

# AHP-based support tools for initial screening of manufacturing reshoring decisions

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## Abstract

**Purpose** – The existing literature expresses a strong need to develop tools that support the manufacturing reshoring decision-making process. This paper aims to examine the suitability of analytical hierarchy process (AHP)-based tools for initial screening of manufacturing reshoring decisions.

**Design/methodology/approach** – Two AHP-based tools for the initial screening of manufacturing reshoring decisions are developed. The first tool is based on traditional AHP, while the second is based on fuzzy-AHP. Six high-level and holistic reshoring criteria based on competitive priorities were identified through a literature review. Next, a panel of experts from a Swedish manufacturing company was involved in the overall comparison of the criteria. Based on this comparison, priority weights of the criteria were obtained through a pairwise analysis. Subsequently, the priority weights were used in a weighted-sum manner to evaluate 20 reshoring scenarios. Afterwards, the outputs from the traditional AHP and fuzzy-AHP tools were compared to the opinions of the experts. Finally, a sensitivity analysis was performed to evaluate the stability of the developed decision support tools.

**Findings** – The research demonstrates that AHP-based support tools are suitable for the initial screening of manufacturing reshoring decisions. With regard to the presented set of criteria and reshoring scenarios, both traditional AHP and fuzzy-AHP are shown to be consistent with the experts' decisions. Moreover, fuzzy-AHP is shown to be marginally more reliable than traditional AHP. According to the sensitivity analysis, the order of importance of the six criteria is stable for high values of weights of cost and quality criteria.

**Research limitations/implications** – The limitation of the developed AHP-based tools is that they currently only include a limited number of high-level decision criteria. Therefore, future research should focus on adding low-level criteria to the tools using a multi-level architecture. The current research contributes to



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the body of literature on the manufacturing reshoring decision-making process by addressing decision-making issues in general and by demonstrating the suitability of two decision support tools applied to the manufacturing reshoring field in particular.

**Practical implications** – This research provides practitioners with two decision support tools for the initial screening of manufacturing reshoring decisions, which will help managers optimize their time and resources on the most promising reshoring alternatives. Given the complex nature of reshoring decisions, the results from the fuzzy-AHP are shown to be slightly closer to those of the experts than traditional AHP for initial screening of manufacturing relocation decisions.

**Originality/value** – This paper describes two decision support tools that can be applied for the initial screening of manufacturing reshoring decisions while considering six high-level and holistic criteria. Both support tools are applied to evaluate 20 identical manufacturing reshoring scenarios, allowing a comparison of their output. The sensitivity analysis demonstrates the relative importance of the reshoring criteria.

**Keywords** Quantitative, Decision-making, AHP, Fuzzy-AHP, Manufacturing relocation, Reshoring, Initial screening

**Paper type** Research paper

## 1. Introduction

Over the past few years, the manufacturing reshoring phenomenon has elicited an increased interest among scholars, practitioners, and policymakers (Moser, 2013; Tate *et al.*, 2014; Zhai *et al.*, 2016). This phenomenon is described as the repatriation of previously owned manufacturing or supplier activities, back to the manufacturer's home country (Gray *et al.*, 2013). In this context, reshoring refers to a location decision that is independent of whether the manufacturing is insourced or outsourced (Barbieri *et al.*, 2018). Although reshoring has been practiced for more than a decade, the prominent surge in academic research has occurred after 2016 (Barbieri *et al.*, 2018). Given that this area of research is still evolving, both industry and academia are finding it difficult to fully comprehend the reshoring phenomenon (Boffelli *et al.*, 2020). Different aspects of reshoring have been studied, such as its definition, the types of industries involved, (de)motivations for reshoring, countries involved, and the duration (Ancarani *et al.*, 2015; Barbieri *et al.*, 2018; Fratocchi *et al.*, 2016; Wiesmann *et al.*, 2017). Even so, the decision-making reshoring process remains poorly understood since it is a viscerally complex process (Barbieri *et al.*, 2018). Due to this complexity, managers tend to rely on their past experiences or heuristic approaches in decision-making when dealing with reshoring issues (Boffelli *et al.*, 2020; Gray *et al.*, 2017). To provide practical and useful decision support, there is a need to develop tools that facilitate accurate and resilient reshoring decisions (Hilletoft *et al.*, 2019a).

This need to develop decision support tools for managers to make accurate and resilient manufacturing reshoring decisions has been highlighted as a highly prioritized research area (Barbieri *et al.*, 2018; Stentoft *et al.*, 2016b; Wiesmann *et al.*, 2017). Additionally, and especially considering the recent Covid-19 pandemic, the global economy is potentially facing a grave situation as closure of manufacturing facilities and travel restrictions have severely disrupted global supply chains (OECD, 2020). This global event has inexorably raised concerns regarding the uncertainty and vulnerability of the supply chains. Early secondary data from press releases have alluded to the triggering role played by the pandemic in reshoring to Europe (Barbieri *et al.*, 2020). Against this backdrop, future supply chains are required to augment their ability to prepare for similar eventualities by providing essential functions to recover from a post-pandemic vulnerability (Barbieri *et al.*, 2020; Golan *et al.*, 2020). A proactive approach is necessary, for example, analyzing the timing of manufacturing reshoring within the supply chain. Thus, decision support tools for manufacturing reshoring are required, since events with global ramifications, such as Covid-

19, can strongly influence decision-making processes. Additionally, with the rapid technological advancements in artificial intelligence (AI) and big data analytics, the desired decision support needs to be in a digital form (Baryannis *et al.*, 2019). Hence, these highly relevant decision-making issues concerning manufacturing reshoring must be urgently addressed.

Extensive reshoring decision-making models have been built using system dynamics that entails a cost perspective (Gray *et al.*, 2017). When studying manufacturing reshoring decision-making, the modeling approach is deemed appropriate because it is possible to decipher the relationship between the variables and the final decision (Bertrand and Fransoo, 2002; Hilletoft and Lättilä, 2012). Decision-making models based on multi-criteria decision-making (MCDM) methods are increasingly applied within the wider operations management domain (Vaidya and Kumar, 2006). The MCDM methods provide a way to identify and choose the “best” alternative based on the comparison of the decision criteria (Rao, 2013). Many such MCDM methods have been explored to solve similar problems within the operations management, such as supplier selection (Banasik *et al.*, 2018). Consequently, it is reasonable to assume that these methods could also be applied to manufacturing reshoring decisions. Some studies have leveraged already existing MCDM methods to explore manufacturing reshoring decisions (Pal *et al.*, 2018a; Sarder *et al.*, 2014; White and Borchers, 2016). However, these studies have a limited perspective regarding the decision criteria. This limitation has been overcome in this study by considering a holistic set of decision criteria.

MCDM methods are interesting from a manufacturing reshoring decision-making point of view and it has been suggested that even more research using MCDM methods should be conducted in the manufacturing reshoring domain (Sarder *et al.*, 2014). One specific MCDM method which has been explored within the manufacturing reshoring decision-making domain is the analytical hierarchy process (AHP). The so-called traditional AHP is based on crisp comparisons between different criteria and is thus, not designed to handle uncertainty. Manufacturing reshoring decisions, however, involve uncertainty due to the dynamics in the global environment that needs to be taken into consideration (Kinkel, 2012). To incorporate uncertainty in the reshoring decision, fuzzy logic is integrated into the traditional AHP, otherwise known as fuzzy-AHP (van Laarhoven and Pedrycz, 1983; Sagar *et al.*, 2015). Fuzzy-AHP has been explored in the manufacturing reshoring decision-making domain where three criteria from the operations strategy have been used (Pal *et al.*, 2018a; White and Borchers, 2016). However, there is still a need to incorporate a wider range of operations strategy criteria. The manufacturing reshoring domain is underdeveloped with regard to MCDM methods when compared to closely related domains, such as supplier selection and evaluation domain, where a plethora of research related to MCDM methods exists (Emrouznejad and Marra, 2017). Having said that, there does exist a need to develop similar decision-making methods for the manufacturing reshoring decision-making domain. This paper attempts to fill this research gap within the purview of manufacturing reshoring decision-making.

