A Supplier Selection Model for the Wood Fiber Supply Industry

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The wood fiber industry has a complex and sensitive supply chain. Consumers and suppliers across the wood fiber supply industry share a highly dynamic relationship, but they lack a structured technique to evaluate and improve the flow of information and materials. The goal of this study was to develop a mathematical model based on supplier selection and assessment criteria using structured, multi-criteria decision-making methods. The first method was the analytic hierarchy process (AHP) and the second method was the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS). These methods were chosen based on their acceptance and use in previous research. The hybrid model was implemented as a software tool based on Microsoft Excel and Visual Basic. The tool improved the way in which wood product firms selected their suppliers and guaranteed that the best available alternatives were selected, thus increasing the chance of a successful supplier-consumer relationship and increasing the value that the company receives from its supplier base. Seven interviews were conducted in the wood fiber industry to validate the tool. The tool was found to be applicable and a valuable approach, as reported by most participants.

Keywords: Supplier selection; Supply chain; Wood fiber supply industry; Purchasing; Multi-criteria decision-making methods

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INTRODUCTION

Today's competitive environment is characterized by thin profit margins, high quality expectations, and short lead times (Yadav and Sharma 2016). Companies are forced to take advantage of every opportunity to optimize their business processes. Academics and practitioners have concluded that for a company to remain competitive, it must work closely with its supply chain partners to improve the supply chain's performance. Thus, the supplier selection and evaluation function of business organizations is becoming more important (Bhutta and Huq 2002). A company's ability to handle the procurement process, including supplier relationships, has a profound impact on its competitiveness and profit-generating capacity (Gadde *et al.* 2010). In addition, adding value to the supply chain is a crucial aspect that must be emphasized when selecting and evaluating suppliers to achieve a competitive advantage (Bhutta and Huq 2002). It is impossible to successfully produce low-cost, high-quality products without the appropriate vendors (Yadav and Sharma 2016). Therefore, one of the most important activities for procurement is the selection of a competent group of suppliers. A suitable supplier may become a long-term partner, which can help the growth of the company. Hence, a systematic and effective method of selecting the most appropriate supplier becomes necessary. The novelty of the approach proposed in this paper relies in the application of structured and systematic methods to select and evaluate suppliers, with a focus on the wood fiber supply industry.

Why is a Supplier Selection Model Helpful for the Wood Fiber Supply Industry?

Supplier selection and evaluation is one of the most critical functions for the success of an organization because a company's ability to handle purchasing has a profound impact on its competitiveness and profit-generating capacity (Bhutta and Huq 2002; Gadde *et al.* 2010). A report on the wood supply chain in the United States by Barynin and Taylor (2013) found that supplier-consumer relationships within the wood industry are currently tense. There is a need to rebuild the business relationships to minimize disruptions in the wood flow throughout the supply chain. In their recommendations, these authors urge both wood suppliers and wood consumers to address their business strategies and relationships to achieve successful performance in the marketplace (Barynin and Taylor 2013). Rodgers *et al.* (2002) indicate that the lack of planning and communication is a drawback that can affect the logger's ability to plan operations in the fiber supply chain. Reactive environments can negatively impact the cost of production, productivity, and efficiency. This implies that effective communication and collaboration with the best suppliers available is necessary to improve planning across the supply chain.

For these reasons, a structured supplier selection system model, fundamental to MCDM models, can be useful to help practitioners in the wood fiber supply industry improve their procurement practices and the relationships with their suppliers.

The wood fiber supply industry includes the processes, procedures, and metrics related to harvesting, transportation, storing, production, and delivery operations of wood products such as lumber, pulp paper, wood pellets, and others.

Literature Review

Supply chain management

Supply chain management is defined by Krivokuka *et al.* (2013) as the effective integration and management of the supply chain, encompassing all activities related to the flow and transformation of goods, from the stage of raw material extraction to the final customer, as well as related information flows. Materials and information flow both upstream and downstream in the supply chain (Ballou 2004). In recent years, the study of supply chain management has become more relevant in modern business environments, seeking to define efficient supply chain management as a key to business continuity (Cabral *et al.* 2012). Competition at the international level as well as the globalization of markets pressure firms to reduce their costs, while demanding a more reactive operational response for the customer (Tinham 2005).

Because of globalization, supply chains are now more vulnerable to disruptive events than before (Ma *et al.* 2014). Disruption can have a huge negative impact if the company does not have a resilient supply chain network. Resiliency is defined as the company's ability to quickly return to a normal performance level after a disruption. Under this condition, the firm is not able to capitalize the market demand due to product shortages. Therefore, a resilient supply chain network design is required to avoid losing market share to competitors while minimizing any risks (Rezapour *et al.* 2017).

The factors that are associated with supply chain disruption are varied (Park *et al.* 2010). These variables are classified into internal, which relates to risks in different entities up and down the supply chain, and external, that relates to risks outside the chain, such as trade policy and armed conflicts (Thun and Hoenig 2011). Supply chain density, network complexity, globalization, demand for greater product variability, outsourcing, and the number of suppliers are some of the factors that have been identified as contributing to higher risk in the supply chain (Thun and Hoenig 2011).

