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Combining decision tree and MAUT for selecting a country for a global manufacturing facility

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Abstract

The paper presents a multi-phase approach for selecting a country in which to locate a global manufacturing facility. An influence diagram is used to frame the decision. A decision tree then analyzes uncertainties regarding cost and generates a risk profile. The risk profile becomes one of the measures in an MAUT model that incorporate a wide range of factors. This sequential approach of using the output from a decision tree as input to MAUT is demonstrated with an example involving an auto supplier locating a new plant in one of five countries. Three decision makers were interviewed to determine the weights and the shape of the individual utility curves. The paper identifies, clearly defines, and incorporates a variety of measures for which national data are readily available. This list is broader and less subjective when compared to other examples reported in the literature.

Keywords: Decision support systems; Location; Multicriteria; Risk

1. Introduction

Business globalization has led to global manufacturing [1]. There are many reasons why companies establish manufacturing facilities in other countries, among them: tariff and trade concessions, cheap labor, capital subsidies, reduced costs, shorter distances to customers and/or suppliers, ability to attract skilled labors, and opportunities for creating new Research and Development (R&D) centers [2].

Global facility location decisions are vital for firms, since the establishment of a new facility is a costly, time sensitive project, and it can influence the global productivity and competitive performance of a multinational company for decades [3–5].Thus, the challenge of facility location problems has attracted the attention of researchers in many disciplines, including economics, industrial engineering, and geography [6].

This paper presents an integrated modeling concept that brings together a decision tree and multi attribute utility theory (MAUT) in a three-phase approach. In the first phase, an influence diagram is used to frame the global site location problem. The second phase uses a decision tree to analyze uncertainties regarding cost and generate a cumulative risk profile. The risk profile is then incorporated as one of the measures in a multi-criteria decision model. The MAUT model enables the consideration of factors that have different measures and different relative importance to the decision. In addition to this three-phase approach, the paper makes a contribution toward clarifying and creating a variety of measures that a decision maker can research and use when comparing country locations. The methodology is not context specific and could be applied to the location of any type of facility that manufactures a component or subsystem. The objectives and measures included in the model are equally applicable to almost any sophisticated

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manufacturing environment in which issues such as level of workforce education, supplier reliability, and national infrastructure are important. We demonstrate the approach with an illustrative example involving the placement of an automotive brake manufacturing facility in one of five countries on four continents. Specifically, we used financial data for an automotive brake manufacturing facility and developed weights by interviewing automotive supplier managers.

2. Literature review

Facility location is a broad area of continuing model development and research. The models generally emphasize finding an optimal solution and use transportation/assignment, linear, integer, and goal programming to minimize cost or distance [7–9]. Manne [10] was one of the first to add uncertainty to the facility location problem. He developed a stochastic model for the problem of capacity expansion over an infinite horizon so as to minimize the sum of discounted installation costs. Current models [11–13] incorporate a wider range of uncertainty that include quantity and location of demand, investment, capacity, labor, and transport costs.

Huchzermeier and Cohen [14] developed a stochastic dynamic programming formulation to solve a global facility location problem. Their model maximizes the expected present value over a planning horizon through exploitation of operational flexibility contingency on exchange rate realization and considers plant capacity and customer demand satisfaction. Vidal and Goetschalckx [13] used mixed integer programming (MIP) to examine the effects of uncertainties in transportation, demand, supplier reliability, and exchange rate. They found that exchange rate fluctuations may have a significant impact on cost. Lowe et al. [15] studied how movements in inflation and exchange rates impact the location and capacity decision using scenario analysis. Their paper introduced a pairwise stochastic comparison and illustrated how excess capacity can provide location flexibility by allowing a global company to switch production among different manufacturing facilities as relative cost changes over time. Owen and Daskin [4], Schniederjans [16], and Goetschalckx et al. [17] provide a comprehensive review of the facility location modeling approaches that focus on economic issues.

A global decision maker will consider both qualitative factors and quantitative factors [3] when deciding in which country to locate a major new manufacturing facility. Multi-criteria decision models have been used in a wide range of facility context decisions, such as for airports [18], convenience stores [19] power plants [20], libraries [21], hospitals [22], and noxious facilities [23]. Many researchers have applied multi-criteria models to the plant or manufacturing facility location problem in a global context. These researchers apply a variety of approaches: Schniederjans [16] and Heizer and Render [24] used a simple rating and scoring model. Badri [25], Yang and Lee [6], and Yurimoto and Masui [26] created an Analytical Hierarchy Process (AHP) model (see Table 1 for summaries of these studies). Qualitative studies on global location selection usually evaluate only a few alternative facility locations. Hoffman and Schniderjans [8] and Badri [25] applied goal programming and Arentze et al. [27] developed an expert system. We review each of these studies below.

Schniederjans [16] and Heizer and Render [24] used a rating and scoring method to select a global facility location site. This method evaluated each country's score using an arbitrary 1 (bad) to 5 (good) rating scale for each location selection factor. The country with the highest total points is selected for the location. When the factors under consideration are not equally important, a mathematical weighting factor is added to the procedure. The ratings and weighting factors were assigned subjectively.

Badri [25] offered an AHP approach to evaluate six possible locations from six Middle Eastern countries for a petrochemical company. There were four criteria for the AHP process: the political situation in the country, global competition and survival, government regulations, and economic factors. Important global site location factors such as availability of labor and labor skill were not included in his study. In addition since all of the countries were from the same geographic and cultural region, the range of issues considered was relatively narrow.

Yang and Lee [6] used a more comprehensive set of location factors while evaluating three potential sites by taking into account the market, transportation, labor, and community factors from major categories of objectives. Each factor was disaggregated into three subfactors. Simulated data that were developed from several location problems were used for the AHP decision process. Some important facility location criteria such as country stability [2,5] supplier reliability, and so forth were not included.

