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Manufacturing Plant Location Selection: A Case Study with Resilient Strategy Using AHP

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Abstract: An organization's decision to start a new location or relocate a current location of their plant is affected by several factors, which directly impacts the performance of the supply chain, and can be a critical decision for the progress of the company. Conventionally, a new manufacturing plant location used to be selected based on quantitative and qualitative variables including shipment price, taxes, exchange duty, etc. However, only a few researchers have conducted studies that emphasize the preparedness of a company to tackle any natural disasters or pandemics, typically called as "resilience" of the company while considering plan location selection. In this paper, an approach towards the qualitative factors of a case study manufacturing company, referred to as ABC Manufacturing Inc. for its new unit location in the North American continent is designed. Factors such as proximity to market, proximity to suppliers, business environment, location of competitors, and its relationship to the resilience of the company in case of disasters will be investigated. A set of alternative models that incorporate possible factors, which can be chosen depending on the priority of the organization is proposed. Finally, the future work with an open-ended conclusion will be highlighted.

Keywords: Plant Location, Multi Criteria Decision, AHP, Resilience

1. Introduction

Selection of a Manufacturing Plant location for any firm is one of the most complicated and challenging decision into this globalized world. Conventionally, a new manufacturing plant location used was selected based on quantitative and qualitative variables including shipment price, taxes, exchange duty, etc. (T. M. C. &. K. A. Brush, 2009). However, in the Covid-19 pandemic, existing oversea factory cannot support their customer as before, which affected their end customer drastically. Therefore, instead of considering cost as the biggest factor in plant location decision, the resilience of supply chain is considered more important than before. Many companies are trying to build or shift their factories close to their end customer (S. I. D. a. D. A. Hosseini, 2019). However, only limited literature emphasizes resilience in manufacturing plant location problems. This paper aims to give a solution in the emerging need in plant location problem. A case study is conducted with a company in Electronics Manufacturing Services (EMS) sector, referred to as ABC Manufacturing Inc. This paper proposed an approach that can help ABC Manufacturing Inc. for selecting its new unit location in the North American continent. Section 3.1 demonstrates how the model is built based on the case study to ABC Manufacturing Inc. Section 3.2 summarized factors that needs to be considered in plant location selection problem and how they are applied to ABC Manufacturing Inc. Additionally, section 3.3 presents the result and analysis of this model (P. &. LH Chang, 2015). Setting a back-up plan that the new plant capacity can be shared among the global network of ABC Manufacturing Inc. to increase the resilience of the ABC Manufacturing Inc. is the main objective. Section 4 provides sensitivity analysis to this model with four different scenarios. In the result, all scenarios gave the same optimal location. This model that incorporates possible factors is designed for robust strategy considering the pandemic, which can be chosen depending on the priority of the organization. Finally, the future work of expanding the model to a more complicated global network are mentioned in this paper.

2. Literature Review

An in-depth literature review was carried out to determine the major factors that affect the overall supply chain significantly. Astudy of a mathematical AHP-OS model was performed keeping in mind the consistency ratio below 10% to get the best possible location inside the USA. A study conducted by (Randhawa, 1995) focused on how a wrong selection of a plant location might have an adverse effect on the entire transportation as well as the manufacturing line, leading to slower growth of the company. Also, a mathematical model that calculates all the Fixed Charges was crafted by (Balinski, 1965), that focused on lowering the stable and shipment cost for new location. A model developed by Church (1976) demonstrated the relation between progress and location efficiency. The determinants reflected access to other network nodes and were ranked uniformly high as the plant location determinants. In such case, the plants are not located primarily in multinational plant networks to take advantage of hedging against exchange rate risk or reducing the impact of trade barriers. Instead, it appears that the more important criteria for plant location involve the manufacturing mission or strategy that these plants are chartered to accomplish.

Additionally, this literature review focused on supply resilience. The need for integration with other plants concerning material flows, knowledge transfers, etc. could alter the location choice for plants relative to stand-alone independent plants. Multiple plant manufacturing should be understood as a system, providing insight into how different plant strategies require integration to different degrees and how this influences the plant location decision. and plant characteristics need to be understood relative to that system (Schmenner, 2001). We categorize plants as integrated plants when the plant has both a high level of material flows with other plants and a high level of managerial coordination. The variable groups with Factors and location determinant are summarized in the Table 1 (Brush, T. H., Marutan, C. A., & Karnani, 1999):

Table 1. Variable groups with Factors and location determinant (Marutan and Karnanani, 1999)