The Supplier Selection Process

In manufacturing, supplier selection is a key function in supporting the procurement process of raw materials. In the context of manufacturing, a supplier is a provider of products that are used at any stage of the production process by a company (Krivokuka *et al.* 2013). There are two fundamental concerns regarding the supplier selection process. The first involves determining the adequate criteria necessary for supplier evaluation, and the second is the selection of a procedure to use the criteria and obtain a result (Chen and Chao 2012). The importance of the criteria is not constant, but instead varies on a case-by-case scenario. The criteria selected to evaluate the suppliers is affected by the impact that the raw material has in the company's production processes. If the item to be purchased does not have a critical impact on the company's performance, then price and availability may be the only needed considerations. However, if the products and services purchased will have a considerable impact on the performance, then this simple view does not apply (Krivokuka *et al.* 2013). Therefore, a trade-off of all the studied criteria should be considered when selecting the best suppliers in any given situation (Athawale *et al.* 2009).

Multiple-criteria decision-making models

Multiple-criteria decision-making methods (MCDM) have been developed to address the problem of making decisions using conflicting criteria. These methods allow decision makers to base their choices on several criteria or attributes (Kasirian and Yusuff 2013), but they do not attempt to compute an optimal solution. Instead, the methods determine a ranking of alternatives *via* several ranking procedures to select the best option with respect to multiple criteria (Triantaphyllou 2000).

The analytic hierarchy process (AHP) is a structured method that uses a multi-attribute approach to address decision-making problems. The AHP is a measurement that focuses on the proportions between given quantities rather than their exact measurements and is considered an efficient method where trade-offs between tangible and intangible factors are required (Brunelli 2015). However, the AHP model also has certain drawbacks. One drawback is its incapacity to consider interdependencies among criteria on different levels (Kasirian and Yusuff 2013). Another criticism to this method is the rank reversal problem, which consists of a change in the order relation of the set of alternatives when an additional criterion is added. However, this last pitfall can be avoided if the priority vectors are aggregated, taking the component-wise geometric mean, instead of a convex linear combination (Brunelli 2015).

Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) is a method by which the best alternative is the closest to the positive ideal solution. This alternative maximizes the benefit criteria, minimizes the cost criteria, and it is farthest from the negative ideal solution. The highest scoring performances by criteria across all the alternatives are part of the positive ideal solution, while the opposite is true for the negative ideal solution (Sultana *et al.* 2015). The TOPSIS core relies on the separation of the alternatives from the positive ideal and negative ideal solutions. A graphical representation of two alternatives with two criteria is shown below in Fig. 1.

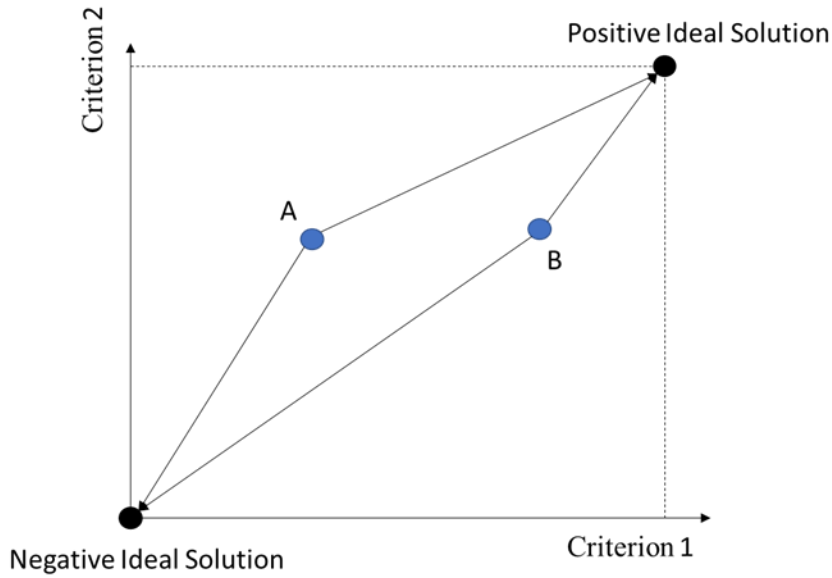

Fig. 1. Notion of the distance in alternatives to the positive and negative ideal solutions (Ishizaka and Nemery 2013)

Multiple-criteria decision-making models and supplier selection

The most frequently applied MCDM methods to supplier selection problems are AHP and TOPSIS (Chai *et al.* 2013). The TOPSIS method is considered an adequate assessment because the evaluation of a supplier's performance is relative to the performance of other suppliers. Therefore, it is a functional method for comparison among all candidate suppliers and is useful when selecting the best one (Sureeyatanapas *et al.* 2018). Additionally, AHP and TOPSIS are methods that have been combined because they complement one another. The TOPSIS method usually assumes that the weights of attributes are given once the method is applied (Shih *et al.* 2007). Some authors suggest using AHP or other techniques to obtain the necessary weights (Shih *et al.* 2007).

