APPLYING FUZZY ANALYTICAL HIERARCHY PROCESS TO RESHORING DECISIONS WITH COMPLEXITY AND UNCERTAINTY

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ABSTRACT
Reshoring decisions are associated with both high complexity and uncertainty. The increased complexity is due to the vast number of factors that need to be considered, while the uncertainty is due to the lack of sufficient information. The existing decision-making frameworks are few and theoretical and have not incorporated uncertainty and complexity aspects. Moreover, they do not provide automatic or digital decision support. In order to deal with this, one of the essential branches of mathematics called fuzzy logic is integrated together with traditional analytical hierarchy process (AHP). The aim of this study is to investigate the feasibility of fuzzy analytical hierarchy process (FAHP) as a tool for reshoring decision making when complexity and uncertainty are involved. In order to achieve this, the FAHP was applied to six reshoring criteria, which also correspond to competitive priorities. The findings show that the criterion Quality received the highest weight, followed by the criterion Cost. It was found that the criterion Sustainability resulted in zero priority weight, which means that this criterion was not given importance in this decision. This reduced the complexity of the decision by removing irrelevant criteria in decision making. The fuzzy sets used for pairwise comparisons also incorporated uncertainty in the decision. The FAHP is a feasible tool for reshoring decision making for most of the decision scenarios. This reshoring decision-making tool is automatic, simple and less time consuming, and can be adapted to suit unique reshoring cases.
Keywords: Reshoring decision making, FAHP, Uncertainty in decision, Decision support tool, Manufacturing location.

1. INTRODUCTION

Over the past thirty years, increasing offshoring has triggered an extensive movement of manufacturing activities from high-wage to low-wage nations (Lewin & Peeters, 2006; Ketokivi et al, 2017). This offshoring has been mostly an economic-driven decision where companies have tried to use the cost advantages from the low-wage nations, particularly cheap labor force leading to a reduction in manufacturing cost (Ellram et al, 2013; Kinkel & Maloca, 2009; Gylling et al, 2015). The economic-driven decision has been debated in literature to have considered too little or inaccurate data which does not cover a complete set of decision criteria that should have been considered while making an offshoring decision (Eriksson et al, 2018), thereby leading to an academic dialogue of reshoring, that is, to move manufacturing back to the home nation (Gray et al, 2013; Wiesmann et al, 2017).

Manufacturing reshoring decisions are complex with regard to its structure and accuracy. This is because a large number of decision criteria needs to be evaluated which makes it difficult for the decision maker to reach an optimum solution that is robust over time (Gray et al, 2017; Hartman et al, 2017). Moreover, they require higher managerial effort in effectively planning, implementing and controlling the process (Manuj & Sahin, 2009). Such processes belong to a category of multi criteria decision making (MCDM), which involves assessment of a large number of conflicting criteria in order to choose the right course of action (Rao, 2013). Multi- criteria decision-making problems fulfils the goals of the organization in the most positive way and there is need of simple, systematic, and logical methods or mathematical tools to guide decision makers in solving such problems (Rao, 2013). These kinds of methods or tools are useful when decision maker has a rational mind-set or when there is at least one argument in favor of the decision and the decision itself is the most positive outcome (Brunsson & Brunsson, 2017).

In order to make a reshoring decision, different factors have been explored in the literature. The most common groups of factors can be grouped homogenously, such as cost- related criteria, out of which labor cost and administrative cost are commonly addressed (Srai et al, 2016; Engström et al, 2018a; Engström et al, 2018b), quality-related criteria, out of which product quality or process quality are commonly addressed (Arlbjørn & Mikkelsen, 2014; Stentoft et al, 2016; Johansson & Olhager, 2018), market-related criteria, out of which global economy is addressed (Kinkel & Maloca, 2009; Kinkel, 2012; Tate et al, 2014), strategy- related criteria, out of which a firm's own manufacturing strategy is addressed (Ellram et al, 2013; Baraldi et al, 2018) and risk-related criteria, such as natural disasters and political conflicts are addressed (Ellram et al, 2013; Tate et al, 2014; Benstead et al, 2017). Therefore, a reshoring decision involves numerous of qualitative and quantitative criteria which cannot be integrated in conventional quantitative decision-making tools. Moreover, firms do not have sufficient knowledge of how to use these qualitative criteria or tools into the decision, which makes present decision models unsuccessful (Gray et al, 2017).