The paper by Yurimoto and Masui [26] involved many global location factors and measure levels. The paper examined the Japanese manufacturers' decision system for overseas plant location, and identified different location factors for selecting countries and sites within a country. Five major factors were identified for country selection process: labor, markets, transportation, financial inducement, and living conditions. The problem was analyzed from a Japanese perspective and the authors used an AHP model to evaluate the countries and then the sites within the selected countries.

Hoffman and Schniderjans [8] used goal programming to develop a facility location selection model on a global scale. Their paper applied the model to a case study involving the selection of a facility site in Europe for a US brewery expansion, using a two-phase process. The first phase evaluates twenty potential European countries so as to determine which country offers the best environmental expansion. The assessment of each country is based on eight criteria: demand in the country, total competitive capacity,

Table 1
Relevant global location modeling literature review

Reference	Solution procedure	Objectives	Measures	Comments
[13]	MIP	Cost	Total cost Transportation; Demand	Used MIP. Examined the effects of uncertainties in transportation, demand, supplier reliability, exchange rate
		Uncertainty	Supplier reliability; Exchange rate	
[15]	Scenario analysis	Cost	Manufacturing cost; Packaging cost	Studied the impacts of inflation and exchange rates on the location and capacity decision
		Uncertainty	Exchange rate; Inflation	
		Design capacity	Production; Sales	
[24] and [16]	Rating and scoring method	Technology (Not included in [16])	Rate of technology change Innovations in process design	Used rating method. Didn't consider cost. Very subjective method.
		Level of education (Not included in [16])	Number of skilled workers National education rate	
		Political and legal aspects	Stability of government Product liability laws; Expert restrictions	
		Social and cultural aspects	Similarity in language; Work ethic	
		Economic factors	Tax rates; Inflation Availability of raw materials Interest rates	
[6]	AHP	Market	Market growth potential Proximity to market Proximity to raw materials	Showed application of an AHP method for site selection using a hypothetical example.
		Transportation	Land transportation Water transportation Air transportation	Used 12 location factors. Measure levels not identified. Didn't involve important location factors such as stability, supplier reliability.
		Labor	Cost of labor; Skilled labors Availability of semi-skilled labor	
		Community	Housing; Education; Business climate	Cost factors not analyzed.
[26]	AHP	Labor	Unemployment rate Number of blue-collar employee Number of registered engineers Ratio of high school students Average wage per employee Rate of unionization Loss-time rate by work stoppage	Examined the Japanese manufacturers' decision system for overseas plant location. Used two stage location selection process: country selection and site selection within the country. Identified measure levels.
		Markets	Proximity; GDP; Number of Japanese firms; Proximity Number of manufacturers	Used an AHP method for site selection decisions. Calculated the means of
		Transport	Railway freight transport volume Airlink freight transport volume Seaport freight transport volume Density of trunk road	preference weights for measures for 14 companies. Measures are from Japanese companies perspectives.
		Financial inducement	Corporate income tax Number of financial inducement Degree of country risk	Developed measures to differentiate developed European countries (regional).
		Living conditions	Number of Japanese Number of facilities Number of criminal offences Consumer price index	Didn't include uncertainties. Less calculation for the minimization of total cost.
[8]	Goal Prog.	Maximize the value of new facility	Demand in the country Total competitive capacity Average price per square foot Growth rate of market Number of potential facility sites Accessibility to suppliers Labor costs; Property tax rates	Evaluated twenty European countries using goal programming. Did not involve uncertainty.

average price per square foot, growth rate of market, number of potential facility sites, accessibility to suppliers, labor costs, and property tax rates. Once a country is selected, the second phase of the model evaluates all available facilities within the country and chooses the best one. Dasci and Verter [28] used mathematical programming to optimize plant location, capacity acquisition, and technology selection in a multi-commodity environment. These models did not involve uncertainty nor do they capture the broad differences in a number of critical factors when considering more disparate countries around the globe.

In this paper, we present a decision tree that is used to capture cost uncertainty that results from randomness in exchange rates, inflation, and productivity growth as input to an MAUT model. Interestingly, none of the multi-criteria papers cited above apply MAUT to the global facility location. This may be the result of a perceived difficulty in defining measures and gathering data when comparing countries. As part of the MAUT model development, this paper provides a detailed discussion of goals and measures and identifies standard sources for the data.

3. Integrated approach (Decision tree and MAUT)

This paper offers an integrated approach for the global facility site selection decision. The integrated approach consists of three phases (Fig. 1). In the first phase, the location problem for the auto supply company is modeled using an influence diagram. The influence diagram displays the uncertainties, their influences on global location factors, and the overall structure of the problem, and it helps to improve communication among the decision makers [29]. In phase two, uncertainties regarding costs are analyzed, and a cumulative risk profile is developed through a decision tree. In the third phase, MAUT is used to evaluate alternatives.

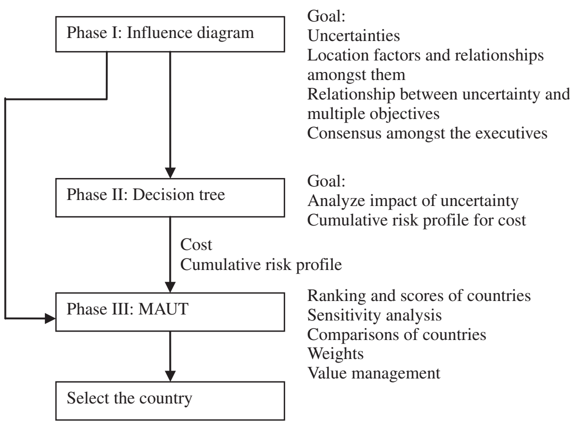

Fig. 1. Solution process of the global location model.