Variable groups	Factors	Determinant of Location
Network Nodes	Proximity of downstream nodes Proximity of upstream nodes	Proximity to important markets, Proximity to key customers, Proximity to key supplies, Proximity to other facilities
Access to factors of production	Access to raw materials and energy Access to labors	Access to raw materials, Access to energy, Access to capital, Access to local technology, Access to skilled labor
National and Regional Characteristics	Government policies	Access to protected markets tax conditions, Regional Trade barrier, Government Subsidies, Advanced infrastructure, Labor practices and regulation, Environmental regulation

3. Methodology

3.1 Model Description

Selecting a plant location is a complex decision. AHP can be effectively used as a supporting tool to understand and solve this problem. AHP allows for smaller inconsistencies in the judgment. Inputs can be actual measurements, but also subjective opinions. According to Tam and Tummala (2001), AHP can be used to arrive at consensus when involving several decision makers with conflicting interests. It involves multiple person and multiple criteria decisions. They use the AHP method to make sure the priority weights of all the data (Tam andnTummala, 2001). Purba and Sinhotang (2015) study useing the AHP method to build a decision support system that is used to assist government better decision making, solving problems with multiple criteria to benefit the whole village

There are four steps in this AHP analysis: Step 1 is to define the overall goal, which is finding optimal plant location; Step 2 is to construct the AHP hierarchy. Three tiers including overall goals, criteria, and alternatives should be constructed. Criteria are factors that affect the performance of the overall goal, which are proximity to market, government policy, regional characteristics, and resilience in this case. After setting up and testing the hierarchical model, the alternatives were defined. For our case study, due to limited scale of the resource, Dallas, Houston, Atlanta, and Nashville as selected the alternative locations. Sub-criteria are inserted between criteria and alternatives for more precise evaluation. It is used to specify a criterion to a more detailed level. Step 3 is to construct the pairwise comparison matrix A between factors and alternatives in each tier. To construct our base model, we will rank cost with the extreme importance (scale = 9) as compared to all the other level-1 factors. The scale of importance is as follows: 1 – Equal, 3 – Moderate, 5 – Strong, 7 – Very Strong, 9 – Extreme (Values 2, 4, 6 and 8 are used for in-between). Consistency ratio was checked with the help of online model developed by Goepel (2018). Step 4 checks the consistency and determines the best strategy based on the calculated weights.

3.2 Variable Selection

In the case study for ABC manufacturing Inc., a company in Electronics Manufacturing Services (EMS) sector, a comprehensive survey has been conducted among supply chain managers and strategy planning team. The following are the criteria and sub-criteria factors that have been chosen in the AHP model for the ABC Manufacturing Inc case study:

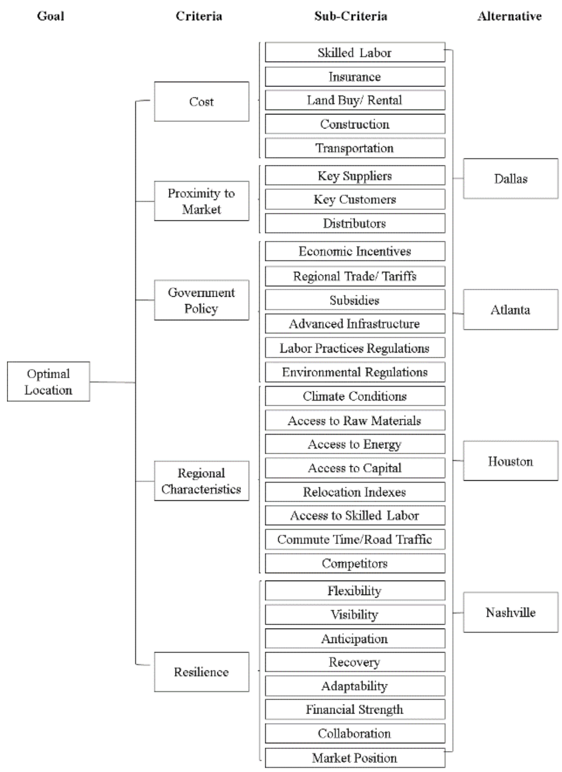

Figure 1. Selection of Variables

1. **Cost**: it includes a) labor cost, b) Insurance cost, c) Land purchasing cost, d) Construction cost. Choosing the lowest wage will reduce the personnel cost of a company, and the country will formulate different regulations insurance requirements and insurance amount, while Land purchasing cost is usually the largest portion in the fiscal budget for building a new plant.
2. **Proximity to market**: the proximity to important markets and proximity to key customers are considered important for domestic plant location. The determinants which reflect access to other network nodes rank uniformly high as plant location determinants.
3. **Government Policies:** these are important considerations for foreign location decision. As location and competitive strategy decisions become more intertwined, local governments increasingly need to view their community's attributes as a potential strategic resource within the overall strategic orientation of the firm.
4. **Regional characteristics**: firms believed to cluster in regions primarily because of demand, supply or other considerations. Agglomeration line of regional development research has contributed greatly to the understanding of location decisions.
5. **Resilience:** is the capacity supply chain ability to be prepared for unexpected risk events, responding, and recovering quickly to potential disruptions and return to its original situation. As mentioned in our literature review, the resilience of plant location is measure by following sub-criteria: a) Fexibility, b) Visibility, c) Anticipation, d) Recovery, e) Adaptability, f) Financial strength, g) Collaboration, and h) Market position.

4. Results and Discussion

To construct our base model, as it shows the AHP-OS model in Figure 2, we rank 'cost' with the extreme importance (ranking = 9) as compared to all the other level-1 factors (ranking = 1): proximity to market, government policy, regional characteristics, and resilience. The resulting priorities can be seen in Figure 3. The cost was given the highest importance.

Each of those factors resulted in the priority as 7.7%, which gives cost 69.2% priority. Therefore, it is evident that all the subfactors (level 2) which fall under cost will carry more weight in the final selection of the location. Dallas, Atlanta, Houston and Nashville are the four locations in the candidate list. All cost subfactors are regarded as equal importance with each other, so they are given the same weights. Other level-1 factors: proximity to market, government policy, regional characteristics, and resilience, are also given equal importance amongst the group.

Resulting Priorities

Cat		Priority	Rank
1	Cost	69.2%	1
2	Proximity to Market	7.7%	2
3	Government Policy	7.7%	2
4	Regional Characteristics	7.7%	2
5	Resilience	7.7%	2

Figure 2. Priorities with Level-1 Factors

Resulting Priorities

Cat		Priority	Rank
1	Skilled Labor Cost	20.0%	1
2	Healthcare/Insurance Cost	20.0%	1
3	Land Purchasing/Rental Cost	20.0%	1
4	Construction Cost	20.0%	1
5	Transportation Cost	20.0%	1

Figure 3. Priorities with level-2 factors of cost

As mentioned, the four alternative plant locations are Dallas, Atlanta, Houston, and Nashville. As shown in Figure 4, skilled labor cost for Dallas is more 'preferrable' as compared to Atlanta by a factor of 5. That means a strong importance is given to Dallas while comparing Dallas and Atlanta. For Dallas and Houston, the skilled labor cost has equal importance. All the four locations are rated accordingly, and their resulting priorities are calculated by the model. The ratings for each of the four locations with respect to all the thirty sub-criteria.

Figure 4. Rating to Skilled Labor Cost

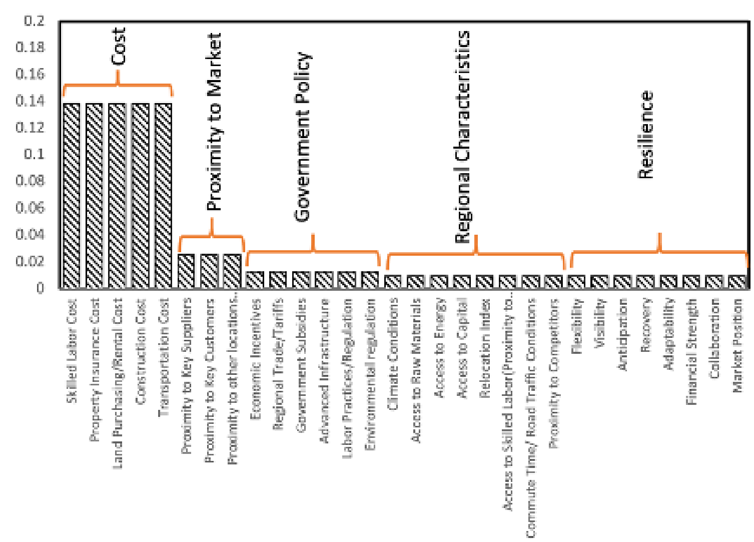

Figure 5. Global priorities for lowest cost model (Base Model)

The model will compute the global priorities for each of the thirty factors based on the rankings that were previously given. After that, these global priorities are compared with the resulting priorities of each of the four alternatives and scores for each location is calculated as shown in the Figure 6. The score is addition of the multiplication of each factor's global priority with each of the alternative's resulting priority. The Dallas location scored maximum with 0.377 and hence will be selected as the best location for that scenario.