Still, developing decision making tools for reshoring decisions is a high priority on research agenda (Stentoft et al, 2016; Barbieri et al, 2018). This has inspired the study to explore multi criteria decision support systems for reshoring decisions. One such decision support system using linguistic tools in the form of fuzzy logic have been recently applied to reshoring decision making that expresses the criteria in qualitative terms (Hilletofth et al, 2019a). Other decision support tools such as analytical hierarchy process (AHP) has been applied in the wider operations management field (Vaidya & Kumar, 2006), but have not been explored specifically for reshoring. In case of complexity and uncertainty in reshoring decisions, the AHP can be integrated with fuzzy logic, called as fuzzy-AHP (FAHP). The FAHP combines both the features from fuzzy logic and AHP (van Laarhoven & Pedrycz, 1983; Sagar et al, 2015). In FAHP, the linguistic preferences can be represented by fuzzy numbers when two criteria are compared (Chan et al, 2008). The fuzzy numbers provide a way to implement vagueness and uncertainty in the decision process (Leung & Cao, 2000). For reshoring decisions, managerial experience is used to express vagueness and uncertainty in the judgement of various criteria. Hence, FAHP seems to be a promising tool for the reshoring decision making applications.

The purpose of this study is to investigate the feasibility of FAHP for reshoring decision-making. In order to operationalize this, the reshoring criteria were first derived from the broader operations management literature, and then the FAHP is applied. Experts from academia were involved in testing the decision-making tool under different scenarios.

The remainder of the paper is structured as follows. To begin with, a brief overview of FAHP process and its main parts are presented in Section 2. After that, related work in FAHP in the area of operations management is reviewed in Section. 3. After that, the FAHP for reshoring decision making application is conceived and described in Section 4. Thereafter, the results from the FAHP are presented for different reshoring scenarios in Section 5. Finally, the research is discussed in Section 6 and concluded in Section 7.

2. THE FUZZY-AHP PROCESS

The fuzzy-AHP is a combination of two concepts, fuzzy logic and AHP, both of which are used for decision making applications (Ho et al, 2010; Govindan et al, 2015). The AHP concept has been widely used in operations management (Vaidya & Kumar, 2006). The AHP stems from applied mathematics and operations research that prefers to quantify judgements of the decision maker in order to make resilient decisions (Brunelli, 2014). It provides a way to structure qualitative and quantitative criteria in a systematic manner and simple way to solve decision making problem (Saaty, 1980). The decision makers compare each criterion in the same level in a pairwise manner to every other criterion, based on their previous knowledge and experience (Schoenherr et al, 2008). However, there are some disadvantages of AHP such as its failure to handle risk and uncertainty, since some reshoring factors can have high uncertainty over time (Tate et al, 2014). In order to handle uncertainty in decision making, fuzzy set theory was proposed by Zadeh (1965).

Fuzzy logic is based on fuzzy set theory, which is an extension of natural set theory and is used to handle imprecision and vagueness in a mathematical way (Ocampo, 2019). fuzzy sets can be understood as a class of objects which has continuous grades of membership, and each object is assigned a grade from zero to one. They are always represented by a tittle "~" symbol and they are placed above a variable if the variable is a fuzzy set, for example $\tilde{P}$.

$$\mu_{\tilde{p}} = \begin{cases} (x-a)/(m-a)\,, if\ a\ \leq x \leq m \\ (b-x)/(b-m), if\ m \leq\ x\ \leq b \\ 0, \qquad\qquad\qquad otherwise \end{cases}$$