3.1. Model of the problem

An illustrative example is used to demonstrate our global location model in which we used real data and interviewed SMEs from a global auto supplier to define the relative importance of the objectives. In our example, a hypothetical auto supply company is evaluating potential plant location sites in five countries from diverse regions and with diverse economies: Mexico, the Czech Republic, Poland, South Korea, and South Africa. These five countries were initially selected since they offer low manufacturing costs and meet minimum selection requirements for achieving the corporate quality standard and concerns about protecting intellectual property. The new plant will manufacture auto brake components and systems. The company assumes that it will initially invest between 210 and 250 million dollars and hire 400 employees for the brake plant. The facility is to serve America, Europe, and Asia-Pacific, in addition to the local market. The goal is to select a site for a new facility in order to maximize the total value.

3.2. Phase I: structuring the problem

An influence diagram model was formulated to structure the problem. An influence diagram is a graphic structure for modeling uncertain variables (ovals), decisions (squares), and goals (rounded rectangles and a diamond) and explicitly revealing the flow of information [30,31]. The concise representation of the factors and uncertainties in a single diagram is useful in interviewing, brainstorming, and developing a consensus among the decision makers [32,33].

The objectives and the uncertainties for this decision are based on an extensive literature review and represented in an influence diagram (Fig. 2). The primary decision is to select a location site for with the ultimate goal of maximizing the total value. A sub-objective is to minimize the total cost, a major reason for opting for an emerging market facility location in the first place [2,3,34]. In this example, total cost consists of the initial investment and labor cost for the next four years. In our example, other important costs (e.g., transportation, tariffs, material) are almost the same since the new plant would serve the global market. Government incentives regarding taxes, energy, and so forth are considered in the initial investment cost. We therefore, left out other cost factors in this example but they are easily incorporated in the model. Total cost is influenced by uncertainties in exchange rate, inflation, and productivity improvement.

A broad objective to be maximized relates to geography and location and includes such factors as available labor force, regional sales market, infrastructure of the country, and membership in a free trade agreement. One of the most important concerns of automotive executives as they seek cost advantages for manufacturing components and subsystems overseas is to maintain the quality of their product. Problems with quality can interrupt the supply chain and

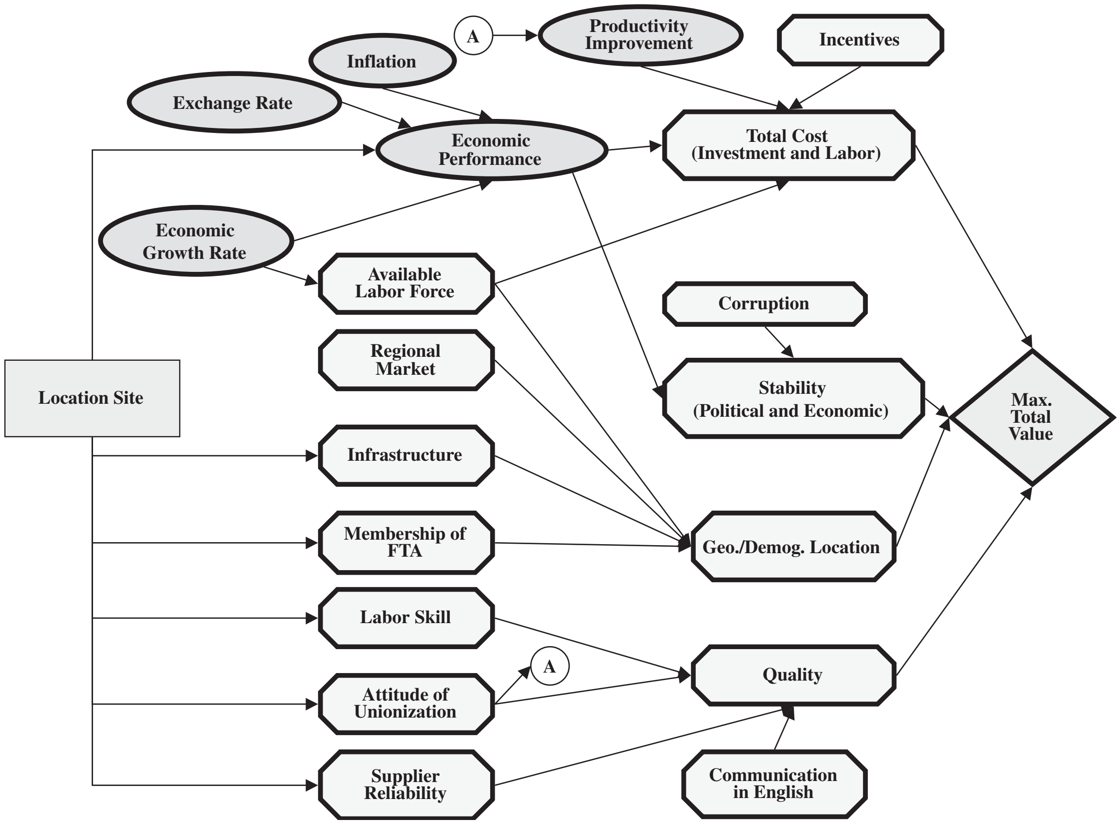

Fig. 2. The influence diagram.

put production at risk or, if discovered too late, can lead to an expensive recall. (The high cost of a recall is unique to the automotive industry because of government requirements. One safety related defect per ten thousand vehicles could lead to a recall of every vehicle sharing the same part and cost hundreds of millions of dollars to inspect and/or repair.) The maximized quality objective is influenced by labor skill, attitude of unionization, local supplier reliability, and English communication skills. This formulation explicitly incorporates the union environment as both labor strife and the converse, labor cooperation, can make or break the company. Associated with each objective is a specific measure as described in Fig. 3 (ovals). Data to describe each of the countries on each of the measures is readily available in the public domain [35–46].