Table 1. Scale Proposed for the AHP Model (Saaty and Vargas 2013)

Intensity of Importance	Linguistic Variable	Explanation
1	Equal Importance	Two activities contribute equally to the objective.
3	Moderate Importance	Experience and judgment slightly favor one activity over another.
5	Strong Importance	Experience and judgment strongly favor one activity over another.
7	Very Strong or Demonstrated Importance	An activity is favored very strongly over another, and its dominance is demonstrated in practice.
9	Extreme Importance	The evidence favoring one activity over another is of the highest possible order of affirmation.

The AHP model frequently utilizes the Saaty Scale because it is the original linear scale, and it is most often utilized in applications (Franek and Kresta 2014). The original linear scale is the best scale to represent the weight ratios described by Saaty (1994). The Saaty Scale is depicted in Table 1.

EXPERIMENTAL

Methods

This research paper worked to answer the following question: How can firms implement qualitative and quantitative criteria to select and assess suppliers in the wood fiber supply industry? The following secondary questions were also raised:

- What are the relevant criteria for supplier selection and assessment in the wood fiber supply industry?
- What are the best methods to integrate the criteria in a structured way to select and assess suppliers?
- How can a model integrating criteria be implemented to provide practitioners with a useful tool for supplier selection and assessment?

The research was performed in four phases: the identification of criteria for supplier selection, design of a supplier selection model, implementation of the model in a software application, and validation of the application. This methodological sequence is represented in Fig. 2.

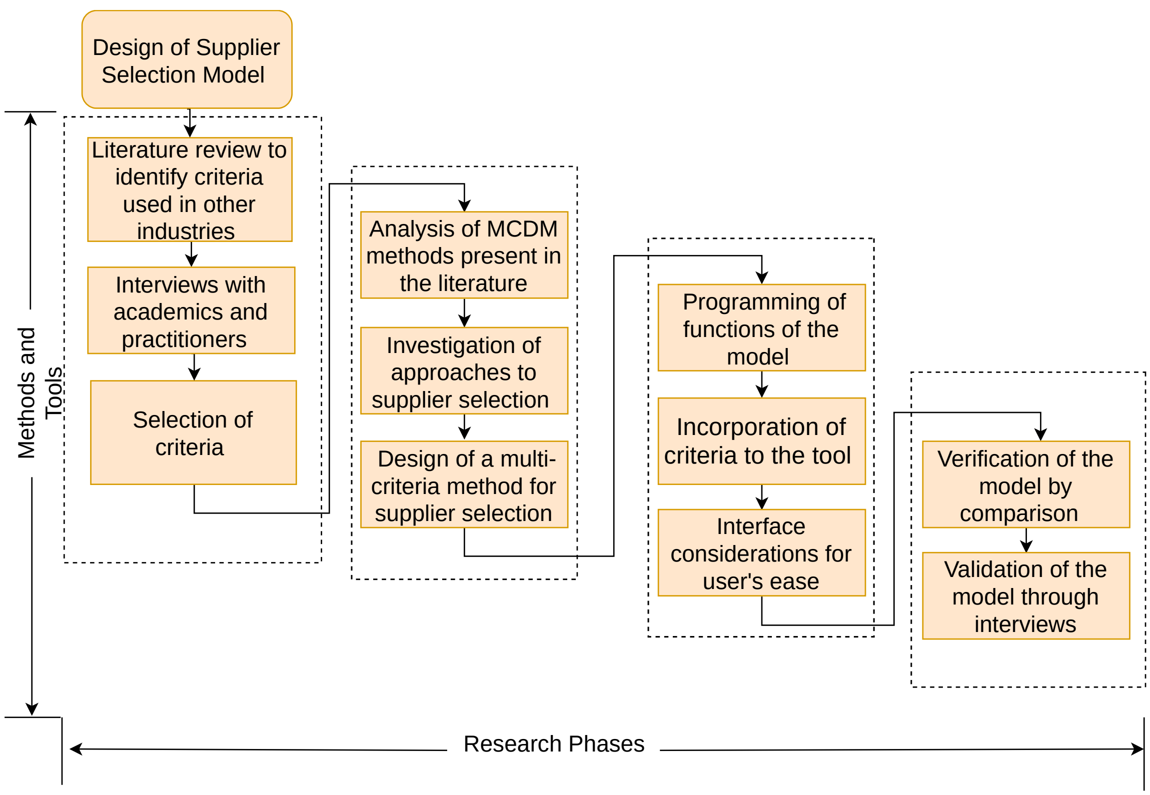

Fig. 2. Methodological sequence of research

The first phase consisted of selecting the criteria. First, a literature review was performed to identify the main criteria utilized in other industries. Second, information was captured *via* interviews and meetings with different sources (*i.e.*, academics in wood science and case studies within the wood products industry). The academics in wood science consisted of two professors, both with areas of research related to the logging industry. The professors were an associate professor from the Virginia Tech Department of Forest Resources and Environmental Conservation and a professor from the Laval University Department of Wood Science and Forest Service. The case studies consisted of two companies that are well-known representatives of the wood fiber supply industry in the United States. Information was captured through semi-structured interviews. Company A was a global producer of specialty papers and fiber-based engineered products based in the United States, with world-wide production facilities, and Company B was one the largest producers and exporters of yellow poplar lumber on the east coast of the United States.