In order to take into the consideration of the vagueness in an assessment of the pair-wise comparison of criteria, triangular fuzzy numbers P_1, P_3, P_5, P_7 and P_9 are used. These represent the assessment from "equally strong (P_1), moderately strong (P_3), strong (P_5), very strong (P_7) and extremely strong (P_9)" with P_2, P_4, P_6, and P_8 as middle values. With the use of triangular fuzzy sets, an extended approach was introduced (see Chang et al, 1996) and has been widely applied due to its computational simplicity (Wang et al, 2008). The extended approach deals with computing fuzzy synthetic sets (S_i) for each criterion. The fuzzy synthetic sets are weight vectors for the criterion and it contains lower, middle and upper values. After computing weight vector, 'degree of possibility' is calculated. The degree of possibility is the level that one fuzzy synthetic set is greater than the other, for a pair of fuzzy numbers (see Chang et al, 1996).

The extended approach for triangular fuzzy sets has also some drawbacks that has led to wrong decisions (Wang et al, 2008). One problem is that this approach may lead to a zero weight in a decision criterion, leading to that the criterion may not be considered in a decision. Another problem is that the weights do not represent the relative importance and cannot be used as priority weights (Wang et al, 2008). However, this is still the most popular approach in spite of criticisms (Kubler et al, 2016).

The fuzzy-AHP procedure combines both attributes of fuzzy logic and AHP. The problem of subjectivity and imprecision in the AHP is resolved through fuzzy-AHP method. The fuzzy-AHP uses multiple values than a single crisp value as in the traditional AHP. Therefore, decision maker can choose any value that resemble the confidence of the comparison. The decision maker compares every criterion to every other criterion and assigns a fuzzy number as shown in the table (Table 1).

Table 1. Scale of preference of two elements

P_1	1,1,1	Equally strong
P_3	1,3,5	Moderately strong

P_5	3,5,7	Strong
P_7	5,7,9	Very strong
P_9	9,9,9	Extremely strong

3. RELATED WORKS

The fuzzy-AHP (FAHP) is one the most widely used decision making tool and it has been applied to many problems in the operations management field (Mardani et al, 2015; Kubler et al, 2016). Within the operations management field, the main problem area where fuzzy-AHP has been applied is in the area of selection and evaluation (Kubler et al, 2016). Supplier selection is a popular application within this area since there exist numerous studies that have used fuzzy- AHP to select the best supplier out of a certain set of alternatives (Chan et al, 2008). Another common application is the evaluation of outsourcing decisions (Kubler et al, 2016). However, when it comes to offshoring decisions, only a single study exists that has applied FAHP to offshoring decisions (Kaur et al, 2019). There are no journal studies, so far, that has applied fuzzy-AHP to reshoring decisions; however, some conference studies exist (Adlemo et al, 2018; Pal et al, 2018).

Among the applications of FAHP in supplier selection, Chan et al (2008) used fuzzy- AHP to deal with both qualitative and quantitative factors in global supplier selection. In total, five main criteria were defined, which consisted of 19 sub-criteria. The main criteria 'Cost of ownership' received the highest weight. Three suppliers were evaluated and the supplier with the highest weight was chosen as the best global supplier. Similarly, Kahraman et al (2003) used fuzzy-AHP to select the best supplier. They define an overall category of criteria for supplier selection: supplier, product performance, service performance and cost. Out of these, the cost criteria require highest effort to estimate and should be evaluated in-detail. Awasthi et al (2018) used integrated fuzzy-AHP method to select the most sustainable global supplier. They consider the criteria that are related to sustainability, including risks from suppliers' sub- suppliers. In total, five sustainability criteria, i.e., economy, quality, environment, social and global risk were weighed. Out of them, economy criteria received the highest weight while the global risk received the least weight.