3.3. Phase II: generate cumulative risk profiles through a decision tree

The next step translate the descriptive model into a two-step analytic process. Step one uses a decision tree to create a risk profile associated with each country's cost structure. The decision tree captures the three primary uncertainties, the inflation rate, the exchange rate, and productivity improvement.

However, a tree structure does not by itself explain how these three factors are combined to determine the cost. The model starts with a country's current unit labor costs, L_j, and adjusts it annually by compounding an adjustment factor A_j.

$$A_j = i_j - e_j - p_j, \quad (1)$$

where i_j is the annual inflation rate in country 'j' (4-year average), e_j the annual increase in exchange rate in country 'j' (4-year average) and p_j the annual improvement in productivity in country 'j' (4-year average).

A country's total four-year labor cost, TLC_j, for a plant projected for a four-year time horizon is

$$\mathrm{TLC}_j = L_j * \{(1 + A_j) + (1 + A_j)^2 + (1 + A_j)^3 + (1 + A_j)^4\} * N \quad (2)$$

where N is the total number of employees.

To understand Eq. (1), consider a US firm setting up manufacturing in Mexico. If the currency of Mexico (Peso) gets weaker, i.e., e_j increases when compared to the US dollar, then the US firm will benefit from that change. But if the Mexican Peso gets stronger, and thus e_j decreases, then the

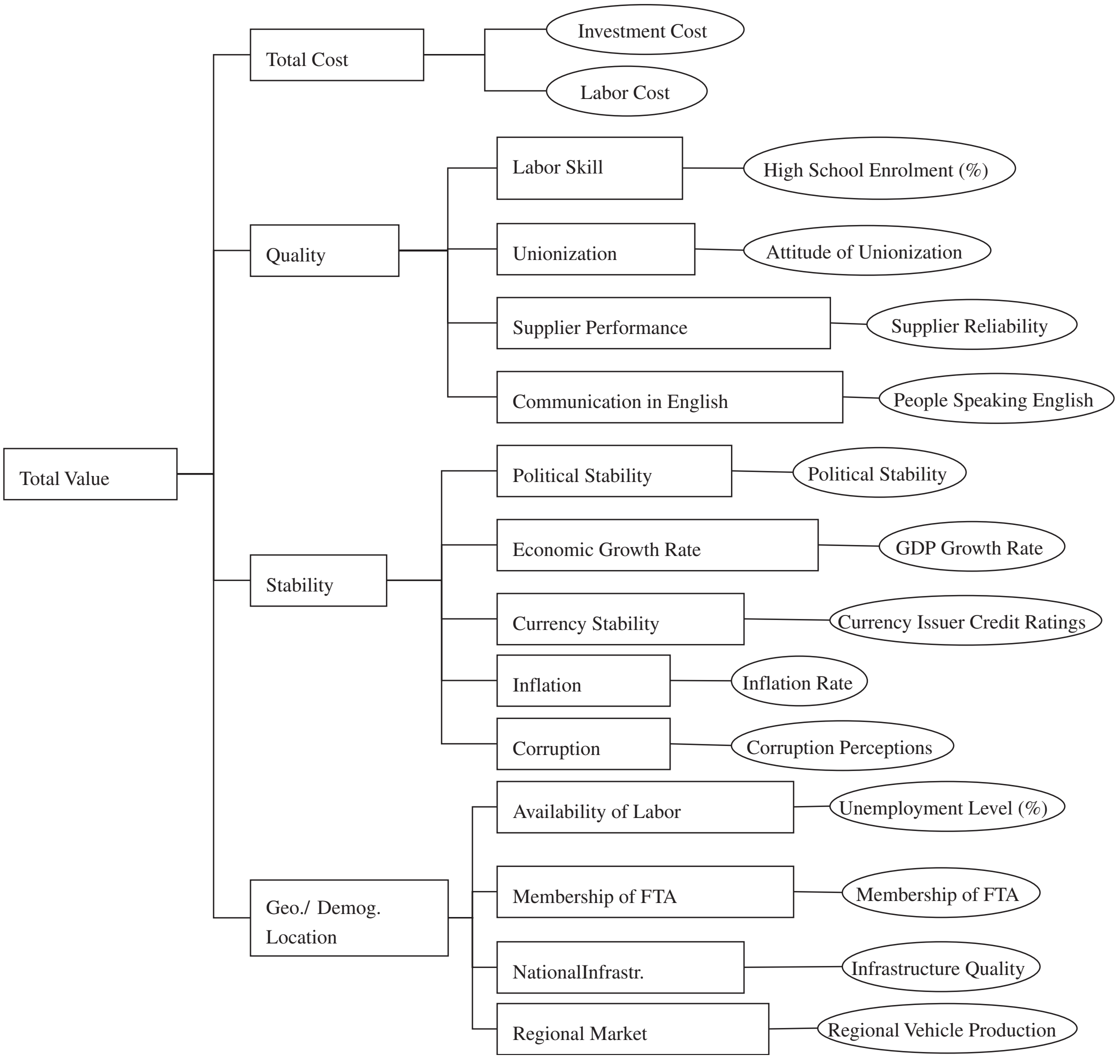

Fig. 3. Goals hierarchy.

competitiveness of the US firm will decrease, as they will have to pay more for the same operations. Similarly, an increase in inflation, without a countervailing decrease in currency, will result in increased real labor costs. With regards to productivity, increased productivity results in growth in output and thus the real labor costs will be reduced. Eq. (2) represents the total four-year cost by compounding a four-year average change in inflation, currency, and productivity.