A case study approach was appropriate given that the research focused on a single-bounded phenomenon, which was the supplier selection process in the wood fiber supply industry (Gerring 2004). The case studies conducted to capture the supplier selection process were selected by the participants' ability to provide information and their representation of the wood fiber supply industry. The questions that were asked to practitioners and academics focused on current procurement practices, the approach to supplier relationships, the relevant criteria to select suppliers, and the process to select suppliers. The final list of proposed criteria to be integrated in the model was produced through intersecting the findings in the literature review with the findings of the interviews performed with case study firms and academic experts.

The next step was to analyze the multi-criteria decision-making methods. A literature review on the topic was conducted, and two methods were selected based on their utilization in previous studies (their differences identified by MCDM methods) and their suitability to the wood fiber supply chain (Mahjouri *et al.* 2017). The differences included aggregation philosophy, structure, algorithm, and the process utilized to integrate multiple decision viewpoints on multiple criteria regarding the selection or evaluation of programs.

The tool was verified and validated as suggested by Thacker *et al.* (2004). Verification determines if a model implementation demonstrates the intended conceptual description and its solution (AIAA G-077-1998(2002) 1998). Feigin (2016) defines verification as "the process of confirming that the model as implemented in software does what the model designer intends." Validation is the process that determines to what degree the model is an accurate representation of the real world within the scope of the intended uses of the model (AIAA G-077-1998(2002) 1998). The AHP and TOPSIS computational steps were verified by creating a trial use case scenario and manually computing the steps. Then, the output provided by the tool was compared to the answers manually obtained to ensure the results matched. This verification demonstrated that the tool was mathematically accurate. To validate the tool, seven case study firms were interviewed within the forest products industry. Three interviews were conducted with three suppliers (loggers), and two interviews were conducted with two types of consumer companies, *i.e.*, a sawmill and a paper mill.

RESULTS AND DISCUSSION

Supplier selection criteria

To determine what criteria are most relevant, a review of the literature was performed and later complemented with semi-structured interviews to determine the final criteria of the supplier selection tool. Aggregated from the twenty articles consulted, the sixteen criteria most utilized are reported in Table 2. For the criteria to be considered, it had to be analyzed or mentioned in at least five or more previous supplier selection studies throughout different industries. The top five criteria were quality, cost, delivery, financial position, and long-term relationship.

Table 2. The Sixteen Most Mentioned Criteria in the Literature for Supplier Selection

Criteria	Related Work
Quality	(Hsu *et al.* 2006); (Perçin 2006); (Kannan and Haq 2007) (Ávila *et al.* 2012); (Chen and Chao 2012); (Kar 2014); (Kumar Kar and Pani 2014); (Gurel *et al.* 2015); (Galankashi *et al.* 2015); (Żak 2015); (Ghorabaee *et al.* 2016); (Govindan and Sivakumar 2016); (Mirmousa and Dehnavi 2016); (Su and Gargeya 2016); (Yadav and Sharma 2016); (De Oliveira Moura Santos *et al.* 2017); (El Mokadem 2017); and (Görener *et al.* 2017)
Cost	(Hsu *et al.* 2006); (Kannan and Haq 2007); (Hätönen and Ruokonen 2010); (Ávila *et al.* 2012); (Chen and Chao 2012); (Kasirian and Yusuff 2013); (Kar 2014); (Kumar Kar and Pani 2014); (Żak 2015); (Galankashi *et al.* 2015); (Govindan and Sivakumar 2016); (Ghorabaee *et al.* 2016); (Mirmousa and Dehnavi 2016); (Su and Gargeya 2016); (Yadav and Sharma 2016); (El Mokadem 2017); and (Görener *et al.* 2017)
Delivery	(Perçin 2006); (Kannan and Haq 2007); (Chen and Chao 2012); (Kasirian and Yusuff 2013); (Kar 2014); (Kumar Kar and Pani 2014); (Galankashi *et al.* 2015); (Żak 2015); (Ghorabaee *et al.* 2016); (Govindan and Sivakumar 2016); (Mirmousa and Dehnavi 2016); (Su and Gargeya 2016); (Yadav and Sharma 2016); (De Oliveira Moura Santos *et al.* 2017); (El Mokadem 2017); and (Görener *et al.* 2017)
Financial Position	(Hsu *et al.* 2006); (Perçin 2006); (Kannan and Haq 2007); (Hätönen and Ruokonen 2010); (Ávila *et al.* 2012); (Chen and Chao 2012); (Kar 2014) ; (Kumar Kar and Pani 2014); (Mirmousa and Dehnavi 2016); (Żak 2015); and (El Mokadem 2017)
Long-term Relationship	(Hsu *et al.* 2006); (Perçin 2006); (Hätönen and Ruokonen 2010); (Ávila *et al.* 2012); (Chen and Chao 2012); (Gurel *et al.* 2015); (Yadav and Sharma 2016); and (El Mokadem 2017)
Flexibility	(Hsu *et al.* 2006); (Perçin 2006); (Chen and Chao 2012); (Ghorabaee *et al.* 2016); (Mirmousa and Dehnavi 2016); (Yadav and Sharma 2016); and (El Mokadem 2017)
Ease of Communication	(Hsu *et al.* 2006);(Kasirian and Yusuff 2013); (Gurel *et al.* 2015); (Ghorabaee *et al.* 2016); (Mirmousa and Dehnavi 2016); (Su and Gargeya 2016); and (De Oliveira Moura Santos *et al.* 2017)