The purpose of this study is to investigate the suitability of AHP-based tools for the initial screening of manufacturing reshoring decisions. The goal of initial screening is to identify the feasibility of continuing with the following steps of the reshoring decision process as early as possible (Figure 1). Arriving at an early decision of not continuing the reshoring process can save a lot of resources. The first stage in this study entails the development of two AHP-based tools. The first tool is premised upon crisp comparisons of the reshoring criteria, while the second is based on fuzzy comparisons. The criteria used by the two tools were obtained from the reshoring literature. Then, a panel of industry experts

was involved in an overall comparison of the criteria, following which the weights of the criteria obtained from the tools were used in the evaluation of twenty reshoring scenarios for initial screening purposes. The output of the tools suggests whether the scenarios are interesting to further evaluate reshoring and spend both time and resources in the decision-making process. The reliability of the tools was measured as a difference between their output and the opinion of industry experts on reshoring scenarios. Finally, a sensitivity analysis was performed to evaluate the stability of the results generated by the decision support tools. The scientific output of the research presented is threefold. First, it addresses a relevant research gap related to manufacturing reshoring decision-making by presenting two decision support tools. Second, holistic qualitative and quantitative criteria used in the developed decision support tools make the decision support generic to different types of companies that are evaluating the reshoring option. Third, a comparison between the crisp and fuzzy-AHP points out which of the two performs the best for the initial screening of manufacturing reshoring decisions.

The rest of the paper is outlined as follows. Section 2 provides a review of related research within manufacturing reshoring decision-making and AHP-based tools. Section 3 elucidates the details of the two AHP-based support tools for manufacturing reshoring decision-making. Section 4 presents the results of the research concerning the final criteria weights, the evaluation of the reshoring scenarios, and the results drawn from the sensitivity analysis. Section 5 discusses the obtained results in relation to the literature. Section 6 presents the implications of this study for both practice and society, whereas Section 7 concludes the paper and presents some future lines of research.

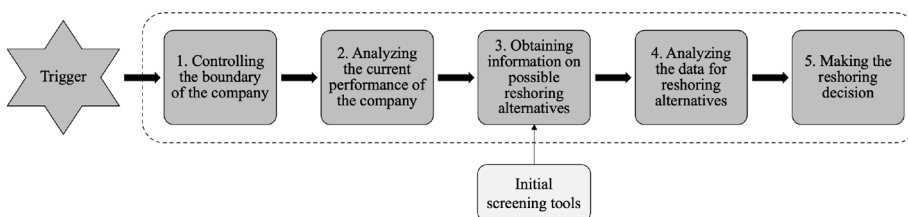
## 2. Literature review

This section provides an overview of literature on the manufacturing reshoring decision-making process and AHP for decision-making.

### 2.1 Manufacturing reshoring decision-making process

The manufacturing reshoring decision-making process comprises five generic steps (Bals *et al.*, 2016), which are as follows:

- controlling the boundary of the company;
- analyzing the current performance of the company;
- obtaining information on possible reshoring alternatives;
- analyzing the data for reshoring alternatives; and
- making the reshoring decision.



**Figure 1.** Initial screening tools in the manufacturing reshoring decision-making process

Source: Bals *et al.* (2016)

There is a limited understanding of various stages and activities within each of these steps. It has been shown that the manufacturing reshoring decision-making process starts with a 'trigger', caused by either an event, opportunity, or problem (Barbieri *et al.*, 2020; Benstead *et al.*, 2017; Boffelli *et al.*, 2018). This trigger then leads to the identification of a gap between the expected and the current performance of the company (step 1) (Gray *et al.*, 2017). A data collection and analysis are realized to evaluate the existing performance of the company. During this process (step 2), the company needs to obtain information about the costs and the investment required, existing and required production capacity, machinery selection, or the current state of a new product development process (Boffelli *et al.*, 2020). Next, (step 3) the company assembles information on the possible reshoring alternatives. For example, some of the alternatives could be to outsource to a local supplier, to relocate to a different region within the home country, or to relocate to the headquarters within the home country. Thereafter, (step 4) the company analyzes the data for the different reshoring alternatives, before arriving at the reshoring decision (step 5). When making this decision, it should be noted that reshoring is only one among several other alternatives that companies pursue after offshoring (Bettiol *et al.*, 2017; Panova and Hilletoth, 2017). Steps (3) – (4) are argued to be especially resource-consuming, thus resulting in opportunity costs (Boffelli *et al.*, 2018, 2020). Therefore, to increase the effectiveness of the decision-making process, we propose that initial screening tools should be used in the nascent steps of the decision-making process to eliminate inappropriate reshoring opportunities (Figure 1).

The initial screening tools are considered as those tools that provide the decision-maker with a way of avoiding unnecessary and costly reshoring options that are most likely not beneficial for the company. The need for initial screening arises from the fact that the decision-making process consumes a significant amount of the company's resources, particularly the involvement of various managerial roles in different stages of the process (Moretto *et al.*, 2020). Furthermore, the decision-making process needs to account for "selective reshoring" which indicate a degree of extent of the activities that needs to be brought back (Baraldi *et al.*, 2018). The decision-making process also involves a governance decision (outsourcing or insourcing), which exacerbates its complexity (Bals *et al.*, 2016; Barbieri *et al.*, 2018). All these activities consume resources in the decision-making process. Therefore, the initial screening tools assist managers in making decisions on whether or not to allocate resources in the first place. The initial screening tools eliminate those reshoring alternatives that do not require further attention from the decision-maker, allowing the decision-maker to concentrate on a smaller set of solutions (Chen *et al.*, 2008). Based on the reshoring decision-making process, it is further proposed that the initial screening tools be used while obtaining information on possible reshoring alternatives. Thus, initial screening tools are beneficial to eliminate uninteresting reshoring alternatives without wasting additional resources. Possible examples of initial screening tools for reshoring are checklists of criteria (Kinkel and Maloca, 2009; Sequeira and Hilletoth, 2019c), fuzzy inference system (Hilletoth *et al.*, 2019b), make-or-buy comparison (Gylling *et al.*, 2015), or other more advanced tools.

Some advanced tools for reshoring decisions have been developed originating from previous offshoring decisions. For example, a new total-landed-cost model was developed for the reshoring decision domain by applying learnings from a previous cost model used for the offshoring decision (Gylling *et al.*, 2015). This model can make a cost-based decision whereby the case company was able to increase its savings through reshoring. However, a need to consider holistic factors has been proposed due to the bounded rationality nature of reshoring decision-making (Boffelli *et al.*, 2020; Ciabuschi *et al.*, 2019; Gray *et al.*, 2017). Therefore, another advanced tool based on a fuzzy inference system was developed to support the reshoring decision-making process in a linguistic manner instead of a numerical

manner which is usually the case (Hilletoft *et al.*, 2019b). The tool, based on fuzzy logic, provides an immediate evaluation of various input values for the different reshoring criteria. The tool was developed using facts and heuristics from experts in the reshoring domain. Six holistic criteria were considered: cost, quality, time, flexibility, innovation, and sustainability. The tool automatically evaluated a reshoring decision based on the six criteria (Hilletoft *et al.*, 2019a). Notably, some AHP-based tools have been developed for reshoring decisions that apply traditional AHP (Sarder *et al.*, 2014; Sequeira and Hilletoft, 2019b) and fuzzy-AHP (Pal *et al.*, 2018a; Sequeira and Hilletoft, 2019a; White and Borchers, 2016). It has been suggested that these kinds of tools should apply a wide set of criteria (Sarder *et al.*, 2014).

