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Analysis of facility location model using Bayesian Networks

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ABSTRACT

In this study, we propose an integrated approach that combines Bayesian Networks and Total Cost of Ownership (TCO) to address complexities involved in selecting an international facility for a manufacturing plant. Our goal is to efficiently represent uncertain data and ambiguous information, and to unite them to improve the quality of the decisions. Bayesian Networks provide a framework to elicit information from experts, and provide a structure guide to efficient reasoning, even with incomplete knowledge. Our method is presented in a hierarchical structure so that it can be decomposed into the forms of more manageable units. We consider many tangible and intangible facility location criteria, then these criteria are grouped into few numbers of factors. These factors are then combined to form a cost perspective using the essentials of TCO.

1. Introduction

The location decision describes, given a set of alternatives, the problem of where to locate an organization's facility (Melo, Nickel, & Saldanha-da-Gama, 2009). Since this decision is strategically important, it has a significant impact: the company's overall success is directly related to the sound decisions on facility location. Over the long-term, location decisions affect every aspect across the organization, so that any poor location decision will result in excessive costs, poor customer service, disappointed workforce, and failure of the organization strategy as well as loss of competitive advantage (Canbolat, Chelst, & Garg, 2007; Stevenson, 2009).

In our study, we focus on the global facility location decision for a manufacturing firm. The numbers of companies that adopt globalization as an organizational strategy have increased in last two decades. Organizations are enthusiastic to work overseas for several reasons: expanding current market, spreading foreign exchange risks, attracting talented workforce, working with capable suppliers, and learning from foreign customers, suppliers, competitors and foreign research centers, as well as savings due to reduced taxes, labor, transportation, and labor costs, incentives and capital subsidies (Ferdows, 1997). In consequence, the question of identifying a best geographic location for facilities has gained attention from both researchers and businesses.

In this study, we propose a novel and integrated approach that combines a Total Cost of Ownership (TCO) approach with a Bayesian Network for selecting an international facility for a manufacturing firm. We analyze the facility location problem from a holistic view that addresses numerous qualitative and quantitative criteria and their effects on different cost items in probabilistic cause-effect relations. Bayesian Networks facilitate modeling of causality in an efficient, intuitive, and transparent way, and the available graphical probabilistic structure allows the user to account for uncertainty and ambiguous domain knowledge within the problem context.

Cost elements that are selected as final measures for comparing different alternatives are not limited to investment costs unique to the location; included are all the costs related to the life cycle of the facility that can vary based on the selected facility. This Total Cost of Ownership approach (TCO) aims to evaluate true cost of the location decision and provide a better estimate of total costs while comparing different alternatives. This approach provides us an opportunity to combine numerous qualitative and quantitative factors by considering the effects on different cost elements that are critical to the location decision. The proposed combined technique will simultaneously tackle both monetary and non-monetary criteria and combine them to create a thorough and accurate measure that takes into consideration all of the costs that are relevant to these selection criteria.

Significant amount of facility location criteria are uncertain and can easily fluctuate before and after decisions have been made (Snyder, 2006). Therefore, it is critical to clearly model the uncertainty in each facility location criteria and their effects on different cost elements. A key problem has been addressing the influence of each criterion on the long horizon, so an explicit representation of uncertainty has gained significant importance. Failure to precisely represent and understand these uncertainties results in strategic mistakes that are difficult to overcome. Human subjective judgment is critical in this task, especially if the decision makers need to make an assessment when there is limited and incomplete data.

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Therefore, there is a requirement for a complete and efficient method to encode human belief to analyze different alternatives under this uncertain and complex environment. The proposed method allows exploring and directing judgment and managers' opinions by following a systematic approach while globally considering all the relations among factors, as well as between factors and cost measures. Bayesian Networks have a high potential to efficiently facilitate incorporating, representing, and propagating the uncertain and ambiguous information.

A Bayesian Networks (BN) approach offers several distinctive features that are useful in our facility location decision analysis. First, BN builds on causality that provides useful insight and intuitive understanding. This feature is particularly important in our case since it will assist to model the relationships between facility selection criteria and their effects on cost elements. Second, BN allows us to incorporate subjective information of the decision makers. This domain information is considerably useful when the data is limited, and human experience is significant. Third, BN can combine historical data with human knowledge while drawing conclusions for the problem at hand. In a facility location decision, some of the information and degree of uncertainty can be learned from historical data such as currency and inflation rates. However, human inputs are required for a significant part of the selection criteria and their effects on the cost elements. BN can unite these two different sources of information. Fourth, BN allows us to model uncertainty by defining probability distributions over the random variables. Modeling uncertainty by plain probability assessments provides compactness and explanations for variability and risks involved in decisions. Finally, BN facilitates reasoning by providing efficient inference algorithms. Even when the information is incomplete and the knowledge of an expert is limited, BN allows us to draw conclusions even in poorly defined environments. This feature also allows the sensitivity analysis to understand the degree of variability that caused by the different selection criteria. This provides explanations for the responsibility of each factor for the company's overall success.