Reputation	(Hsu *et al.* 2006); (Perçin 2006); (Galankashi *et al.* 2015); (Żak 2015);(Mirmousa and Dehnavi 2016); and (El Mokadem 2017)
Technical Capability	(Perçin 2006); (Kannan and Haq 2007); (Chen and Chao 2012); (Kar 2014); (Ghorabaee *et al.* 2016); and (Görener *et al.* 2017)
Customer Relationships	(Kannan and Haq 2007); (Hätönen and Ruokonen 2010); (Ávila *et al.* 2012); (Chen and Chao 2012); (Mirmousa and Dehnavi 2016); and (Görener *et al.* 2017)
Services	(Kannan and Haq 2007); (Ávila *et al.* 2012); (Galankashi *et al.* 2015); (Mirmousa and Dehnavi 2016); (Yadav and Sharma 2016); and (El Mokadem 2017)
Logistics Cost	(Hsu *et al.* 2006); (Ávila *et al.* 2012); (Gurel *et al.* 2015); (Govindan and Sivakumar 2016); and (Yadav and Sharma 2016)
Manufacturing Capability	(Perçin 2006); (Ávila *et al.* 2012); (Kar 2014); (Kumar Kar and Pani 2014); and (El Mokadem 2017)
Continuous Improvement Programs	(Hsu *et al.* 2006); (Perçin 2006); (Chen and Chao 2012); (Gurel *et al.* 2015); and (De Oliveira Moura Santos *et al.* 2017)
Geographical Location	(Hsu *et al.* 2006); (Perçin 2006); (Ávila *et al.* 2012); (Galankashi *et al.* 2015); and (Ghorabaee *et al.* 2016)
Order Fulfillment Lead Time	(Kannan and Haq 2007); (Kasirian and Yusuff 2013); (Gurel *et al.* 2015); (Żak 2015); and (Su and Gargeya 2016)

The literature criteria listed are comprehensive, as they pertain to a broad range of industries. In contrast, the criteria found in the case study company interviews are more specifically related to the wood fiber supply industry from a practical standpoint. Company A stated that the most important criteria that they considered were truck insurance, business relationship, reliability, trustworthiness, equipment, financial situation, sustainable forestry practices, product quality, and reputation. For company B, given that is does not have a formal procedure for selecting or assessing suppliers, the list includes reliability, financial capability, technical capability, and reputation. In contrast, academic sources point out that the key criteria to consider when selecting and assessing suppliers are proper equipment, infrastructure to deliver the product on time, expertise to complete the job, reputation, cost, geographic location, quality, and flexibility. The selected criteria displayed in Table 3 are based on the information provided by the case study companies, by the academics consulted, and by the literature on the topic of consumer-supplier relationships in the wood products industry.

Table 3. Supplier Selection Criteria Proposed for the Model

Criteria Proposed for the Model	
Quality	By managing quality features, a mill can work with a defect rate for their suppliers, which will represent the percentage of product that does not meet the specified requirements.
Cost	The product cost can be the price that a mill must pay to a contractor for a delivered ton of purchased wood or the price for harvesting services in the case of contractors that harvest on the company's lands.
Delivery	Delivery refers to the contractor's ability to deliver an agreed volume of wood in time. Using this metric, a delivery indicator can be established, representing the percentage of time in which an agreed volume was provided on time.

Financial Position	The Altman Z scores combine five financial indicators and market value measures to assess the financial health of a company and eventually classify it as distressed, which prompts bankruptcy, or non-distressed.
Relationship	Relationship refers to how easy it is to communicate, coordinate, and cooperate with a contractor at the tactical and operational levels.
Reputation	Reputation refers to the widespread perception of the contractor's overall performance within the industry.
Technical Capability	Technical capability constitutes the ability of a contractor to perform the task of successfully harvesting operations, for which appropriate equipment is required.
Reliability	A reliable contractor is one that performs its services in accordance with negotiated agreements.
Geographic Location	Geographic location refers to the distance between the contractor and the land that a company wants to harvest or the distance between the contractor and the facility where the company requires the wood to be delivered.
Flexibility	The ability of a contractor to increase or decrease production level according to demand if requested and/ or to move effectively to new operating areas.

The case study company interviews found that no company used a structured method to select and prioritize suppliers. Their methods varied in complexity, from a few phone calls to considering certain criteria and making the decision in a meeting using unstructured methods.