### 2.2 Analytical hierarchy process

The AHP, proposed by Saaty (1980), is a popular MCDM method that has a potentially wide range of applications for various problems related to decisions within the operations management domain (Emrouznejad and Marra, 2017; Ho and Ma, 2018; Subramanian and Ramanathan, 2012). The AHP has several advantages over other MCDM methods, such as hierarchical modeling of criteria and the ability to combine qualitative and quantitative criteria. Consequently, the AHP appears to be an adequate method for decision support related to reshoring decisions that use both qualitative and quantitative criteria. Typically, AHP comprises several key steps. In the first step, the decision-makers select the quantitative and qualitative criteria and layer them into a hierarchy, thereby breaking down the complex problem (Saaty, 1980, 2013; Vaidya and Kumar, 2006). Next, the decision-makers compare each criterion with all the other criteria on the same level in a pairwise manner in accordance with Saaty's scale (Saaty, 1980, 2013). Then, a consistency ratio (CR) for each pairwise comparison is calculated. The CR acts as a thermometer for the decision-makers to ascertain whether their comparisons are consistent or not (Wang *et al.*, 2004). In the final step, the AHP method is accompanied by a sensitivity analysis which enhances the overall quality (Borgonovo and Plischke, 2016). The sensitivity analysis helps to understand the stability of the weights of the criteria.

Despite being a feasible decision support tool, the AHP is not impervious to some shortcomings. For example, the AHP is unable to handle fuzziness or any kind of uncertainty in the data (van Laarhoven and Pedrycz, 1983; Leung and Cao, 2000). From a reshoring perspective, some factors can possess high uncertainty over time (Tate *et al.*, 2014). Fuzzy-AHP is therefore introduced as a method to mathematically handle uncertainty and vagueness by implementing the fuzzy set theory, which is an extension to natural set theory and can be applied to the decision-making domain when considering imprecision and vagueness (Zadeh, 1965). The fuzzy set theory is the second most used decision-making method after traditional AHP (Ho, 2008; Liu *et al.*, 2020; Mardani *et al.*, 2015). The reason for implementing fuzzy-AHP is because crisp numbers cannot fully express decision-makers' judgments of qualitative comparisons. Such judgments are represented by different mathematical distributions of the fuzzy sets. When fuzzy sets are used, the procedure to compute the weights is different from that of the traditional AHP method. Therefore, an extended approach was introduced in the development of the fuzzy-AHP method (Chang, 1996). In the fuzzy-AHP, it is difficult to ensure a consistent pairwise comparison. Furthermore, establishing a pairwise comparison matrix requires  $n * (n - 2)/2$  judgments for  $n$  criteria present. Hence, the decision-makers' judgments will most likely be inconsistent when the number of criteria increases. Wang *et al.* (2008), however, presented a method that provides consistent decision rankings from only  $n-1$  pairwise comparisons, thus improving the consistency in the fuzzy-AHP method.



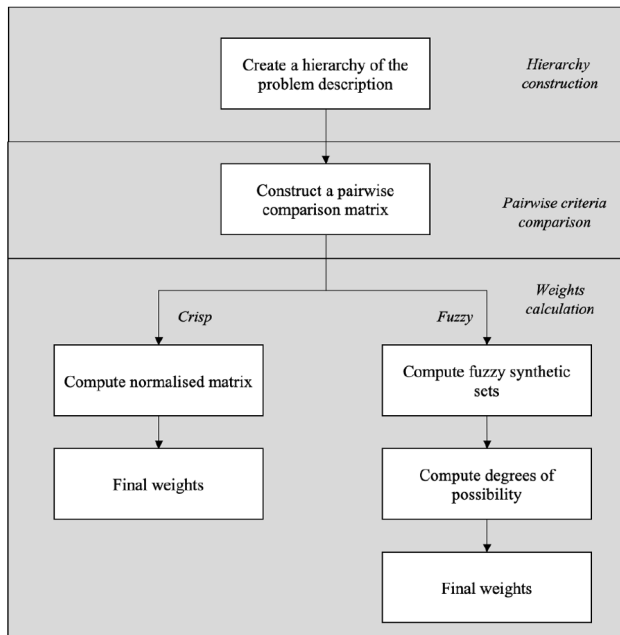
### 3. AHP-based support tools for initial screening of manufacturing reshoring decisions

Two AHP-based support tools have been developed to investigate their suitability for the initial screening of manufacturing reshoring decisions. The development process consists of three main steps for both AHP and fuzzy-AHP: hierarchy construction, pairwise criteria comparison, and weights calculation (Figure 2).

#### Step 1: hierarchy construction

To develop the AHP-support tools for initial screening of manufacturing reshoring decisions, reshoring criteria need to be defined. There are several different ways of defining the criteria, such as literature reviews or a Delphi study with experts (Pal *et al.*, 2018b). In this study, the criteria have been identified based on the reviews pertaining to reshoring drivers, enablers, and barriers (Barbieri *et al.*, 2018; Wiesmann *et al.*, 2017). The criteria can be grouped based on the following competitive priorities that have been addressed in the extant literature: cost, quality, time, flexibility, innovation, and sustainability (Sansone *et al.*, 2017, 2020). The references that led to the selection of these criteria are shown in the table (Table 1).

The six high-level and holistic criteria were structured in the form of a hierarchy (Figure 3). In this hierarchy, the first criterion is “cost”, which is an aggregation of cost, resource, and flow efficiency. Meanwhile, the second criterion is “quality”, which comprises the quality of the product, process, and operations (Robinson and Hsieh, 2016; Di Mauro *et al.*, 2018). The third criterion is “time”, consisting of lead time and time to market (Stentoft *et al.*, 2016b), whereas the fourth criterion is “flexibility”, which is the ability to incorporate changes within operations. This includes how quickly a company can respond to changes in demand and customization (Gray *et al.*, 2017; Zhai *et al.*, 2016). The fifth criterion is “innovation”, which represents the company’s ability to be innovative regarding products, processes, or supply chains (Ancarani



**Figure 2.**  
Development process  
for AHP and fuzzy-  
AHP

et al., 2019; Dachs et al., 2019; Engström et al., 2018a, 2018b). The sixth and final criterion is “sustainability”, which signifies the company’s ability to have sustainable operations (Ashby, 2016; Fratocchi and Di Stefano, 2019). These criteria are relevant for the initial screening of reshoring decisions because they are used to assess competitiveness at any manufacturing location (Hilletoft et al., 2019b). The output of the decision support tool will lead to a course of action, whether to further evaluate reshoring or not (Figure 3). The first alternative implies that a detailed investigation of the reshoring decision situation needs to be pursued, while the second alternative means that no such investigation is necessary.

Step 2: pairwise criteria comparison

A panel of eight industry experts compared and evaluated the six main criteria. The chosen industry experts comprise of the management team from a manufacturing company located in Sweden. The company manufactures various types of forklifts. The Swedish plant oversees the final assembly of the forklifts. Recently, the company has reshored some of the component manufacturing back to Sweden to improve lead-time and flexibility. This type of decision is referred to as ‘reshoring for insourcing’ of the component (Gray et al., 2013). The

No.	Criteria	Selected references
1.	Cost	Gylling et al. (2015), Eriksson et al. (2018), Engström et al. (2018a), Engström et al. (2018b), Gray et al. (2017)
2.	Quality	Robinson and Hsieh (2016), Di Mauro et al. (2018), Engström et al. (2018a), Engström et al. (2018b), Gray et al. (2017)
3.	Time	Bals et al. (2016), Gray et al. (2017); Joubioux and Vanpoucke (2016); Stentoft et al. (2016b); Tate et al. (2014)
4.	Flexibility	Gray et al. (2017), Gylling et al. (2015); Stentoft et al. (2016a); Zhai et al. (2016)
5.	Innovation	Di Mauro et al. (2018), Dachs et al. (2019), Ancarani et al. (2019), Engström et al. (2018a), Engström et al. (2018b)
6.	Sustainability	Ashby (2016), Fratocchi and Di Stefano (2019), Orzes and Sarkis (2019)