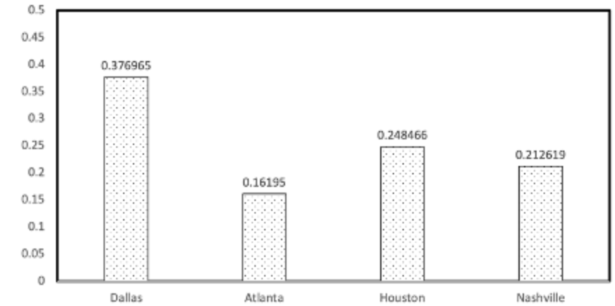

Figure 6. Consolidated Result (Base Model)

4.1 Sensitivity Analysis

In this case study, there are thirty variables, and their values can potentially change the result of the AHP model. The sensitive analysis aims to test if our 'optimal location' is still Dallas even if different weights are assigned to different level-1 and level-2 factors. Four different scenarios are analyzed as shown below:

Scenario 1: Most resilient location

Compared to all the other four level-1 factors, priorities will be 7.7% for cost, proximity to market, government policy, regional characteristics, and 69.2% for resilience. The impact of these factors on the alternatives is obviously going to remain the same but as assigned different weights are assigned to the level-1 factors, the score will continue to change. The consolidated result for this scenario is shown in Figure 7.

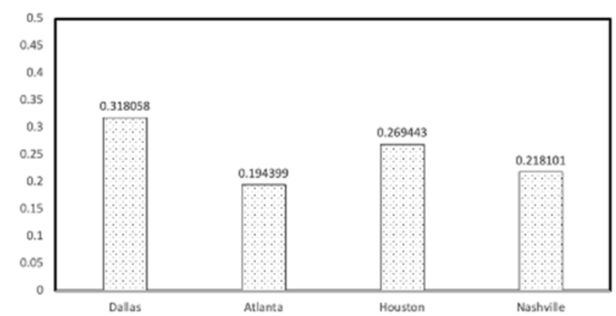

Figure 7. Resilient Model Result

Scenario 2: Government Policy Oriented

Given extreme importance to resilience comparing to any other factor. Similarly, in this scenario, extreme importance to government policy is given comparing to all other four level-1 factors. priorities results will be: 69.2% for government policy, and 7.7% for all other level-1 factors. The impact of these factors on the alternatives is obviously going to remain the same but as we assign different weights to level-1 factors, the score will continue to change. The consolidated result for this scenario is shown in Figure 14.

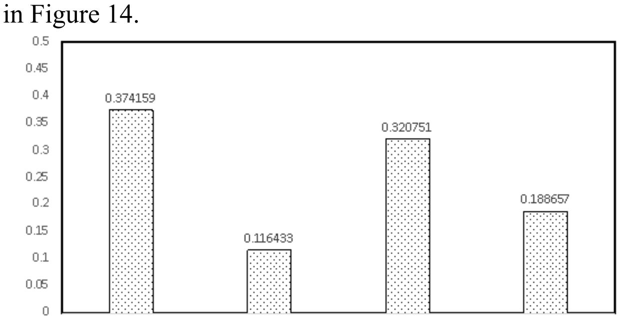

Figure 8. Policy-Oriented Result

Scenario 3: All level-1 factors with equal importance

Extreme importance to government policy is given comparing to other factors, while keeping all level-1 factors on the same level of importance. The resulting priorities are 20% for: cost, proximity to market, government policy, regional characteristics, and resilience. The impact of these factors on the alternatives is obviously going to remain the same but as we assign different weights to the level-1 factors, the score is going to change. The consolidated result for this scenario is shown below in Figure 9.

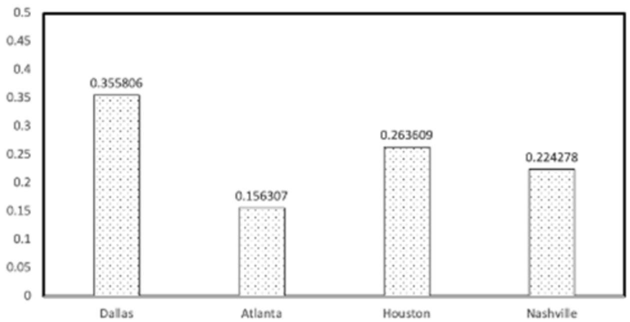

Figure 9. All Level-1 Factors Equal Result

Scenario 4: All level-2 factors with equal importance

In this scenario, all level-2 factors are given the same importance. The resulting priorities for level-1 factors will be proportional to the number of subfactors each one has. Therefore, the resulting priority will be: 16.7% (=3.33% *5) for cost, 10% (=3.33%*3) for proximity to market, 20% for government policy, and 26.7% for regional characteristics and resilience as each of these categories have 8 level-2 factors. The impacts of these factors on the alternatives are obviously going to remain the same but as we assign different weights to the level-1 factors, the score is going to change. The consolidated result for this scenario is shown in Figure 10.