Supplier Selection and Assessment Model

The chosen supplier selection and assessment model combined two different multi-criteria decision-making methods, the AHP and the TOPSIS. The AHP method is used to obtain the weights of the selected criteria, and the TOPSIS method is utilized to compute the rankings of each considered alternative.

This hybrid AHP-TOPSIS method was selected because AHP is the most accepted and widely used method in the literature for determining relative measurements and TOPSIS is the rating procedure that produces the fewest rank reversal outcomes.

Software application

The proposed hybrid AHP-TOPSIS model was implemented as a software tool in Microsoft Excel and Visual Basic. This tool incorporated all the functions of the theoretical model selected. The supplier selection and assessment tool (SSAT) allowed company practitioners to obtain a ranking for the alternative suppliers that were being evaluated, which enabled the personnel in the procurement and supply chain departments to identify the best suppliers to work with, increasing the value received from purchasing. As a selection tool, the SSAT can be used when the company needs to add a new supplier to its supply network and must decide between a given number of alternatives. As an assessment tool, it can be used to identify which current suppliers are the best performing, from whom the company should buy more, with whom the company should pursue a stronger relationship, and which supplier or suppliers could be removed if the company needs to reduce its supplier base. The following sections present an example of the use of the software application, that was exercised with one of companies interviewed to validate the model and application.

Table 4. Pairwise Comparisons Matrix

	Quality	Cost	Delivery	Financial Position	Relationship	Reputation	Technical Capability	Reliability	Geographical Location	Flexibility
Quality	1	1	7	3	3	3	3	1	1/3	3
Cost		1	5	3	3	3	3	1	3	5
Delivery			1	1	1/5	1/5	1/5	1/5	1/7	1/5
Financial Position				1	1/3	1/3	1/3	1/5	1/7	1/5
Relationship					1	1	3	1	1/5	3
Reputation						1	3	1	1/5	1
Technical Capability							1	1/5	1/5	1/5
Reliability								1	1/3	1
Geographic Location									1	9
Flexibility										1

The values of the matrix represent how the criteria in the left column was compared to the criteria in the row. Following the example in the pairwise comparisons matrix (Table 4) when “Cost” was compared with “Relationship” (value 3 is in the position (2,5) in the matrix), “Cost” was considered moderately more important than “Relationship,” according to the Saaty Scale. In contrast, when “Quality” was compared with “Geographical Location” (the value 1/3 is in the position (1,9) in the matrix), “Quality” was moderately less important than “Geographical Location.” The diagonal row in the matrix will always be 1, given that it is the i^{th} criterion compared to itself.

Determination of relative importance for criteria

The first step was to compute the weights for each criterion by setting pairwise comparisons for the criteria. The criteria weighting function is a pairwise comparisons matrix in which the user must specify the relative importance of the criteria introduced to the tool based on his or her own judgment. The tool uses the AHP method to calculate the weights of each criterion (Athawale *et al.* 2009).

An example of the pairwise comparisons matrix is shown in Table 4. The user only worked with the upper half of the matrix. The lower half was automatically computed by the tool. The Saaty Scale, consisting of grades of intensity from 1 to 9, was used to determine the relative importance of the selected criteria by giving a numeric value. This numeric value can then be associated to a linguistic variable and is explained in Table 1.

Once all the values were introduced in the matrix, the next step was assigning rates for each supplier. In case of doubt concerning the meaning of any of the criteria predefined in the tool, the user was provided with a 'Help' section. The result of computing the weights according to the pairwise comparisons exemplified in Table 4 is presented below in Table 5.

Table 5. Determination of Relative Importance for Criteria Example Results

Quality	17.77%
Cost	25.14%
Delivery	3.47%
Financial Position	3.44%
Relationship	8.66%
Reputation	8.96%
Technical Capability	4.44%
Reliability	14.63%
Geographical Location	9.92%
Flexibility	3.56%

Assigning rates and the overall score for each alternative

The rates were assigned according to the information available to the decision maker about the level of performance of each alternative for each criterion. The validity of the model results depended on the accuracy of the information provided by the decision maker. The results can only be as valid as the information provided. The proposed scale for assigning rates is presented in Table 6.

Table 6. Proposed Scale for the Assigning of Rates for the Alternative Suppliers

Intensity of Performance	Linguistic Variable for the Level of Performance
1	Poor
3	Below Satisfactory
5	Satisfactory
7	Highly Satisfactory
9	Excellent

* (Sultana *et al.,* 2015)

The proposed method for the scoring phase is the TOPSIS, which is a relatively easy way of ranking alternatives. The best alternative will be nearest to the positive ideal solution. The first step in the TOPSIS method is to assign the rates for each alternative to the selected criteria. The "Edit Ratings" function can be accessed by the user either from the control panel or automatically by computing the weights in the criteria weighting function. The ratings function is the table where the user must enter the rates for each supplier and for each criterion considered.