Among the applications of FAHP in outsourcing, Uygun et al (2015) used integrated fuzzy-analytical network process (FANP), which is an extension of traditional fuzzy-AHP for choosing the outsourcing provider for a telecommunications company, that just decided to outsource their maintenance activities. The advantage of FANP is that the set of criteria can be represented by a network, instead of a hierarchy due to the interdependence of high-level criteria on low-level criteria (Saaty, 2005). Five main criteria were defined, which consisted of 17 sub- criteria and 14 sub-subcriteria. The main criteria 'Financial reliability of the company' received the highest weight, while two of the other main criteria received zero weights. The outsourcing provider with the greatest relative weight was chosen. Chen and Hung (2010) used integrated fuzzy-AHP to select outsourcing partners for R&D in the pharmaceutical industry. In total five criteria and 15 sub-criteria were considered. The main criteria Quality had the highest weight, followed by the main criteria Financial consideration. Three outsourcing candidates were evaluated and ranked based on the criteria weights.

Among the applications of FAHP in offshoring, Kaur et al (2019) model joint offshoring and outsourcing decisions using fuzzy-AHP. The common ground for addressing both offshoring and outsourcing in same model is that it meets the economic goals. The case company was a multi-factory manufacturing company that has three facilities located in different locations around the world, different products produced during four time periods, and supplies them to four different markets. Both qualitative and quantitative criteria were considered. In total 19 criteria were used in order to evaluate eight suppliers. The model selects the best supplier and also provides order allocation at the respective facilities.

Among the applications of FAHP in reshoring, Pal et al (2018) used fuzzy-AHP in a workshop consisting of industrial and academic experts. The criteria were 12 operational capabilities derived from the reshoring literature. The weights from the criteria were categorized into 3 groups. The weights influence four reshoring decisions: make-onshore, make-nearshore, buy-onshore, buy-nearshore. The most important criterion was availability of production capabilities in the home country. Adlemo et al (2018) have used fuzzy logic to make reshoring decisions based on competitive priorities. Five reshoring criteria were used to make the decision whether to evaluate reshoring or not.

4. FUZZY-AHP TO RESHORING DECISION MAKING

In order to apply fuzzy-AHP to reshoring decision making, the reshoring criteria are first defined. The reshoring criteria can be regarded as factors that influence reshoring decisions and these could be found in the literature that address reshoring drivers, barriers and enablers (Barbieri et al, 2018; Stentoft et al, 2016; Wiesmann et al, 2017). In this study, six high-level criteria were chosen that relate to established competitive priorities since the main goal of any reshoring decision is to increase competitiveness (Hilletofth et al, 2019a; Sansone et al, 2017). The six reshoring criteria are: cost, quality, time, flexibility, innovation and sustainability (Hilletofth et al, 2019a).