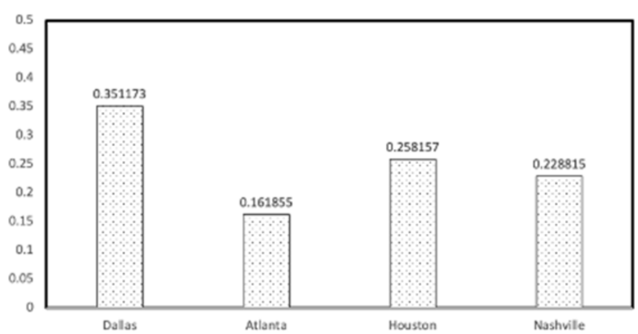

Figure 10. All Level-2 Factors Equal Result

According to all scenarios, “Dallas” is the “optimal location”, even when changing the global priorities from values as low as 1% to as high as 13.2%. There is no significant change in the result of different scenarios, therefore the model is robust. All simulation scenarios were performed using the online AHP-OS software as shown in figure 11.

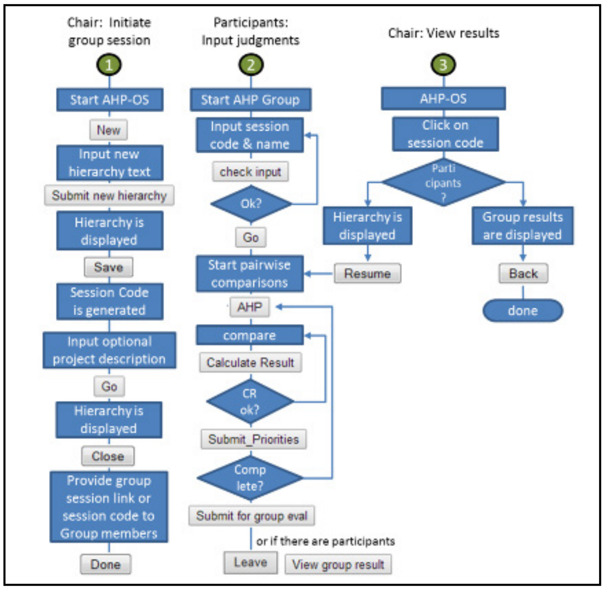

Figure 11. Flowchart for AHP-OS Software.

5. Conclusions and Future Work

The AHP model has proven to be effective in selecting the location for new manufacturing plant. Our model incorporated conventional factors that have been considered traditionally in the literature as well as 'resiliency' a relevant factor in this COVID-19 era that we live in. We did modify the factors for a company in Electronics Manufacturing Services (EMS) sector – ABC Manufacturing Inc. Adding 'resilience' factor in the model helped the company validated the model to account for unforeseen circumstances. The model developed for ABC Manufacturing Inc. was tested in five different scenarios including the most cost-effective model with four different alternatives and every single time the result was 'Dallas' as the best location. The robustness of the model was checked with sensitivity analysis. The proposed model can not only be used for an Electronics Manufacturing Services company but can be applied to any manufacturing company by altering some of the factors and rating the locations in contention according to the chosen factors. The model can also be used by business development managers to check if the new location that the company is considering is worthwhile. The researchers are encouraged to modify the weights of different factors as per their need.

The current model encompasses the parameters for a particular company in an EMS sector. The model can be expanded by adding criteria that are more suited for a particular company in contention. The model can also be run for more focused scenarios such as optimizing fixed cost or optimizing variable cost. The locations were gauged by an experienced individual with vast geographical experience. This can also be expanded to multiple surveyors and the survey can be given a weight depending on the experience or quality of the surveyor. The hierarchy model can be sent out to multiple or all the managing directors to get the opinions of the entire board before selecting a location. The researchers can include more than four locations if the resources are available. One of the other complexities that can be added to the model could be the presence of existing locations for ABC Manufacturing or any other company that the evaluator is considering. The model then can be used to balance the supply-demand ratio of the global supply chain as well as potentially find if there is a need to invest and start a new location which can potentially save the lead times and lower the burden on one plant.

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