For the purposes of this paper, we reviewed fifteen years of data on each measure for each of the five countries. Fluctuations around the fifteen-year average were used to create a three-point approximation based on the Pearson–Tukey method [47].The method uses the median and the 10th and 90th percentiles and assigns a 0.40 probability to the median and 0.3 to the two extremes. The data for the five countries are in Table 2. South Africa has the highest forecasted average inflation rate but the range is relatively narrow. In contrast, there is a high level of uncertainty regarding the forecasted inflation rate in the Czech Republic. Annual productivity gains are forecasted to be highest in the Czech Republic and South Korea, three times as high as in South Africa. Poland and Mexico are forecasted to have minor increases in productivity. The productivity measure includes relatively little uncertainty in its forecast. Last, the exchange rate is the most volatile of all of the measures. In every case except South Korea, the range from low to high is more than 25%.

The baseline first-year total labor costs for each country are listed in Table 2. South Africa and Poland have the lowest labor costs, under $3 per hour. South Korea is at the other end of the spectrum, with labor costs approaching $9 per hour. As a result, South Africa and Poland have at least a $6 million labor cost advantage for the first year of operation of the proposed 400-worker automotive component plant.

Table 2
Data for five countries

Inflation	Inflation [45]			Productivity [46]			Exchange rate [48]			Labor cost [49]
	Low (30%)	Medium (40%)	High (30%)	Low (30%)	Medium (40%)	High (30%)	Low (30%)	Medium (40%)	High (30%)	
Poland	4	5	7	3	3.5	4	3.5	4	5	$2,564,506
Czech	4	6	8	8	8.9	10	31	32	38	$3,201,210
South Korea	1	1.5	3	7	7.7	9	1225	1250	1400	$8,547,782
South Africa	6	7	8	1.5	2.3	3	10	10.5	13	$2,211,744
Mexico	5	6	7	4	5.3	6	9	9.5	12	$4,146,368

Table 3
Cumulative risk profile for labor cost

Country/cumulative probability	0	0.2	0.4	0.6	0.8	1
Mexico	7.7	10.5	14	17.5	22.6	29.1
Czech Republic	7.40	8.52	11.1	14.13	17.94	20.16
Poland	4.62	5.13	7.73	8.48	11.27	12.32
South Korea	18.1	20.1	26	30.7	38.9	42.3
South Africa	4.92	5.26	8.29	9.15	13.71	14.44

The risk profiles are the basic output of this phase and will be used as input in the multi-attribute analysis in the next phase. Palisade precision tree software was used to build the decision tree. Risk profile in tabular format is presented in Table 3. In terms of labor cost, South Korea is stochastically dominated by the other alternatives. In South Korea and Mexico uncertainty in productivity, inflation, and exchange rates results in a labor cost range that exceeds $20 million. For example, in South Korea the four year total labor costs ranges from a forecasted low of $18 million to a high of $42 million. In contrast, in Poland and South Africa the range in labor costs is only $8 million dollars as a result of uncertainty. These latter two countries also dominate all other alternatives with regard to total labor costs.

3.4. Phase III: multi attribute utility theory

In this section, we apply MAUT to structure the multi-objective decision. MAUT, when compared to AHP, has the advantage and disadvantage of tending to be more data intensive and structured with regard to its measures and scaling. It is a disadvantage in that the process of creating measures and scales can be complex and it may be difficult to find good data. However, this added structure enables a decision maker to perceive the strengths and weaknesses of the various alternatives. While AHP operates on a ratio scale, MAUT works on a range scale. The final score of an alternative has definite meaning as compared to an ideal with a score of 1. This insight is critical to the development of hybrid alternatives that may be better than any of the original list of alternatives. One major thrust of this section of the paper is to provide measures and scales that are prerequisite for the application of MAUT and demonstrate that the data are available to populate an MAUT model. MAUT also has the advantage that it can explicitly incorporate the quantification of uncertainty.

3.4.1. Objectives and measures

The set of objectives and measures (also called "attributes") was derived through an extensive literature review. Fig. 3 shows the structuring of the global site selection problem into a goals hierarchy of four levels. The ultimate or overall goal of the company is to maximize total value as decomposed into four sub-objectives: minimize total cost, maximize product quality, maximize country stability, and maximize the geographical and demographical location. At the third level, these goals are further decomposed and finally, at the lowest level each objective is associated with a specific measure. Table 4 presents each measure and its corresponding scale.

Minimize total cost objective consists of two readily understandable components, labor and investment. Although it is possible to combine these two values into net present value, in reality decision makers treat these as two separate measures to be traded-off. The unit of measurement is millions of dollars. The cumulative risk profile in Table 3 that is generated using decision tree is input for labor cost in MAUT. Thus, MAUT includes uncertainties regarding exchange rate, inflation rate and productivity through risk profile.

Maximize product quality is linked primarily to a number of surrogate factors that describe the workforce and also

Table 4
Measure levels

	Best				Worst
Country measures	1	2	3	4	5
High School Enrollment	80–100%	65–80%	50–65%	Less than 50%	
Attitude of unionization	Co-operative: never work stoppage	Work stoppages less than once a year	Work stoppages more than once a year—infrequent short strike during contract negotiations	Highly organized and aggressive union, frequent work stoppages and strikes at negotiations.	
Supplier reliability	High quality, on time delivery	High quality, late delivery	Moderate quality, on time delivery	Low quality, late delivery	
Political stability	No impact of government changes on business, No threats for long term stability	Less impact of government changes on business, Less threats for long term stability	Likely impact of government changes on business, Likely risk of insurgency, Long-term threats to stability		
Membership of Free Trade Agreement	Member of NAFTA, APEC	Member of EU	Member of APEC	South Africa-EU FTA	
People Speaking English (%)	More than 40% (Very High)	30–40% (High)	20–30% (Medium)	10–20% (Low)	Less than 10% (Very Low)
Currency issuer credit ratings (S & P)	A−	BBB+	BBB−		
Unemployment level	More than 30% (Very High)	10–15% (High)	5–10% (Medium)	0–5% (Low)	
Infrastructure Quality	Excellent transportation, communication, energy services readily available	Normally good services but specific shortcomings	Widespread shortcomings but basically adequate		

the supplier infrastructure reliability. One measure of the labor skill of the country's workforce is the percent of the population that has completed high school. We could have used the actual percent but instead chose to create aggregate categories. A decision makers is unlikely to care about the exact percentage. The most preferred category, scored as one, is greater than 80% and the least preferred, scored a four, is under 50%. The education level is an easily obtained indirect measure of the workforce's ability to learn new concepts. A modern manufacturing facility uses data, charts, and basic statistics in order to achieve consistent quality products and the workforce must learn from experience to continuously improve performance.