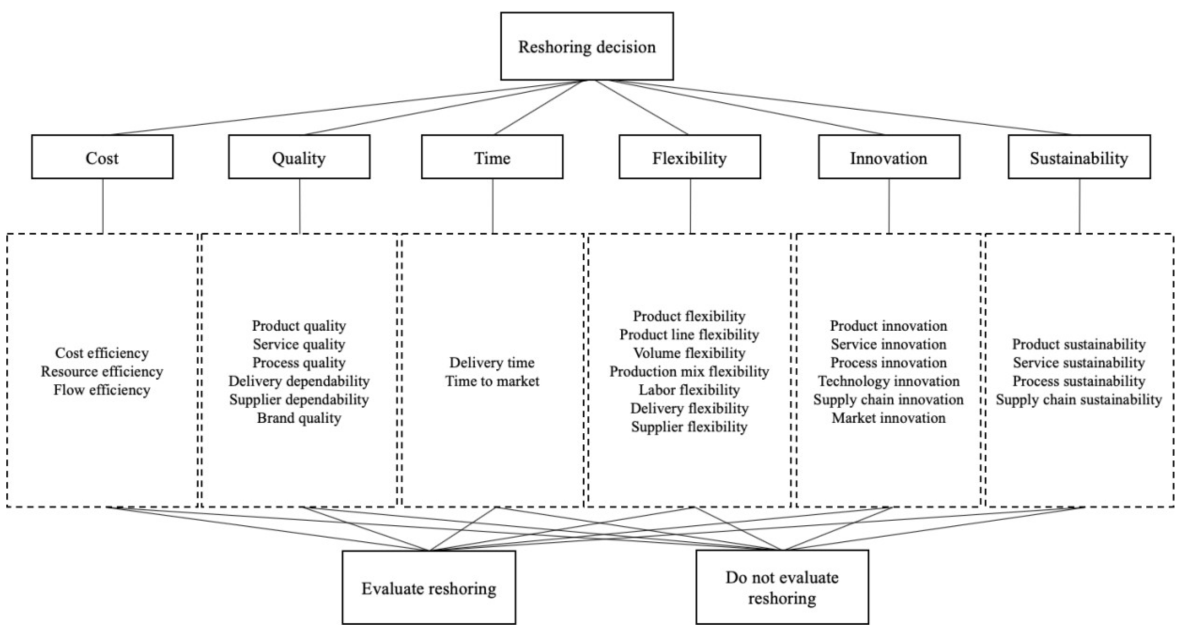

Figure 1. The hierarchy of reshoring decision making

Then, the domain experts compare each criterion in the same level to every other criterion in a structured pairwise manner, based on their past experience and judgement. For the purpose of this study and to check the feasibility of the decision-making tool, the comparison was only done on a main criteria level that includes the six criteria. The pairwise comparison is done on a nine-point scale, which uses nine fuzzy sets each having a lower, middle and an upper value (Table 1). The fuzzy values resemble vagueness and uncertainty in their decision (Sagar et al., 2005; Saaty, 1980). For example, if Quality is moderately preferred over Cost, then the fuzzy values (1,3,5) are entered in row Quality and column Cost. Also, for example, if Time is equally preferred as Flexibility then, the fuzzy values (1,1,1) are entered in both places. The complete pairwise comparison matrix is shown in the table (Table 2).

Table 2. Pairwise comparison using fuzzy sets

	Cost	Quality	Time	Flexibility	Innova-tion	Sustain-ability	l	m	u
Cost	(1,1,1)	(1/5,1/3,1)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	15,2	23,3	32
Quality	(1,3,5)	(1,1,1)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	16	26	36
Time	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(1,1,1)	(1,1,1)	(3,5,7)	6,2	8,4	10,6
Flexi-bility	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(1,1,1)	(1,1,1)	(3,5,7)	6,2	8,4	10,6
Innova-tion	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(1,1,1)	(1,1,1)	(3,5,7)	6,2	8,4	10,6
Sustain-ability	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	1,6	1,8	2,4
							51,7	76,4	102,4

Next, the fuzzy synthetic set (S_i) is calculated for each criterion using the lower, middle and upper values (Table 3). Next, the degree of possibility is calculated for each pair of synthetic fuzzy set (Table 4). For instance, in this study the degree of possibility that the synthetic fuzzy set for Cost (S_1) is greater than the synthetic fuzzy set for Quality (S_2) is 0.929.

Table 3. Fuzzy synthetic set (S_i)

Synthetic set	**l**	**m**	**u**
Cost (S_1)	0,1484375	0,305333998	0,618860511
Quality (S_2)	0,15625	0,340229312	0,696218075
Time (S_3)	0,061383929	0,109920239	0,206286837
Flexibility (S_4)	0,061383929	0,109920239	0,206286837
Innovation (S_5)	0,061383929	0,109920239	0,206286837
Sustainability (S_6)	0,016121032	0,024675972	0,046414538

Next, the minimum value of all the degrees of possibility is determined in each column which gives the weight vector for each criterion. After this the weights are normalized to get the final weighted matrix (Table 5).