Table 7. Ratings matrix

	Weight (%)	A	B	C	D	E	F	G	H	I	J
Quality	8.6	9	5	9	1	9	7	9	3	9	5
Cost	12.53	5	5	5	5	5	5	7	5	7	5
Delivery	13.24	9	5	5	7	1	5	5	5	1	5
Financial Position	7.9	9	9	9	9	3	9	9	7	9	9
Relationship	10.49	9	7	5	5	5	9	4	3	1	7
Reputation	9.56	9	7	9	7	5	9	5	1	7	7
Technical Capability	7.9	9	7	9	7	3	9	9	3	9	7
Reliability	14.4	9	7	3	5	3	5	3	3	1	5
Geographical Location	9.52	7	9	5	9	1	5	7	5	7	7
Flexibility	5.87	9	5	7	1	3	7	3	5	3	5

The application gives the user the option to review a predefined guide on how to assign the rates according to certain indicators defined for eight of the ten proposed criteria. The specified ranges of values for each indicator can be modified by the user according to his or her own judgment. If the user is unable to gather the quantitative information necessary to have a solid base when assigning rates for suppliers, then he or she will have to rely on his or her judgment or expertise on the matter, which might be detrimental to the accuracy of the tool that reflects the actual supplier performance. Results will be as accurate as the information available and provided by the user. The tool itself does not guarantee valid results.

Once all ratings are assigned, the user clicks on the "Get Ranking" button. The tool will automatically calculate a performance coefficient and show a graphic of the final global ranking, as shown below (Fig. 3).

As stated, the TOPSIS methodology works with both positive and negative ideal solutions. The positive ideal solution is the set composed of the maximum values from the alternatives for each criterion. In this case, the "ideal supplier" is an abstraction, a hypothetical supplier that combines the best performances by criterion from all suppliers considered. The negative ideal solution, or "worst supplier," is the hypothetical supplier that combines the worst performances by criterion from all suppliers considered. The next step was to obtain the positive and negative ideal solutions based on the weighted normalized matrix that was previously computed, assuming all criteria were defined as positive criteria. A better level of performance resulted in a better the rating.

Once the positive and negative ideal solutions were computed, the next step consisted of understanding the distance between each alternative to the ideal and negative solutions. Then, the similarity of each alternative to the positive ideal solution was calculated as a distance coefficient with the negative and positive distances obtained earlier. In addition, this coefficient could be interpreted as the percentage of which the supplier resembles an "ideal supplier." Thus, the best supplier was the one with the highest coefficient. The preference order was obtained by setting the alternatives' coefficients in descending order, as shown in Fig. 3. The tool computes the order of preference using the TOPSIS method (Athawale *et al.* 2009).

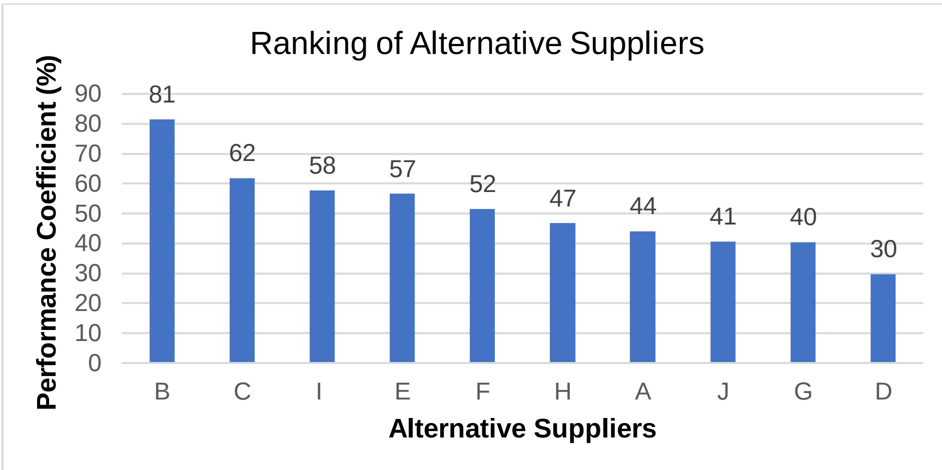

Fig. 3. Graphic ranking

The final output of the tool is a ranking of suppliers, whose scores represent the extent to which each individual supplier embodies the hypothetical ideal supplier that is derived from all the available suppliers. The supplier that most closely resembles the ideal supplier will be at the top of the ranking.

Verifying and validating the tool

The verification of the supplier selection tool was performed by utilizing the data obtained from an interview and manually computing the weights, the distances to the negative and positive ideal solutions, and the coefficients to get the rankings. Verification here is understood as proving that the tool provides accurate mathematical results, whereas validation means that the tool is able to aide companies when selecting and evaluating suppliers.

A comparison between the output of the tool with manual results was obtained and the tool was verified. The validation of the tool was performed by interviewing seven companies within the wood fiber supply chain industry. The interview questionnaire was separated into two different sets of questions and processes depending on whether the user was the supplier or the consumer. Three loggers, two sawmills, and two paper mills were part of the validation process. The four consumer companies included two lumber sawmills, and two paper mills. Validating the tool was divided into the validation of the criteria and the validation of the model. The loggers were asked only questions regarding the criteria and how a systematic approach could potentially change the current procurement environment. The consumer companies validated the criteria and discussed the systematic approach, but they also utilized the tool.