The performance of the workforce is affected by the strength and attitude of the unions in the country. The most preferred environment is one in which the unions are cooperative and there is never a work stoppage. At the other end of the spectrum is a country with highly organized and aggressive unions who instigate frequent work stoppages and strikes in support of negotiations.

As a US firm is planning to locate a global facility, wide spread use of English was considered important to make it easier for the US trained technical managers to communicate with suppliers and management of the factory. In addition, crises are a common occurrence and communication ease is critical to finding a quick resolution. A five point Likert scale representing the percent use of English, as described in Table 4, was constructed to measure this objective.

The last measure within this quality objective is supplier infrastructure reliability as measured by its products' quality and delivery performance. A country is rated both on quality (low or high) and timeliness (low or high) and results in a four point scale. There are no hard data to categorize each candidate country. This is one measure in which subject matter experts will need to be consulted in order to categorize each country's supplier infrastructure.

Table 5
Swing weight assessment table

Measure	Least preferred	Most preferred	SME 1 score	SME 2 score	SME 3 score	Consensus	
						Score	Rescaled weight
Investment cost ($ million)	250	210	100	100	90	100	0.185
Labor cost ($ million)	44	4	80	90	100	90	0.167
Supplier reliability	Low	Very high	40	55	60	50	0.093
Regional vehicle production (Thousands)	407	18 500	35	40	40	40	0.074
Political stability	Stable	Highly stable	30	45	25	40	0.074
Infrastructure quality	Moderate	Highly developed	35	50	30	35	0.065
Membership of free trade agreement	SA-EU Agreement	NAFTA, APEC	5	35	35	35	0.065
Attitude of unionization	Aggressive	Co-operative	30	10	45	30	0.056
High school enrollment	Less than 50	80–100	25	20	25	25	0.046
Inflation rate	12	3.62	20	30	20	25	0.046
GDP growth rate	0.48	4.76	15	20	25	20	0.037
Currency issuer credit ratings (S & P)	BBB−	A−	15	25	20	15	0.028
Corruption perceptions Index	3.7	4.8	5	15	15	15	0.028
Unemployment level	0–5	More than 30	10	20	20	10	0.019
People speaking English	Very low	Very high	20	10	10	10	0.019

A third group of objectives relates to national stability. A company making a long-term investment in a plant is concerned about the long-term political and economic stability of the overall environment. Political stability is identified in terms of impact of changes in government on business conditions and any threats to the stability of the current government. Economic stability is captured by three measures, GDP growth rate, the S&P currency issuer credit rating and the inflation rate. All of these have standard scales. The last measure is of special interest to US companies, the extent of corruption in the country. This issue was important enough that a Corruption Perceptions Index was created. This index captures the degree of corruption as perceived by business people, academics and risk analysts, and ranges between 10 (highly clean) and 0 (highly corrupt).

The final major grouping is somewhat diverse; it relates to the overall demographics and location of the country. The percent unemployed is used to reflect the availability of labor. A higher percentage is preferred. The countries under consideration participate in a variety of free trade agreements and executives will have preferences in this regard. The most preferred in this context is to be a member of NAFTA. The country's infrastructure quality characterizes the quality and availability of transportation, communication, and energy services. On this category scale there is a minimum standard for a country to even be considered. Although the proposed plant will be a global supplier, it is also advantageous to have potential component customers within the region. This is measured in thousands of units of regional vehicle production.

3.4.2. Weights and utility scale

As in every multi-criteria scoring method, weights reflect a decision-maker's preferences with regard to the importance of the various objectives or measures. The approach used in this paper for assigning weights is called the swing weight method. Weights are assigned based on the significance of the range of each measure from worst to best and not just what the measure stands for. First the decision-maker rank orders the measures, based on the preferences as to which measure he would prefer to increase from its least preferred level to most preferred level. Then he assigns a score as to relative significance of the range when compared to the most important range [50]. We interviewed three managers from a major automotive supplier that has dozens of plants around the globe, first individually, then followed by a group discussion to reach a consensus in order to obtain realistic weights. The weights obtained from these discussions (individual and group) are shown in Table 5.

We were especially interested in the relative importance of the two cost measures. The ranges in both cases were approximately forty million dollars. The two economic measures, investment cost and labor cost, were ranked either first or second. The differences were minor and it was easy to reach a consensus. There were significant differences as to relative weights with regard to the membership in a free

Table 6
Data

Measure	Mexico	Czech Republic	Poland	South Korea	South Africa
Investment cost ($ M)	230	210	210	250	230
Labor cost ($ M)	18.05	14.25	8.64	26.25	9.97
High school enrollment (%)	50–65	80–100	65–80	80–100	Less than 50
Attitude of unionization	Demanding	Co-operative	Co-operative	Aggressive	Rational in demands
Supplier reliability	Medium	Very high	High	Very high	Low
People speaking English (%)	Low	High	Medium	Very high	Very Low
Political stability	Stable	Highly stable	Highly stable	Very stable	Stable
GDP real growth rate (%) (Average of last 5 years)	4.3	0.48	4.76	3.94	2.1
Currency issuer credit ratings (S & P)	BBB−	A−	BBB+	BBB+	BBB−
Inflation rate	12	5.98	10.22	3.62	6.1
Corruption perceptions index	3.7	3.9	4.1	4.2	4.8
Unemployment level (%)	0–5[a]	5–10	10–15[b]	5–10	More than 30
Membership of free trade agreement	NAFTA, APEC	EU	EU	APEC	SA–EU Agreement
Infrastructure quality	Developed	Developed	Moderate	Highly developed	Developed
Regional vehicle production (Thousands)	17 870	18 500	18 500	17 497	407

[a]Actual unemployment level is higher than official rate.
[b]Actual unemployment level is lower than official rate.

trade association, unionization, infrastructure quality, political stability, and corruption and the final group score represents a consensus reached after discussion and not just an average.