Table 4. Degree of possibility

$S_1 \geq S_2$	0,929	$S_2 \geq S_1$	1	$S_3 \geq S_1$	0,2284	$S_4 \geq S_1$	0,2284	$S_5 \geq S_1$	0,2284	$S_6 \geq S_1$	0
$S_1 \geq S_3$	1	$S_2 \geq S_3$	1	$S_3 \geq S_2$	0,1784	$S_4 \geq S_2$	0,1784	$S_5 \geq S_2$	0,1784	$S_6 \geq S_2$	0
$S_1 \geq S_4$	1	$S_2 \geq S_4$	1	$S_3 \geq S_4$	1	$S_4 \geq S_3$	1	$S_5 \geq S_3$	1	$S_6 \geq S_3$	0
$S_1 \geq S_5$	1	$S_2 \geq S_5$	1	$S_3 \geq S_5$	1	$S_4 \geq S_5$	1	$S_5 \geq S_4$	1	$S_6 \geq S_4$	0
$S_1 \geq S_6$	1	$S_2 \geq S_6$	1	$S_3 \geq S_6$	1	$S_4 \geq S_6$	1	$S_5 \geq S_6$	1	$S_6 \geq S_5$	0
Minimum	0,929		1		0,1784		0,1784		0,1784		0

Table 5. Final weights

Criteria	Weight vector	Final normalised weights
Cost	0,9298	0,3771
Quality	1	0,4056
Time	0,1784	0,0723
Flexibility	0,1784	0,0723
Innovation	0,1784	0,0723
Sustainability	0	0

5. RESULTS

The weights from the fuzzy-AHP method is applied to evaluate different reshoring decision scenarios (Table 6). In this study, fifteen reshoring scenarios have been evaluated by experts in reshoring domain. The scenarios provide the necessary test data to evaluate if the results from AHP provided accurate results, when compared to the expert's opinion. A scenario consists of a sextuple input values of the six criteria that range from -5 to +5. -5 indicates the worst impact on the criterion if reshoring would take place while +5 indicates the best impact on the criterion. The output value has a range of -5.00 to +5.00 where the values between -5.00 to 0.00 suggest a negative impact if reshoring would take place, hence the output from the AHP would indicate 'don't evaluate'. On the other hand, the values between 0.01 to +5.00 suggest a positive impact if reshoring would take place, hence the output from the AHP would indicate 'evaluate'. The values of the different scenarios are multiplied with the corresponding priority weights and summed to get the output values from FAHP. The decision from the FAHP output is determined depending on the output from the fuzzy-AHP. The values from FAHP outputs and the expert's opinion are compared to see if there is any conflict in decision between the expert and fuzzy-AHP method.

The results indicate that for most of the scenarios there is a correct decision from the fuzzy-AHP output. Out of 15 scenarios, 12 scenarios did not show any conflict in the decision. The remaining 3 of the scenarios showed conflicts between the expert and fuzzy-AHP output. The change in decision is caused by the reversal of the direction of the output. However, it is noticed that the difference between the conflicting outputs is not huge. For example, in scenario 7, the output from the fuzzy-AHP is -0.34 which is very small in order to make a confident decision not to evaluate reshoring. The experts suggest otherwise. Similarly, in scenario 12, the output from the AHP is -1.43, which is also rather small in order to make a confident decision to evaluate reshoring.

Table 6. Input decision scenarios and decision evaluation from fuzzy-AHP

Scenarios	Criteria (final weights)						Expert's opinon	Output from AHP	Decision from AHP output	Conflict between expert's opinion and AHP
	Cost (**0.3771**)	Quality (**0.4056**)	Time (**0.0723**)	Flexibility (**0.0723**)	Innovation (**0.0723**)	Sustainabilty (**0**)				
1	-5	-1	-3	-2	-3	3	-5	-2,87	Do not evaluate	No
2	2	5	-1	3	4	1	4	3,22	Evaluate	No

3	-3	-4	-3	-1	4	-1	-4	-2,75	Do not evaluate	No
4	3	-4	-1	-3	-5	-3	-4	-1,14	Do not evaluate	No
5	-4	-2	5	-1	-1	5	-4	-2,10	Do not evaluate	No
6	4	2	-4	2	2	-5	4	2,32	Evaluate	No
7	-4	2	1	2	2	5	4	-0,34	Do not evaluate	Yes
8	2	-1	3	-1	1	5	3	0,57	Evaluate	No
9	3	5	5	2	5	-3	5	4,03	Evaluate	No
10	-3	-5	3	-2	5	-2	-4	-2,73	Do not evaluate	No
11	-3	5	5	3	5	-3	4	1,84	Evaluate	No
12	1	-5	1	1	1	-5	3	-1,43	Do not evaluate	Yes
13	-5	1	-5	-5	-5	1	-3	-2,57	Do not evaluate	No
14	5	-1	5	5	5	-1	3	2,57	Evaluate	No
15	-1	5	-1	-1	-1	5	-3	1,43	Evaluate	Yes