Table 1. Selected references supporting the reshoring criteria

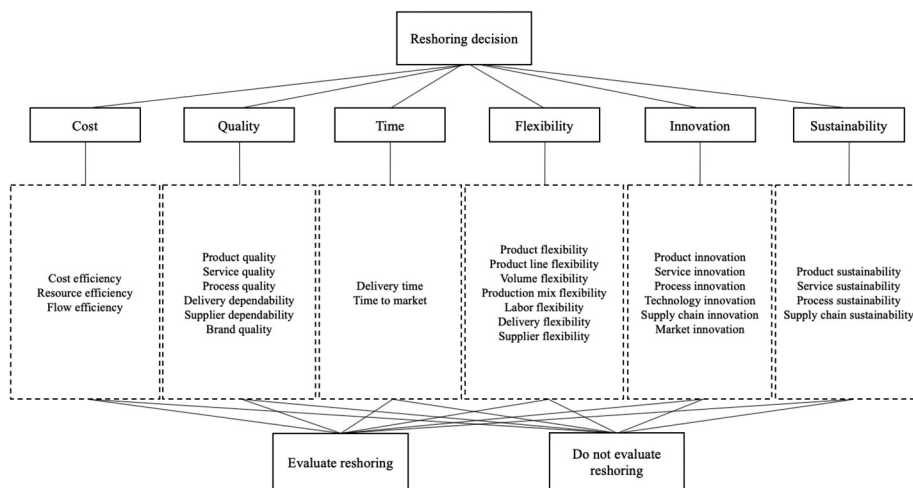


Figure 3. Hierarchy of decision criteria



chosen group of experts handles the reshoring decisions in the company. The experts made an overall comparison of the criteria based on their previous reshoring experience. The criteria comparison was made during a workshop where the experts were physically present, and an average value of their comparisons was considered. All the involved experts concurred that the competitive priorities criteria are a relevant group of criteria to be considered for the development of a decision-making tool for initial screening purposes. According to the involved experts, the relative importance of the criteria may differ in various situations. For example, different companies could assign different degrees of importance to the criteria in general or based on a specific product.

Next, the overall comparisons of the experts were translated into pairwise comparisons using Saaty’s scale (Saaty, 1980, 2013). The pairwise comparison was made in two different ways for the AHP and the fuzzy-AHP respectively. The first one used crisp values, while the second used fuzzy values (Table 2).

These values are used to express the experts’ preferences (Routroy and Pradhan, 2013). The allocation of integers is made in the following manner: for example, if ‘quality’ is moderately preferred over ‘cost’, then either a crisp value 3 or a triangular fuzzy value (1, 3, 5) is entered in the corresponding row and column for the AHP and fuzzy-AHP. This, in turn, leads to a pairwise matrix (A) represented as:

$$A = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix}, \text{ and } a_{ij} = 1 \text{ if } i = j \quad (1)$$

*Step 3: weights calculation*

For the AHP, the matrix is normalized for  $n$  criteria and the resulting weighted normalized matrix (N) is denoted by the following equation:

$$N = \begin{pmatrix} w_{11} & \cdots & w_{1n} \\ \vdots & \ddots & \vdots \\ w_{n1} & \cdots & w_{nn} \end{pmatrix}, \text{ where } w_{ij} = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}} \quad (2)$$

The term  $\sum_{i=1}^n a_{ij}$  is the sum of each column. Next, the weights  $w_i$  are calculated by the equation:

$$w_i = \frac{\sum_{j=1}^n w_{ij}}{n} \quad (3)$$

	Crisp value	Fuzzy values	Verbal interpretation
	1	1,1,1	Equal preference
	3	1,3,5	Moderate preference
	5	3,5,7	Strong preference
	7	5,7,9	Very strong preference
	9	9,9,9	Extremely strong preference

**Table 2.**  
Scale of preference of  
two criteria

Thereafter, the consistency ratio (CR) is calculated as a ratio of consistency index (CI) to random index (RI), and is represented by the following equations:

$$CR = \frac{CI}{RI} \tag{4}$$

$$CI = \frac{\lambda_{\max} - n}{n - 1}, \text{ where } \lambda_{\max} \text{ the maximum eigenvalue of the matrix} \tag{5}$$

As a standard value depending on the number of criteria, the RI value is obtained from the table below (Table 3).

An extended approach is used for the fuzzy-AHP (Chang, 1996). In this approach, first the extent analysis values for each criterion with respect to each decision alternative are obtained. For a given set of criteria  $X = \{x_1, x_2, \dots, x_n\}$  and a set of  $m$  decision alternatives, the extent analysis values are represented by  $M_i^1, M_i^2, \dots, M_i^m$  (where  $i = 1, 2, \dots, n$ ). All of the  $M_i^j$  (where  $j = 1, 2, \dots, m$ ) are triangular fuzzy numbers. Next, the fuzzy synthetic set ( $S_i$ ) is defined by:

$$S_i = \sum_{j=1}^m M_i^j \otimes \left[ \sum_{i=1}^n \sum_{j=1}^m M_i^j \right]^{-1} \tag{6}$$

The degree of possibility for  $M_1 \geq M_2$  is defined by:

$$V(M_1 \geq M_2) = \sup_{x \geq y} [\min(M_1(x), M_2(y))] \tag{7}$$

When a pair  $(x, y)$  exists such as  $x \geq y$  and  $M_1(x) = M_2(y)$ , we then have  $V(M_1 \geq M_2) = 1$ , otherwise,

$$V(M_1 \geq M_2) = \frac{hgt(M_1 \cap M_2)}{(m_2 - u_2) - (m_1 - l_1)}, \tag{8}$$

In the above equation,  $(l_1, m_1, u_1)$  and  $(l_2, m_2, u_2)$  are lower, middle and upper values of  $M_1$ , and  $M_2$  respectively. The values  $V(M_1 \geq M_2)$  are normalized to obtain the final priority weights.

The resulting weights from AHP and fuzzy-AHP are used to evaluate the reshoring scenarios using a weighted sum technique to arrive at an output from the AHP and fuzzy-AHP using the following equation:

$$O_1 = \sum_{i=1}^n x_i w_i \tag{9}$$

**Table 3.**  
Average random  
inconsistency index  
based on number of  
criteria (Saaty, 1980)

No. of criteria (n)	1	2	3	4	5	6	7	8	9	10
Random inconsistency (RI)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

In the above equation,  $O_1$  denotes the output of either AHP or fuzzy-AHP,  $x_i$  signifies the value of the criteria in the reshoring scenario,  $w_i$  is the weight of the criteria from either AHP or fuzzy-AHP.

**4. Results**

The following section presents the results concerning the priority weights obtained for both AHP and fuzzy-AHP, the output of the evaluation of the manufacturing reshoring scenarios, and the output from the sensitivity analysis.

*4.1 Priority weights*

For the AHP, the result of the pairwise comparison of the reshoring criteria is shown in Table 4, whereas a normalized matrix is presented in Table 5. As per the priority weights, “quality” has the highest weight (0.41), followed by “cost” (0.29). Meanwhile, “sustainability” has the lowest weight (0.03). Finally, the value of the CR is calculated to be 0.069, which is within the acceptable limit of 0.1 (Saaty, 1980).

For the fuzzy-AHP, the result of the pairwise comparison of the reshoring criteria is shown in Table 6.

The values of  $L_i$ ,  $M_i$  and  $U_i$  for a criterion are computed by adding the corresponding lower, middle, and upper values across the row. This process is repeated for each of the six criteria and summed along the column  $L_i$ ,  $M_i$  and  $U_i$ . Next, the fuzzy synthetic set ( $S_i$ ) and degrees of possibility are calculated and summarized (Table 7). These values are normalized to obtain the final weighted matrix (Table 8). According to the priority weights, “quality” has the highest weight (0.41), “cost” is second (0.38), while “sustainability” has zero weight.