Criteria

The criteria proposed for the model and implemented in the tool was reviewed by the participating companies. Table 8 displays the overall results for each industry segment.

Table 8. Results of Tool Criteria Validation

Criteria Proposed for the Model	Paper Mill Perspective	Sawmill Perspective	Logger Perspective
Quality	✓	✓	✓
Cost	✓	✓	✓
Delivery	✓	✓	✓
Financial Position	✓	✓	✓
Relationship	✓	✓/ X	✓
Reputation	✓	✓	✓
Technical Capability	✓	✓/ X	✓
Reliability	✓	✓	✓
Geographic Location	✓	✓	✓
Flexibility	✓	✓	✓

The majority approved the criteria. The checkmarks represent both companies' approval. If one criterion is marked with both a check and an "X," it means that one company agreed while the second company under the same category disagreed.

Systematic approach to supplier selection

As part of the research, the consumer interviewees' perception was discussed. There were different results when addressing a systematic approach in the supplier selection process. The interviewees representing the paper mills agreed that there was no need for a systematic approach, because there was an existing system established. The existing system was not described as systematic or formal. There were mixed responses from the sawmill interviewees. One sawmill interviewee responded that a systematic approach would improve the supplier selection method. The other sawmill interviewee believed a systematic approach would not be applicable because there are always different situations presented that do not align well with a systematic approach.

From the suppliers' perspective, every logger had a different position. One supplier stated that the introduction of such criteria could push all loggers to become more competitive but holding every logger in the competitive pool to a higher standard would not place any one supplier at an advantage. A second supplier found the criteria appropriate and felt that a remarkable number of responsible loggers already complied with the criteria. Nevertheless, there was a concern about loggers that did not comply with imposed regulations (*e.g.*, worker's compensation) but were still selected as mill suppliers because of their lower prices. Therefore, if a systematic approach was utilized, and the ranking was followed, this might help responsible loggers. The third supplier said that the system would work if it were implemented year-round and may alleviate the challenges found in the supply chain.

The tool's output and the user experience

Most of the consumer companies that were a part of the interview process found the tool applicable to their business. Out of the four consumer companies, only one described their satisfaction level as "Somewhat Satisfied". The concern arose from how the criteria were weighted to establish a final ranking. For the tool to be completely applicable, the user might need to modify the weights used to establish the ranking (or the AHP phase result). The consensus about the introduction of the criteria to the current supplier selection process was that the proposed criteria was adequate. After utilizing the tool, the consumer companies evaluated its effectiveness, as shown in Table 9.

Table 9. Effectiveness of the Tool

Effectiveness of the Tool	Paper Mill Perspective	Sawmill
Comprehensiveness	✓ ✓	✓ ✓
Objectiveness	✓ ✓	✓ X
Reliability	✓ ✓	X ✓
Flexibility	✓ ✓	✓ X
Mathematically straightforward	✓ ✓	X ✓

The tool's effectiveness was approved by the participating paper mill interviewees, but not by the participating sawmill interviewees. Both sawmill participants considered the tool to be comprehensive but had different takes on objectiveness, reliability, flexibility, and mathematically straightforward criteria. In terms of limitations, the tool did present a pressing concern on behalf of all the participants concerning imprecision due to subjective evaluation and the lack of previous data on supplier performance. This concern highlights the importance of having reliable, measurable data and information to improve the accuracy of the tool.

The SSAT application should be used as a selection tool when companies need to add a new supplier to their supplier base and have multiple alternative candidates. The company must assign personnel capable of gathering the information required from the suppliers. Therefore, face-to-face visits are required to assess the supplier situation and performance. The procurement department, in cooperation with other areas within the company, must determine the strategies that are going to be used to assess the performance of an unknown supplier in terms of the established indicators. The SSAT application should be used as an assessment tool when the company needs to assess its supplier base to decide about which suppliers add the most value to the company, which suppliers should be used, and which suppliers can be eliminated. The main difference between the supplier selection process and the supplier assessment process is that in the selection process, the information compiled by the company about the supplier comes from the supplier because the company does not yet have a relationship with them. In contrast, when assessing current suppliers, the information gathered by the procurement department must predominantly come from the measurements that the company takes concerning the supplier's service. The assessment process provides more certainty regarding the information about supplier performance, given that this information is obtained inside the firm.

The implementation of the tool should not be considered as an end itself; it should be part of a broader change in the way that procurement departments in the wood fiber supply industry think about their relationships with their suppliers.

CONCLUSIONS

1. A structured model implemented in a software tool based on Microsoft Excel was proposed for the selection and evaluation of suppliers in the wood fiber supply industry. The selection and evaluation criteria proposed for the model were derived based on

literature review as well as with the input of academics and practitioners in the field of forestry and wood products.

2. The tool was verified and validated. The validation process of the tool demonstrated differences depending on the stakeholder. This reflected major discrepancies in the current wood fiber supply chain. The tool's criteria were approved by supplier and consumer companies. The tool's effectiveness was approved by most participating consumer companies. Limitations to the tool were listed as imprecision due to subjective evaluation and the inexistence of previous data on supplier performance.

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