6. DISCUSSION

The reshoring decision making has been an under-investigated subject due to the novelty of the phenomenon (Barbieri et al, 2018). These decisions are complex since it is a multi-criteria decision-making problem that involves a large number of factors. These factors have previously been homogenously grouped according to firm's competitive priorities (Wiesmann et al, 2017; Sansone et al, 2017). Moreover, these factors can change over time, which brings an element of uncertainty among the different criteria (Tate et al, 2014). In the past, the tool total cost of ownership was commonly used as decision support tool for making relocation decisions, since these decisions were purely made from a cost perspective (Ellram 1995; Gylling et al, 2015). However, the uncertainty in cost factors was not fully incorporated in these tools due to which managers turned towards other decision support tools (Gylling et al, 2015). Therefore, managers require support tools that also takes into account the uncertainty in order to make a reshoring decision more robust and resilient over time (Hilletofth et al, 2019a; Hilletofth et al, 2019b). In order to incorporate this uncertainty in decision making, there has been several tools used in the operations management domain, and one such tool is fuzzy analytical hierarchy process (FAHP) (Rao, 2013). The FAHP tool has been used in this study in order to investigate the feasibility of the tool for reshoring decision making when complexity and uncertainty are involved.

The FAHP tool is a combination of two parts: fuzzy logic and traditional AHP. The fuzzy logic part implements uncertainty whereas the AHP part derives the priority weights of all the relevant criteria. Six criteria and their corresponding sub-criteria were defined from the existing literature in operations management and reshoring (Hilletofth et al, 2019a). The six criteria correspond to how the firms can remain competitive and generate positive revenue. The six criteria and their sub-criteria were arranged in a hierarchy. The hierarchy provides an overview of the criteria and their corresponding sub-criteria. The FAHP tool is only applied at the criteria level, however, it is also possible to extend the tool at the sub-criteria level. This would require a comprehensive categorization of the six reshoring criteria (Sequeira & Hilletoth, 2019). For each of the criteria in the overall level, a pairwise comparison was done. During this comparison, the fuzzy logic incorporated uncertainty in the decision (van Laarhoven & Pedrycz, 1983). The very use of fuzzy logic in the traditional AHP requires additional steps to be performed, such as the calculation of degree of possibility of superiority between different criteria. This is used to calculate the final priority weights of each criteria. The final priority weights suggest which of the criteria is more important for the reshoring decision.

The final priority weights for each criterion was calculated. The Quality criterion received the highest weight (0,4056) followed by the Cost criterion (0,3771). This is in line with previous related studies in supplier selection and outsourcing, which puts high values for the cost criterion

(Awasthi et al, 2018; Chan et al, 2008; Kahraman et al, 2003). However, within the reshoring domain, previous surveys indicate that quality is more relevant that costs (Stentoft et al, 2016; Kinkel, 2014; Johansson & Olhager, 2018). One reason for this is that reshoring mainly occurs to the high-cost environments where the quality is the main driver (Johansson & Olhager, 2018). This explains why quality has slightly higher priority weight than cost, even though both together make up for more than three-fourths of priority weights. The other criteria Time, Flexibility and Innovation have received equal priority weights (0,0723) in this study. This suggests that the domain expert considers these three criteria equally important in this tool, however some studies in reshoring suggest a slightly higher importance on Flexibility criteria (Stentoft et al, 2016; Kinkel, 2014; Johansson & Olhager, 2018). So, these differences among these three criteria should be incorporated in the pairwise comparison stage. The Sustainability criterion resulted in zero priority weight, which means that this criterion is not considered important in the decision. This is in line with the recent literature review (Barbieri et al, 2018) that environmental and social sustainability as a reshoring criterion is less researched (Ashby, 2016; Wiesmann et al, 2017). Sustainability is a global issue and its impact of manufacturing reshoring on sustainability performance should be further researched (Ashby, 2016).

