorado	4	1	4	2
Idaho	5	4	3	3
Massachusetts	1	3	12	4
Washington	14	15	2	5
Nevada	10	10	8	6
Arizona	13	27	5	7
Georgia	6	17	10	8
Texas	15	12	9	9
California	2	32	14	10

5. Results and Discussion

The results of calculating local and global weights for each criterion and sub-criteria on the capability dimension are calculated through Analytic Hierarchy Process (AHP) as shown below; (see Table 3). Region Properties and Market Economy (R.M.) hold the priority concerning location selection for a manufacturing facility in one of the U.S. States, followed by Transportation and Optimum Distance (TO) and Cost and Capital Investment (CC).

Table 3. Weight of criteria and sub-criteria

Goal: Location Selection for a Manufacturing Facilities in US				
Criteria	Weight of the criteria	Sub criteria	Weight of the sub criteria	Global weight
Cost and Capital Investment (CC)	0,230	C1	0,480	0,011
		C2	0,185	0,043
		C3	0,430	0,010
		C4	0,511	0,117
		C5	0,214	0,049
Region Properties and Market Economy (RM)	0,293	R1	0,045	0,013
		R2	0,288	0,084
		R3	0,193	0,056
		R4	0,424	0,124
		R5	0,050	0,015
Environmental and Social Effects (ES)	0,036	E1	0,167	0,006
		E2	0,167	0,006
		E3	0,667	0,024

Table 3. Weight of criteria and sub-criteria

Goal: Location Selection for a Manufacturing Facilities in US				
Criteria	Weight of the criteria	Sub criteria	Weight of the sub criteria	Global weight
Transportation and Optimum Distance (TO)	0,277	T1	0,732	0,203
		T2	0,138	0,038
		T3	0,130	0,036
Availability, Accessibility and Land Potential (AL)	0,130	A1	0,204	0,027
		A2	0,072	0,009
		A3	0,144	0,019
		A4	0,097	0,013
		A5	0,103	0,013
		A6	0,074	0,010
		A7	0,136	0,018
		A8	0,146	0,019
		A9	0,024	0,003
Labor and Workforces (LW)	0,034	Q1	0,528	0,018
		Q2	0,076	0,003
		Q3	0,304	0,010
		Q4	0,093	0,003

Suitable location selection is carried out to classify states assessed through the TOPSIS method by normalizing the proximity coefficient's value on each dimension; (see Table 4).

Table 4. Suitable location selection

U.S. States	Goal: Location Selection for a Manufacturing Facilities in US	
	CCn_i	Rank
State A	1,0000	1
State B	0,5670	2
State C	0,5495	3
State D	0,5457	4
State E	0,5361	5
State F	0,5043	6
State G	0,4419	7
State H	0,4070	8
State I	0,3894	9
State J	0,3811	10

The chosen ten states, according to their rank in Table 2. The naming from A to J is not based on alphabetical order or its overall rank in Table 2. Results depicted in Table 4 are experts' judgments calculated by TOPSIS in terms of the respected criteria and sub-criteria. State A is chosen and is the most suitable state for the forthcoming facility location.

6. Conclusion

Based on the research done on selecting the most suitable facility location in some of the states considered for one of the Chinese excavator manufacturers using the AHP method and the TOPSIS method, this research obtains six criteria and 29 sub-criteria for selecting one appropriate state. Region Properties and Market Economy (R.M.) hold the priority concerning location selection for a manufacturing facility in one of the U.S. States, followed by Transportation and Optimum Distance (TO) and Cost and Capital Investment (CC). Results depicted state A as the most suitable state for the forthcoming facility location.

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