The proposed approach consists of mainly four steps: one, identify the selection criteria, factors and cost elements that are significant for global location decision; two, determine the structure by building relations among the selection criteria and factors, and among factors and cost elements; three, construct conditional and unconditional probabilities and collect alternatives; four, make decisions. Fig. 1 shows the model elements in a hierarchical view. The uncertainties related to facility location are conceptualized by the data and human judgment. For example, the uncertainty involved in current and future inflation rate and demand may be addressed by analyzing the historic data. The overall mean and variability can be parameterized by the existing data. On the other hand, for some factors the decision maker may have inadequate information due to a lack of historical data. However, the incomplete knowledge of the decision maker due to vagueness in the selection criteria is still critical and needs to be included in the analysis. BN has the potential to combine existing data with incomplete expert knowledge.

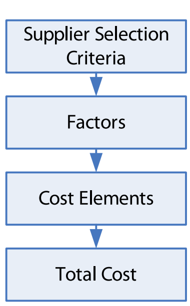

Fig. 1. Hierarchical view of model.

The remainder of this paper is structured as follows. In Section 2, the relevant research is presented concerning the global facility location. Section 3 provides a short overview of BN. The proposed model and its details are explained in Section 4. The model is then tested and a manufacturing sector illustrative example is presented in Section 5. The last section presents a summary and conclusion of the proposed method.

2. Literature review

For years, the complexities and risk of facility location has attracted a great deal of interest from both academia and industry, generating a wide variety of approaches and methods, and each having its own objectives and attributes. (For details, readers are referred to comprehensive reviews in facility location by Owen and Daskin (1998), Goetschalckx, Vidal, and Dogan (2002), Bhutta (2004), Klose and Drexl (2005), Meixell and Gargeya (2005), Snyder (2006), Sahin and Süral (2007), ReVelle, Eiselt, and Daskin (2008), Melo et al. (2009), and Farahania, Seifi, and Asgaria (2010)).

Our focus is global facility location modeling. The literature for this can generally be divided into two groups: one that presents and describes facility location factors, importance and steps of international facility decisions (Canel, Khumawala, Law, & Loh, 2001); one that attempts to quantify and model the problem.

In the first group of studies, researchers discuss the overall environment in facility location decisions. MacCormack, Newman, and Rosenfield (1994) highlight the importance of qualitative factors in global site selection. They analyze the effects of technological advances and new production systems on shaping the future strategies of global corporations. They conclude that these expansions will increase the requirement for flexible and decentralized plants so the sophistication of the location owing to regional infrastructure and quality of labor will be vital on location decision. Hoffman and Schniederjans (1994) developed a two-stage model that uses goal programming for global site selection. In the first stage, numerous environmental factors are identified that are country-specific, and in the second stage, goal programming is used to select a site that has close fit with the organization's overall strategy. Ferdows (1997) highlights the importance of foreign facilities to utilize a source of competitive advantage. He emphasizes the fact that if managers consider manufacturing as a competitive advantage, they have gained more from their overseas factories by achieving low costs and high productivity. MacCarthy and Atthirawong (2003) provide a survey and explanatory study to describe the importance of different global facility location criteria using the Delphi study. They identified cost, infrastructure, labor characteristics, government-political, and economic as top significant factors in the global facility location decision. Lee and Wilhelm (2010) provide explanations to the facility location problem from an international economics perspective by considering and relating comparative advantage, competitive advantage, and competitiveness of country; and discuss the measures in two popular competitiveness reports, the Global Competitiveness Report (GCR) and World Competitiveness Yearbook (WCY).

In the second group, different quantitative models are used including stochastic programming, mixed-integer optimization, transportation, multi-attribute utility theory, analytical hierarchy process, analytical network process, goal programming models, and combined approaches including fuzzy logic and sets. Min (1994) used the multi-attribute utility theory approach to selecting an international supplier, taking into account many quantitative and qualitative criteria such as trade restrictions, cultural and communication barriers, quality, risk, and financial and service performance.