The reshoring evaluations were carried out by implementing the final priority weights in fifteen different reshoring scenarios. The values on different criteria on each scenario were multiplied by their corresponding priority weights in order to make an evaluation. A correct evaluation was done for most of the scenarios (80%). The high percentage of correct evaluations indicate that FAHP tool is feasible for reshoring decision making. Along with the evaluation, there is a value for the system output. The value from the system output would assist in making confident reshoring decisions. Three out of fifteen evaluations showed that there was a conflict between the expert and the system. The conflicting scenarios, however, do show low values on the decision, which suggests a low confidence in the decision. Therefore, for a manager making reshoring evaluation, this would mean not to take any action unless there is further investigation as evaluations with a low confidence level would mean a high uncertainty in the evaluation. In this case, the manager might look into other alternatives such as nearshoring (Panova & Hilletofth, 2017; Slepniov et al, 2013). On the contrast, if we consider scenario 9, there is high confidence in the evaluation. Therefore, a manager looking at this type of scenario should proceed with evaluating reshoring.

As a decision-making tool for reshoring, the FAHP is feasible for most of the scenarios. The tool is simple and automatic since it provides an immediate valuation of the output. This tool is able to filter out the criteria that are least important to the decision, by assigning a zero weight. In one way, this reduces the complexity of too many factors in the system. However, this might lead to misleading results in some cases (Wang et al, 2008). In this study, Sustainability criterion got zero weight, making it irrelevant in the reshoring decision. However, studies have shown that sustainability is gaining importance from a supply chain perspective since it is environmentally friendly and fosters relationships in the supply chain (Ashby et al, 2016). The importance of sustainability in reshoring have not been captured in existing surveys among managers (Stentoft et al, 2016; Johansson & Olhager, 2018). So, for future improvement, the suggestion would be to raise the importance of this criteria during pairwise comparisons. Some research in FAHP already exists in evaluating the most sustainable supplier (Awasthi et al, 2018), and this could be tailored to compare suppliers only in home country to make a reshoring decision motivated by sustainability.

7. CONCLUSION

Reshoring decisions are associated with both high complexity and uncertainty due to too many factors that need to be considered and a lack of sufficient information. In order to create a decision support tool for reshoring decision, the tool must be able to handle this complexity and uncertainty. This study has investigated the feasibility of one such support tool, that is fuzzy analytical hierarchy process (FAHP). The FAHP deals with reducing the complexity of too many factors by first creating a hierarchical relationship between the factors. Furthermore, the complexity is also reduced by removing irrelevant factors in the decision. The FAHP deals with uncertainty by introducing fuzziness in the weights during the pairwise comparisons. The criteria cost and quality received the highest weight making them important in a reshoring decision. The criterion sustainability received a zero weight, and its effect on the decisions were eliminated. Fifteen decision scenarios were evaluated based on the priority weights calculated. Most of the scenarios were evaluated similarly as the reshoring experts. Therefore, this study concludes that FAHP is feasible for reshoring decision-making with complexity and uncertainty. This tool is automatic, simple and less time consuming. The tool provides implications for managers in terms of decision support for reshoring.

For future research, the FAHP tool needs to be applied to a lower level of criteria (i.e., sub criteria and sub-sub criteria). This would make the tool more sophisticated than the one used in this study. Extending the tool to a lower level of criteria would generate an extra set of 'local' priority weights. Incorporating such high sophistication would make the decision more robust, however will increase experts' task of making too many pairwise comparisons of sub criteria. Another important aspect for future research would be to consider different levels of relative importance for the criteria which are based on updated surveys in reshoring. In this study, some of the priority weights were too low for some criteria and zero for one criterion. These weights should be updated in future studies, before being implemented in the tool. Lastly for future research, it would be interesting to explore other automatic decision-making approaches and make a comparative analysis of the best tools for reshoring decision making.

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