These measure weights were then aggregated to determine the corresponding weights for major goals. The consensus aggregate weight for cost was 0.35. The remaining 0.65 weight was allocated almost equally amongst the other three major goals. There is a consensus amongst the SMEs regarding only the relative importance of cost and all SMEs ranked cost first. Quality is ranked second by SME 1 and SME 3, while it is ranked fourth by SME 2. The geographic and demographic location, and stability objectives were ranked second and third by SME 2. In the results section we demonstrate that these differences amongst experts do not affect the final rankings.

4. Application and results

Five countries were candidates for the proposed plant: Mexico, Czech Republic, Poland, South Korea, and South Africa. Required data were collected from the US Commercial Service [42], the US Department of State [41], Central Intelligence Agency [36], Czech Republic Investment [37], NAFTA [40], Czech Statistical Office [38], Standard and Poor's [44], Transparency International [43], International Monetary Fund [39], and Asia-Pacific Economic Cooperation [35]. Table 6 shows data for alternative countries with respect to each measure.

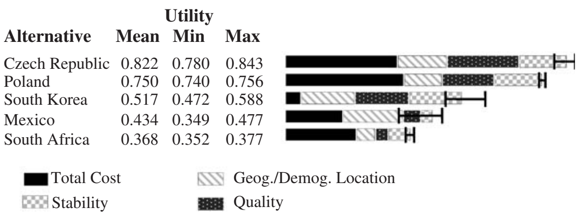

Fig. 4. Stacked bar ranking.

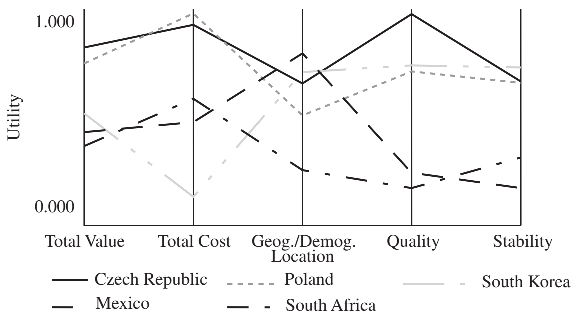

Fig. 5. Strengths and weaknesses of alternatives.

4.1. Results

Logical Decisions software was used to evaluate the alternatives. One strength of this software is that allowed us to track the decision for each of the decision maker's preferences as well as for consensus weights. Figs. 4 and 5 show

Table 7
Utility scores for all subject matter experts and group consensus

	SME1	SME2	SME3	Mean	Std. Dev.	Group
Czech Republic	0.818	0.850	0.795	0.799	0.022	0.822
Poland	0.743	0.758	0.705	0.744	0.022	0.750
South Korea	0.525	0.536	0.560	0.522	0.027	0.517
Mexico	0.422	0.398	0.411	0.436	0.017	0.434
South Africa	0.358	0.365	0.357	0.383	0.025	0.368

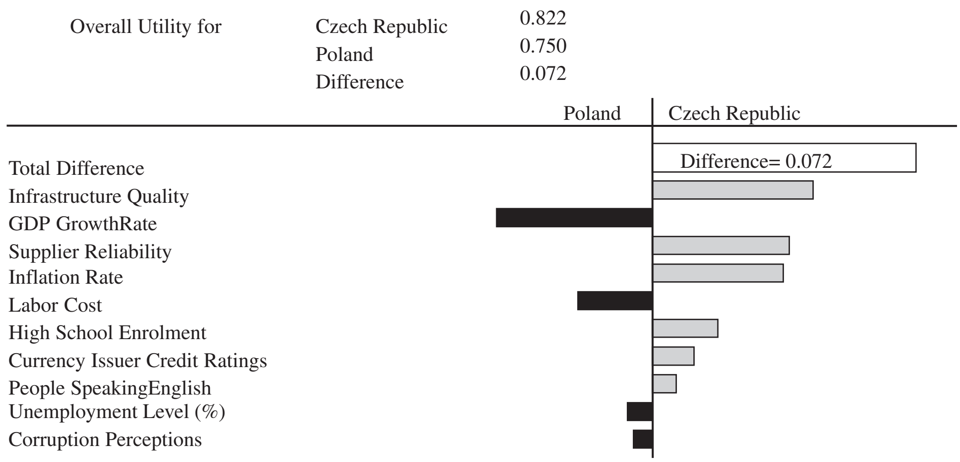

Fig. 6. Comparison of the best two countries.

the overall ranking, strengths, and weaknesses of alternatives in terms of fundamental objectives for the consensus weights. The Czech Republic is ranked first with a utility score of 0.822. Poland is ranked second with a utility score of 0.750, South Korea third with a utility of 0.517, Mexico fourth with a utility of 0.434, and finally South Africa is ranked fifth with a utility score of 0.368. Our results are consistent with recent foreign direct investment decisions in the automotive industry. The Czech Republic and Poland are amongst the most successful countries in winning investments in automotive component manufacturing in Europe. For example, Poland assembled or manufactured at least thirty brands of cars, busses or trucks from thirteen countries in 1999 [51]. Similarly, the Czech Republic attracted 18% of the total number of projects implemented in the sector in Europe in 2002 [52]. Many leading global auto suppliers such as General Motors, Toyota, and Visteon invested billions of dollars recently in manufacturing facilities in these two counties.