*4.2 Scenario evaluation*

The priority weights from the AHP and fuzzy-AHP methods are applied to 20 reshoring scenarios (Table 9). A reshoring scenario consists of six input values  $X = [x_1, x_2, x_3, x_4, x_5,$

**Table 4.**  
Pairwise comparison  
of criteria

Criteria ( $x_i$ )	Cost	Quality	Time	Flexibility	Innovation	Sustainability
Cost	1	1/3	5	5	5	7
Quality	3	1	5	5	5	7
Time	1/5	1/5	1	1	1	5
Flexibility	1/5	1/5	1	1	1	5
Innovation	1/5	1/5	1	1	1	5
Sustainability	1/7	1/7	1/5	1/5	1/5	1

**Table 5.**  
Normalized table and  
final weights

Criteria	Cost	Quality	Time	Flexibility	Innovation	Sustainability	Final weights
Cost	0.21	0.16	0.38	0.38	0.38	0.23	0.29
Quality	0.63	0.48	0.38	0.38	0.38	0.23	0.41
Time	0.04	0.10	0.08	0.08	0.08	0.17	0.09
Flexibility	0.04	0.10	0.08	0.08	0.08	0.17	0.09
Innovation	0.04	0.10	0.08	0.08	0.08	0.17	0.09
Sustainability	0.03	0.07	0.02	0.02	0.02	0.03	0.03

**Note:**  $\lambda_{max} = 6.43$ ; CR = 0.069

	Cost	Quality	Time	Flexibility	Innovation	Sustainability	$L_i$	$M_i$	$U_i$
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
Flexibility	(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
Innovation	(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
Sustainability	(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

**Table 6.**  
Pairwise comparison  
using fuzzy sets

$x_6$ ] representing the six reshoring criteria presented in section 3. The input values range from  $-5$  to  $+5$ , where a value of  $-5$  indicates that reshoring will have an extremely negative impact on the criterion. Similarly, a value of  $+5$  indicates that reshoring will have an extremely positive impact on the criterion. Additionally, the value  $0$  indicates that reshoring would have no impact on the criterion. A total of twenty reshoring scenarios were defined based on realistic reshoring situations. The industry experts were asked to share their views on how the scenarios would be evaluated in a realistic reshoring decision situation. The output values also range from  $-5$  to  $+5$ , where all values between  $-5$  and  $0$  are assigned the output recommendation 'Do not evaluate', while values above  $0$  are assigned the output recommendation 'Evaluate'. The outputs from both the AHP decision support tool ( $O_1$ ) and the fuzzy-AHP decision support tool ( $O_2$ ) are calculated as a weighted sum, before being compared to evaluate whether there exists any noticeable difference between the two tools. Thereafter, the difference in outputs between the two tools is measured as an absolute error (e). The mean absolute error (MAE) between the tools is also calculated for the twenty scenarios (Table 10).

For instance, in the first reshoring scenario (Table 9), the cost criterion will be extremely negatively impacted, whereas the quality, time, flexibility and innovation criteria will be slightly negatively impacted. In contrast, the (social) sustainability criterion will be positively impacted (e.g. a case in which reshoring of the component becomes a labor-intensive process). After examining this scenario, the involved experts confidently agreed that this scenario is not interesting to further evaluate. The developed decision support tools indicate a similar decision, albeit with a lower value than the experts. In another instance, in the ninth reshoring scenario, all the criteria except for sustainability, are positively impacted (e.g. a case in which reshoring the component would increase carbon emissions in the manufacturing process). The involved experts confidently agreed that this scenario is interesting to pursue reshoring. A similar decision was suggested by the developed support tools, albeit with a lower value than the industry experts. Other scenarios can be interpreted from the table in a similar manner.

The results indicate that there exists some level of agreement in the decisions between the AHP and the fuzzy-AHP tools. Out of the 20 scenarios, 18 of them provided the same

**Table 7.**  
Degree of possibility

$S_1 \geq S_2$	0.93	$S_2 \geq S_1$	1	$S_3 \geq S_1$	0.23	$S_4 \geq S_1$	0.23	$S_5 \geq S_1$	0.23	$S_6 \geq S_1$	0
$S_1 \geq S_3$	1	$S_2 \geq S_3$	1	$S_3 \geq S_2$	0.18	$S_4 \geq S_2$	0.18	$S_5 \geq S_2$	0.18	$S_6 \geq S_2$	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	0.93		1		0.18		0.18		0.18		0

**Table 8.**  
Final weights

Criteria	Weight vector	Final weights
Cost	0.93	0.38
Quality	1.00	0.41
Time	0.18	0.07
Flexibility	0.18	0.07
Innovation	0.18	0.07
Sustainability	0	0

Scenarios	Cost	Quality	Time	Flexibility	Innovation	Sustainability	Expert opinion	AHP out-put (O <sub>1</sub> )	Decision from AHP	Fuzzy-AHP output (O <sub>2</sub> )	Decision from fuzzy-AHP	Absolute error e
1	-5	-1	-3	-2	-3	3	-5	-2.49	Do not evaluate	-2.87	Do not evaluate	0.38
2	2	5	-1	3	4	1	4	3.21	Evaluate	3.22	Evaluate	0.01
3	-3	-4	-3	-1	4	-1	-4	-2.56	Do not evaluate	-2.75	Do not evaluate	0.19
4	3	-4	-1	-3	-5	-3	-4	-1.67	Do not evaluate	-1.14	Do not evaluate	0.53
5	-4	-2	5	-1	-1	5	-4	-1.57	Do not evaluate	-2.10	Do not evaluate	0.53
6	4	2	-4	2	2	-5	4	1.84	Evaluate	2.32	Evaluate	0.48
7	-4	2	1	2	2	5	4	0.26	Evaluate	-0.34a	Do not evaluate	0.60
8	2	-1	3	-1	1	5	3	0.58	Evaluate	0.57	Evaluate	0.01
9	3	5	5	2	5	-3	5	3.92	Evaluate	4.03	Evaluate	0.11
10	-3	-5	3	-2	5	-2	-4	-2.47	Do not evaluate	-2.73	Do not evaluate	0.26
11	-3	5	5	3	5	-3	4	2.26	Evaluate	1.84	Evaluate	0.42
12	1	-5	1	1	1	-5	3	-1.66a	Do not evaluate	-1.43a	Do not evaluate	0.23
13	-5	1	-5	-5	-5	1	-3	-2.34	Do not evaluate	-2.57	Do not evaluate	0.23
14	5	-1	5	5	5	-1	3	2.34	Evaluate	2.57	Evaluate	0.23
15	-1	5	-1	-1	-1	5	-3	1.66 <sup>a</sup>	Evaluate	1.43 <sup>a</sup>	Evaluate	0.23
16	0	0	0	0	0	0	-3	0.00	Do not evaluate	0.00	Do not evaluate	0.00
17	3	-4	2	-2	-2	2	-3	-0.90	Do not evaluate	-0.66	Do not evaluate	0.24
18	-5	0	3	5	5	4	3	-0.18a	Do not evaluate	-0.94a	Do not evaluate	0.76
19	-5	4	2	-1	-4	3	-3	0.03 <sup>a</sup>	Evaluate	-0.48	Do not evaluate	0.51
20	-2	-5	-5	-2	-5	5	-5	-3.57	Do not evaluate	-3.65	Do not evaluate	0.08

Note: <sup>a</sup>Conflict in decision between output from the tool and the experts

**Table 9.**  
Evaluation of  
reshoring scenarios  
based on outputs  
from AHP and fuzzy-  
AHP



decision. The remaining two scenarios (scenarios 7 and 19) provided conflicting decisions from the two tools. For these two scenarios, the absolute error (e) between the AHP and fuzzy-AHP is 0.6 and 0.51, respectively. The errors between the two outputs are small when compared with the range of the output (that is, -5 to +5). Outputs that are close to zero suggest a weak decision in both the support tools.

When the outputs from the AHP are compared with the experts' recommendations, four of the decisions stemming from the tool are found to conflict with the experts' recommendations. The conflicting decisions were observed for scenarios 12, 15, 18 and 19. Also, when comparing the outputs from the fuzzy-AHP with the experts' recommendations, four of the decisions are observed to be inconsistent. The conflicting decisions were observed for scenarios 7, 12, 15 and 18. When cross-comparing the errors between the experts, AHP and fuzzy-AHP, the following can be observed (Table 10).

#### 4.3 Sensitivity analysis

In this paper, cost and quality emerge as the most important criteria when it comes to manufacturing reshoring decisions. This is consistent with the results from previous studies that indicate that cost, but especially quality, are important to companies in high-cost countries (Engström *et al.*, 2018a, 2018b). The presented decision support tools involved subjective judgments, which creates a risk of altering the order of importance of the criteria (Moktadir *et al.*, 2018). Consequently, it is paramount to comprehend the manner in which even small changes in the weight of one criterion may cause a relative change in the weights of the other criteria. Sensitivity analysis is thus applied to examine the stability of the ranking of the criteria when subject to small changes (Chang *et al.*, 2007). A sensitivity analysis is performed for the two most influential reshoring criteria, namely, cost and quality, for the AHP and the fuzzy-AHP. The criterion cost is incremented in steps of 0.1 in its priority weight, after which the corresponding changes in the priority weights of the other criteria are recorded (Figure 4). Next, the criterion quality is incremented in steps of 0.1 and the corresponding changes in the weights of the other criteria are recorded (Figure 5). In both figures, the lines for the criteria time, flexibility, and innovation overlap indicating that their priority weights are the same. A similar behavior was observed for fuzzy-AHP, the major difference being that the sustainability criterion obtained zero priority weight for all combinations of values for cost and quality.

In Figure 4, when the priority weight of the cost criterion increases, the criteria cost and quality switch position in their importance. At high values for the priority weights of cost, the sustainability criterion slowly reduces its priority weight to zero. This implies that for high values of cost or quality, the decision is mainly driven by the input values of cost and quality. Any uncertainty or change caused by internal or external events or other criteria will not have any effect on the decision. On the other hand, for low values of priority weight of cost, other criteria, such as time, flexibility, and innovation switch their level of importance. This means that the order of importance is unstable for low values of cost and quality (between 0.3 and 0.4). For these values of cost and quality, any uncertainty or change induced by internal/external events or other criteria will have an impact on the decision.

**Table 10.**  
Mean absolute errors  
between AHP, fuzzy-  
AHP and expert's  
opinion

Comparison in error	Mean absolute error
Between expert's opinion and AHP	2.28
Between expert's opinion and fuzzy-AHP	2.23
Between AHP and fuzzy-AHP	0.30

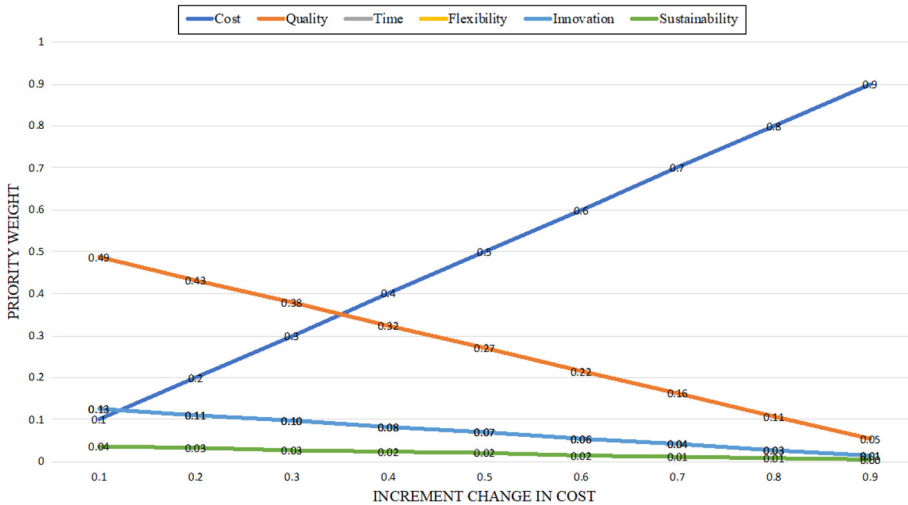


Figure 4. Sensitivity analysis concerning Cost

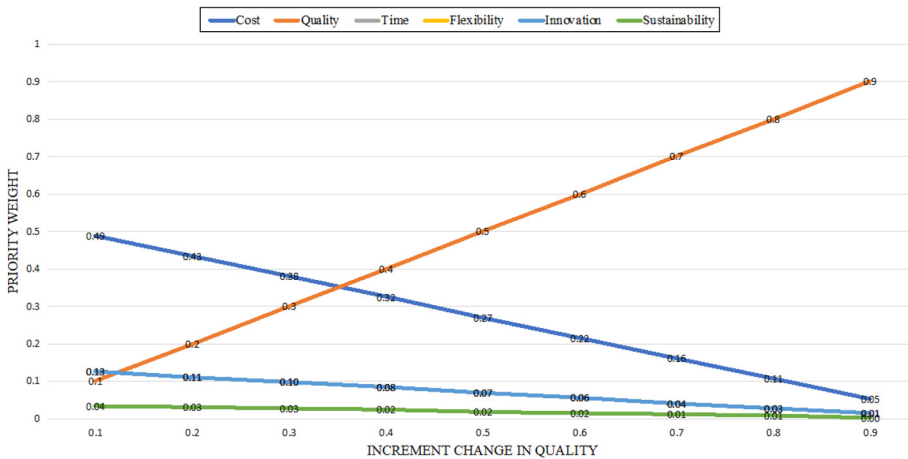


Figure 5. Sensitivity analysis concerning Quality

Similar observations were made when the quality criterion was incrementally increased or decreased.

### 5. Discussion

The decision-making process of manufacturing reshoring has not yet been extensively studied due to the novelty of the phenomenon (Barbieri et al., 2018; Stentoft et al., 2016b). So far, limited studies have been carried out on AHP-based support tools for the decision-making process relating to manufacturing reshoring (Pal et al., 2018a; Sarder et al., 2014; Sequeira and Hilletoft, 2019a, 2019b; White and Borchers, 2016), whereas nearby domains, such as supplier selection and evaluation, have, to a large extent, taken advantage of a multitude of decision support tools (Emrouznejad and Marra, 2017; Vaidya and Kumar,

2006). Consequently, complex reshoring decisions necessitate the development of more tools to support the decision-making process. An interesting avenue to follow for the purpose of developing decision support tools concerning complex reshoring decision-making is related to initial screening. An initial screening tool eliminates uninteresting reshoring alternatives and allows the decision-maker to concentrate on a limited set of solutions (Chen *et al.*, 2008). Such a tool is used to signal to the decision-makers not to invest time and resources on unpromising reshoring activities, and therefore, to end the decision-making process early. This study investigates support tools for the initial screening of manufacturing reshoring decisions. Two methods have been previously explored in the context of manufacturing reshoring decision-making: AHP (Sarder *et al.*, 2014) and fuzzy-AHP (Pal *et al.*, 2018a; White and Borchers, 2016). However, further research on these methods is still required (Sarder *et al.*, 2014). Therefore, two tools based on the AHP and fuzzy-AHP were explored for initial screening of manufacturing reshoring decisions by applying twenty different reshoring scenarios. The results indicate that the differences between both these tools are negligible, as evidenced by the presented MAE values. This suggests that both tools behave similarly on a high level. This observation was also confirmed by the sensitivity analysis.