Table 7 shows a summary of utility scores and rankings for all subject matter experts and group consensus. Although the utility scores are different for the decision-makers, the individual rankings of the countries are the same.

As seen from Fig. 4, the uncertainty range of the best (Czech Republic) and second best (Poland) alternatives do not overlap. Thus, uncertainty cannot affect the rank ordering of best two alternatives. However, the rank orderings of Mexico, ranked fourth, and South Korea, ranked fifth, might change depending upon the uncertain factors in each country.

Logical decision offers several charts to compare the alternatives. A line graph summarizes the data for all of the alternatives, where data is plotted against the utility score of 0 to 1. The graph in Fig. 5 reports the utility of each alternative on the particular sub-objective. Note that the Czech Republic is ranked first on "quality"; it is a close second on total cost and third on stability, and geographical and demographical location. Though Czech Republic is ranked first, Poland, the second best alternative, offers an average 4.9 million dollars labor cost advantage when compared to the Czech Republic.

A stacked bar graph, of all of the alternatives, Fig. 4, enables the decision maker to see the relative strengths in terms of the weight that each sub-objective contributes to the total. It is clear the reason South Korea is a distant third is due to the high relative total cost, which the decision-maker has assigned more than one-third of the total weight. Mexico, in general ranks poorly from a global perspective, even though it has the major advantage of being close to the United States and part of NAFTA.

Fig. 6 provides a more detailed comparison of the two best alternatives, the Czech Republic and Poland. The Czech

Republic draws almost all of its comparative advantages from infrastructure quality, supplier reliability, inflation rate, and high school enrollment. On the other hand, Poland has significant advantages on GDP growth rate, and labor cost.

After obtaining the initial solution with the given weights of measures, sensitivity analysis was carried out to explore the response of the overall utility of alternatives to changes in the weight of each measure. A series of sensitivity analyses were conducted using the Logical Decision software. GDP growth rate was the most sensitive measure. The current weight (relative importance) of GDP growth rate is 0.037. Because the Czech Republic is weak on GDP growth rate, it is not sensitive to any decrease in the weight as its overall score increases as this weight decreases. If the weight of GDP growth rate is increased above 0.105, Poland will be the most preferred alternative and the Czech Republic will be second best alternative. Note that none of the SMEs assigned higher weight to GDP growth rate. It is not realistic to increase the relative importance of GDP growth rate by 2.84 times. Therefore, moderate changes in the weights do not change the rank of the most preferred alternative, Czech Republic, which confirms the robustness of the solution.

4.2. Value analysis

With MAUT, which provides an absolute utility score, a decision maker can study the weaknesses of the top alternatives in order to possibly create an improved hybrid alternative by addressing a specific weakness. For example, the second best alternative, Poland, offers $4.9 million labor cost savings over four years but is weak on infrastructure quality, supplier reliability, high school enrollment, inflation rate, and currency issuer credit ratings. These factors represent national averages. The decision maker cannot improve the inflation rate, or the currency issuer credit ratings. On the other hand, a decision maker can take a closer look at alternative regions within Poland that might have a higher quality infrastructure, higher high school enrollments, and more English speakers relative to the national average. (There are numerous discrete optimization models that can help identify the best location within a country.) The decision-maker can also commit to spending resources to oversee and improve the reliability of the Polish suppliers his company will be working with. If by better choice of locale, the infrastructure quality can be improved to 'developed' as compared to 'moderate', high school enrollment rates increase from 65–80 to 80–100, and proportion of English speakers moves from medium to high, then the company might be willing to incur additional costs to be in a better location and closely supervise its suppliers. Assume for argument's sake that these improvements can be achieved by increasing the Poland investment by $2 million. This new alternative which we call Poland modified has a final score of 0.842 and surpasses the score for the Czech Republic.

5. Conclusions

Global location decisions are complex and risky due to quantitative and qualitative location factors, and the uncertainty of international environments. The decision makers should not ignore the influence of qualitative factors such as stability, labor skill, etc. in addition to economic factors related to host country.

In this study, we developed a three-phase methodology to deal with the global location problem. In the first phase, we used an influence diagram to elicit location factors, uncertainties, and relationship amongst them. The decision tree was used to analyze the uncertainties, and gain cumulative risk profile for labor cost in phase two. The cumulative risk profile was incorporated as one of the measures for the MAUT that evaluated the alternative countries in the phase three. In this particular study, the relative uncertainties did not affect the rankings. The top two highest ranked alternatives had relatively little uncertainty. The alternatives with the most uncertainty, South Korea and Mexico, were far behind on other important measures.

In the final phase MAUT software enables the decision maker to clearly understand the magnitude of the relative strengths and weaknesses of the various alternatives. It also allows for easy tracking of decision maker differences. In this study we found as is often the case that difference in decision maker preferences were not enough to change the rank ordering of the alternatives. MAUT decomposes the complex site location problem into smaller subproblems that can be better managed in terms of scaling, weighting, and combining criteria or objectives. It also easily integrates both quantitative and qualitative data to produce a final score between 0 and 1. This is an absolute scale in which a score of 1 would be obtained if an alternative scored the maximum on each measure. This allows the decision maker to easily assess whether or not it would be worthwhile to invest time and money to tackle one of the weaknesses of a highly ranked alternative. This is crucial as the ultimate goal of the modeling effort is to "update the intuition of the decision maker" [53] and not have the software or model make the decision for him.

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