When comparing the AHP and fuzzy-AHP tools, different priority weights have been obtained for the reshoring criteria, although the differences are not significant. One of the less important criteria in the AHP evaluation, sustainability, received a zero-priority weight in the fuzzy-AHP evaluation. This suggests that during uncertainty, it is possible that some of the criteria receive zero weights, thus implying that they will not be considered in a decision (Wang *et al.*, 2008). Furthermore, the criteria's order of importance did not change when incorporating fuzziness. The sensitivity analysis, however, revealed that the order of importance is likely to switch for higher priority weights for the cost and quality criteria. Regarding low priority weights for cost and quality, other criteria (time, flexibility, and innovation) are likely to switch their order of importance. When comparing the findings of this study to those of previous MCDM studies related to reshoring decision support, it is interesting to note that a similar order of importance among the criteria was observed (Sarder *et al.*, 2014). As a case in point, quality was considered the most important criterion followed by cost (logistics cost) in the reshoring domain (Sarder *et al.*, 2014). However, in another study, where fuzzy-AHP was used, flexibility emerged as the most important criterion followed by quality in the reshoring domain (Pal *et al.*, 2018a). The sustainability criterion did not receive high weights and it is claimed that sustainability is often taken for granted (Pal *et al.*, 2018a). This may partially explain why sustainability turned out to be the least important criterion in the developed decision support tools, especially for initial screening purposes. Future research needs to be directed toward incorporating sustainability objectives in decision support tools for the initial screening of manufacturing reshoring decisions.

The confidence in the decisions is indicated by the output values from the decision tools. Despite the inconsistency between the experts' recommendation and the decision from the tools for some reshoring scenarios, the output values indicated a low confidence in these decisions. One way to mitigate the problem of low confidence is by defining multiple output values, rather than binary output values, as observed in the tools involved in this study. Comparing both tools, fuzzy-AHP was found to have a slightly lower MAE than the AHP when both were compared against the experts' recommendations, thus indicating that fuzzy-AHP performed only slightly better. The mean error in decision is 2.28 and 2.23 for AHP and fuzzy-AHP, respectively. The size of the errors was observed to be higher than the reshoring decision support tools based on a fuzzy inference system (Hilletoft *et al.*, 2019b). One plausible reason for this behavior is that the fuzzy inference system is more advanced

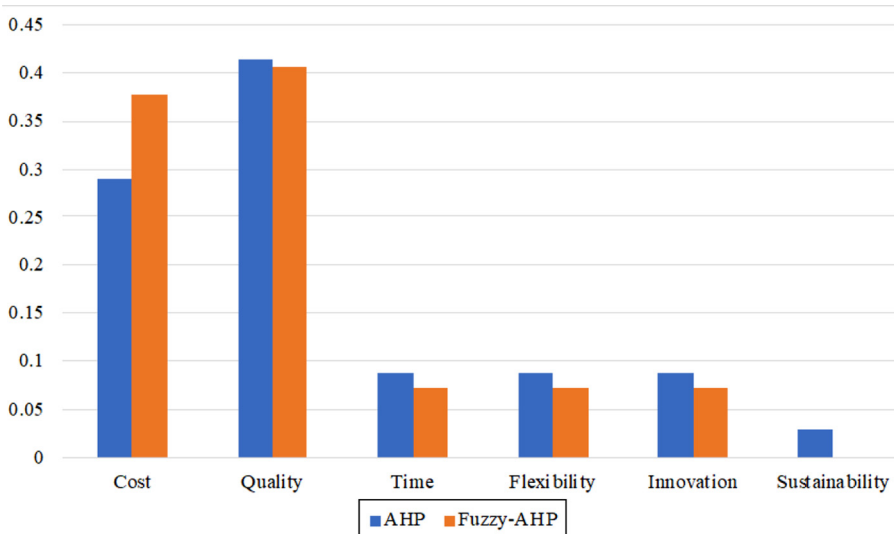
concerning configurations, membership functions, and fuzzy rules, something that is lacking in AHP-based tools. As initial screening tools for reshoring decisions, 80% out of the twenty reshoring scenarios have been consistent with the experts' recommendations. Therefore, it can be inferred that traditional AHP and fuzzy-AHP support tools provide satisfactory results. Regarding the generalizability of the tools, the developed tools cannot claim to be fully generalizable because the criteria were evaluated by only a limited number of industry experts. In order for these tools to be fully generalizable, the priority weights should be in agreement with those arrived at by other decision-makers through a larger sample of experts. This leads to the following propositions:

- P1. AHP and fuzzy-AHP are suitable tools for the initial screening of manufacturing reshoring decisions.
- P2. Incorporating fuzziness into the manufacturing reshoring criteria slightly enhances the accuracy of the decision.

Many existing frameworks have used the criteria originating from companies' competitive priorities (Benstead *et al.*, 2017; Wiesmann *et al.*, 2017). In line with such research, this study also applied the criteria that correspond to competitive priorities. This is because competitiveness is usually highly requested by most companies. The six criteria applied in this paper are based on the recent studies conducted on competitive priorities (Hilletoft *et al.*, 2019b; Sansone *et al.*, 2020). The competitive priorities criteria constitute a feasible set to develop initial screening tools for manufacturing reshoring decisions. Notably, the six criteria are on a high level comparable to those used in prior AHP and fuzzy-AHP studies within the manufacturing reshoring domain (Pal *et al.*, 2018a; Sarder *et al.*, 2014).

The priority weights of the criteria obtained in both AHP and fuzzy-AHP were slightly different (Figure 6).

A difference was observed in the cost criterion, where an increase was observed in the weight of the criterion for the fuzzy-AHP. This suggests that when uncertainty is introduced



**Figure 6.**  
Comparison of  
priority weights of  
criteria in AHP and  
fuzzy-AHP

in a decision, the weight of an already important criterion increases compared to the weight in AHP. Consequently, the uncertainty in decision-making will favor important criteria. In contrast, the opposite was observed among the less important criteria. The importance of the sustainability criterion, for example, was reduced to zero in the fuzzy-AHP. This, in turn, leads to important decision-making implications involving sustainability being a low weight criterion. First, the zero-weight criterion will be completely neglected in the initial screening of manufacturing reshoring decisions, which can be perceived as a disadvantage (Wang *et al.*, 2008). It becomes a disadvantage when criteria from competitive priorities are used since one of the priorities is completely neglected in a fuzzy-AHP decision tool (that is, sustainability). This is consistent with a recent literature review, according to which “neither scholars nor firms’ managers and entrepreneurs considered the environmental and social pillars of sustainability” during reshoring decision-making (Fratocchi and Di Stefano, 2019, p. 468). A plausible reason for this assertion is that the companies that are reshoring back to high-cost countries are required to contemplate more stringent environmental and social sustainability regulations from the onset and thus, take sustainability issues for granted (Pal *et al.*, 2018a). To reiterate, there is a paucity of research related to sustainability and its associated impact on reshoring decisions. Also, assigning low importance to sustainability during the pairwise analysis in the fuzzy-AHP is something that needs to be further evaluated by the industry experts. As shown in this paper, incorporating uncertainty in decision-making leads to the augmentation of the weights of the more important decision criteria, while simultaneously reducing the weights of the less important decision criteria. However, this might lead to questions, such as why environmental and social sustainability reshoring criteria are still highly unexplored (Orzes and Sarkis, 2019). This leads to the following propositions:

- P3.* Competitive priorities criteria is a suitable group of criteria to include in the initial screening tools for manufacturing reshoring decisions.
- P4.* Incorporating fuzziness into manufacturing reshoring criteria augments the importance of already important criteria and reduces the importance of already unimportant criteria.

In this study, both presented tools provided an equal number of coherent decisions when compared to those of the industry experts. Out of the twenty presented reshoring scenarios, both tools provided 16 coherent decisions, thus yielding a decision reliability of 80%. This indicates that there is a scope for further improvement of the decision reliability of the tools. One way could be to explore other means of combining weights with values of criteria. For example, a weighted product technique has shown to be superior to the classical weighted-sum technique (Krejčí and Stoklasa, 2018). In previous studies, AHP and fuzzy-AHP have been used to obtain criteria weights, but they have not been used to evaluate different reshoring scenarios. Unfortunately, this means that the reliability of the decisions presented in this study cannot be compared with those reported in previous studies (Pal *et al.*, 2018a; Sarder *et al.*, 2014). It can also be disputed if the pairwise comparisons are situational and company-dependent and if the weights for reshoring decisions can be linked to competitive priorities in a general manner. It is for this reason that further research could bring about improvements in the decision support tools within this area. The decisions provided by the developed support tools are binary decisions, that is either ‘Evaluate or ‘Do not evaluate’. Furthermore, a small value is enough to switch the decisions. As a case in point, for an output value of 0.00, the decision is ‘Do not evaluate’, while for an output of 0.01 the decision is ‘Evaluate.’ Hence, a diminutive increase of only 0.01 in the output can lead to a shift in the decision, whether to evaluate reshoring or not. Therefore, and to further improve the tools’

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accuracy, it would be desirable to introduce a range of “middle” decisions (for instance, strongly or weakly-recommend evaluation) containing all the non-coherent output values from the AHP and fuzzy-AHP. This leads to the following proposition:

- P5.* The reliability of the traditional AHP and the fuzzy-AHP tools in manufacturing reshoring can be increased by incorporating middle decisions to complement the two extreme decisions.

Rapid changes in global competitive conditions, caused, for example, by the coronavirus pandemic, create uncertainty in decisions that needs to be factored into the decision support tools. In this study, the fuzzy-AHP tool is shown to be capable of handling uncertainty by increasing the weights of the important criteria. This emphasizes the importance of uncertainty-based decision support tools, such as the fuzzy-AHP, in manufacturing decisions. A significant step in the process is by limiting the number of criteria on a high level to reduce the complexity of the decision-making problem. The complexity is also reduced further by structuring the criteria in a hierarchy, which is the first step in simplifying the complex reshoring problem. This also makes the criteria observable to the decision-makers (Sequeira and Hilletoft, 2019c). It requires, however, the decision-makers to possess sufficient knowledge of the criteria and the relationships between them (Saaty, 1980; Vaidya and Kumar, 2006).

## 6. Implications for practice and society

This study has several managerial implications concerning the decision-making process when dealing with manufacturing reshoring. The first implication is that the developed AHP and fuzzy-AHP tools provide a decision-related suggestion to the managers on whether the reshoring decision-making process should be continued or not. Managers can evaluate various reshoring scenarios with the same tools and, accordingly, pursue the most promising scenario. Considering the recent findings of behavioral aspects inherent in the decision-making process (Boffelli *et al.*, 2020), the need for fuzzy-AHP tools is paramount. Furthermore, when the complexity is high, the balance of weights of the criteria shifts toward already important criteria, such as cost and quality. Therefore, the second implication is that the managers benefit more from fuzzy-AHP than a traditional AHP when dealing with complex reshoring decisions. While making reshoring decisions, managers find themselves ambivalent as to whether they should wait for complete information or take an early decision. The presented tools guide managers to consider holistic criteria of competitiveness while providing a rapid evaluation of any possible reshoring opportunity. The holistic competitiveness criteria are regarded as a suitable starting point to evaluate reshoring opportunities. Thus, the third implication is that the managers would not have to experience an “information overload” during the initial screening of reshoring decisions as they only need to consider a few, yet holistic criteria. In this study, the criteria were weighted using pairwise comparisons. Therefore, the fourth implication is that competitiveness criteria can be suitably prioritized in a reshoring decision-making process. The potential success of the AHP method suggests the suitability of a hierarchical structure of criteria in the reshoring decision-making process. This hierarchy could be tailored to the needs of the company by incorporating company-specific sub-criteria and sub-sub-criteria. To conclude, the tools explored in this study are most beneficial to managers to avoid unnecessary and costly reshoring options.

This study also has several implications for society. Firstly, manufacturing reshoring is a part of an important economic agenda in several industrialized countries. This can be ascribed to the positive impact of the manufacturing industry on a country's overall



economy, particularly at a time when the ongoing pandemic has been catastrophic for the global economy at large. Therefore, as a step toward rebuilding the economy, the developed decision support tools help accelerate the reshoring decision-making process. Secondly, manufacturing reshoring can re-ignite relationships with local suppliers and help create a positive rate of employment in a region. Therefore, the developed tools have the potential to expedite these positive impacts. Thirdly, the use of a relative scale from  $-5$  to  $+5$  for the criteria in the developed support tools allows for simpler communication with external stakeholders (e.g. customers, suppliers, or policymakers) than absolute values (Hilletoft *et al.*, 2019b). Furthermore, this type of scale can facilitate both rational and intuitive behavioral types of decision-making (Boffelli *et al.*, 2020). Finally, this study contemplates the sustainability criterion in the developed decision support tools to ensure that companies do not disregard the United Nations' sustainability goals in this process. Surprisingly, the sustainability goals seem to have been taken for granted while evaluating reshoring decisions (Pal *et al.*, 2018a). Therefore, these goals must be explicitly communicated to society. We hope that a sustainability thinking is increasingly taken into consideration in such types of decisions.

## 7. Conclusion

This paper presents how decision support tools, built upon AHP and fuzzy-AHP methods, can be used for the initial screening of manufacturing reshoring decisions based on competitive priority criteria. The current literature within the reshoring domain suffers not only from a paucity of research on how manufacturing reshoring decisions are taken, but also from a limited number of support tools that enable optimal decision-making related to reshoring. Furthermore, manufacturing reshoring decisions are inherently complex and can be both time consuming and resource intensive, thus escalating the opportunity costs. An initial screening tool has the potential of eliminating uninteresting reshoring opportunities. Using this as a starting point, this study investigated the suitability of the AHP and fuzzy-AHP methods as potential tools for the initial screening of manufacturing reshoring decisions. Although both methods are well established in literature, they have not been adequately applied to the manufacturing reshoring decision-making domain. To validate the feasibility of applying the AHP and fuzzy-AHP methods in this domain, six criteria stemming from the competitive priorities area were used, since the general goal of any relocation decision should be to increase the company's competitiveness. The six criteria were subjected to pairwise comparisons in both AHP and fuzzy-AHP by engaging a panel of industry experts on manufacturing reshoring; as a result, priority weights for the six criteria were obtained. The research presented in this paper contends that both AHP and fuzzy-AHP are suitable tools for the initial screening of manufacturing reshoring decisions. In the latter tool, the fuzziness introduced to the reshoring criteria led to a slightly better alignment between the tool and the experts' recommendations. The fuzziness introduced also augmented the weights of already important criteria while reducing the weights of the less important criteria. The research proposes that the reliability of the tools can be improved by incorporating middle decisions in the output, since errors were detected among a small set of output values when the output lied in the middle of two extreme binary decisions. Moreover, the competitive priorities criteria observed to be suitable when developing the initial screening tools for manufacturing reshoring decisions.

For future research, the traditional AHP and fuzzy-AHP need to be applied to other types of criteria in the manufacturing reshoring domain instead of those stemming from the competitive priorities, such as specific companies' resources, capabilities, or risks. This would make the tools more sophisticated and applicable beyond initial screening. Both

traditional AHP and fuzzy-AHP should be explored using real cases, where the collected data should be incorporated into the tools. Such explorative studies could yield interesting findings, not only with respect to the tools themselves, but also in terms of the reshoring decision-making process. Furthermore, these tools need to be explored in other manufacturing contexts with a view to increase their generalizability. Another important avenue for future research would be to investigate the role of 'sustainability' in reshoring research. As a matter of fact, recent calls for this type of research have already been proposed (Orzes and Sarkis, 2019). One potential reason for the low interest in sustainability might be that many sustainability issues are already legislated in many countries. Furthermore, companies might need to consider sustainability in the new location, but it is regarded more as a boundary condition (or an order qualifier) than a competitive priority. Hence, there exists an unexplored relationship between sustainability and reshoring which merits further investigation. Another future research avenue would be to explore priority weights in different types of contexts. In this study, the priority weights had the perspective of reshoring to a high-cost country; however, other contexts may entail priority weights that are dissimilar to those applied in this study, thus leading to different results.

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