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Resilient sustainable supplier selection criteria assessment for economics enhancement in Industry 4.0 context

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Abstract. In recent years, market globalization and natural disasters that companies have experienced oblige them to consider technologies from Industry 4.0, and smart manufacturing to improve their supply chain performance and customer satisfaction. Digitalization leads companies to a faster, flexible, and efficient supply chain. The improvement of organizations' performance and high competitiveness depends on their suppliers. In our days, companies need to include other criteria such as resilience, smartness, and sustainability in supplier selection to acquire a competitive advantage. This paper aims to discuss supplier selection criteria in digital, resilient, and sustainable supply chains, examine the relationship between them and prioritize them. This study presents a questionnaire survey addressed to professionals' experts to determine the main criteria related to the resilient, sustainable, and digital context that impact the supplier selection in different industries. To analyze and prioritize the supplier selection criteria, the authors use the approach of the analytical hierarchy model (AHP). The results are useful for practitioners and academics as they illustrate the decision-making with multiple criteria.

Keywords: Supplier selection, Digital supply chain, Resilience, Sustainability, AHP, Multicriteria.

1 Introduction

The main objective of the managers has always been to have an efficient supply chain, faster and at the lowest cost. In the meantime, supply chains have become more complex, more expensive, more uncertain, and more vulnerable. Unexpected exchange rates, supply fluctuations, volatile economies, political instability, unpredictable demand, and natural disasters are examples of significant uncertainties in an organization's environment. [1–3]. To effectively deal with this dynamic complexity and growing challenges, supply chains need to become much smarter and resilient [4]. One of the principal factors in increasing the organizations' competitiveness is to select the right supplier for the right mission. [5, 6]. In other words, in smart supply chain

management, supplier selection is highlighted as a critical and sophisticated decision problem (Chattopadhyay et al., 2016). Evaluating and selecting suppliers is a complex task for decision-makers as they have to consider different criteria. Therefore, it is crucial to choose the appropriate criteria for supplier selection that will allow companies to reduce purchasing risk and increase the profitability of the entire supply chain [7]. In previous studies, much attention has been paid to the issue of supplier selection [8](Chattopadhyay et al., 2016). Several authors have considered the multi-criteria methods for supplier selection using AHP, TOPSIS, DEMATEL, and ISM. Others have used a hybrid multi-criteria approach. However, most of these researches have considered the quality, cost, reliability, and delivery time as the main criteria for selecting a supplier [9, 10]. Further ones show that other factors must be included in the process of supplier selection for a smart supply chain in a crisis environment [3]. Therefore, it is important to include new criteria that deal with the smart supply chain implementation and crisis situation to achieve sustainability, agility, and resilience. To do so, the main criteria to include are those related to 'resilience' and 'smartness' beside the ecological, economic and social concern to keep sustainable, smart, and resilient supplier selection. A supply chain's resilience is its inherent capacity to maintain or recover stable actions and performance, enabling it to continue regular operations after a disruptive event. Resiliency is achieved by the acquisition and implementation of technology through industry 4.0. Thanks to Industry 4.0's technological advancements, the supplier will acquire new technology and technical assets for research and development activities and processes in order to enhance the product creation process in terms of quality and quantity while also reducing development time.

This study aims to fill the gap by prioritizing supplier selection criteria in the context of digitalization and resiliency. It addresses the new category of criteria born with supply chains 4.0. In addition, this paper aims to provide academicians with other criteria that enable the supply chain to cope with crises. Therefore, due to its mathematical simplicity and flexibility, AHP method has been widely used by numerous researchers in various fields, such as education, manufacturing, food, health, etc., to solve multi-criteria decision problems. According to this, the AHP method is used to prioritize supplier selection criteria in the digital era, and then rank the suppliers. More clearly, we provides a framework for dealing with logical, quantitative, and qualitative dimensions of multiple criteria situations by: (1) Identifying the criteria and sub-criteria related to supplier selection in a context of resiliency, digitalization, and sustainability; (2) Addressing a survey to collect professionals' opinions to attribute weights to the criteria; (3) Developing an AHP model to prioritize suppliers and (4) Illustrating the findings with a case study.

This article is organized as follows: in the following section, we present the literature review to well understand the smart supplier selection and methods used in the literature to select suppliers. Section 3 describes the research methodology used for the study. And finally, Section 4 illustrates the application of AHP for smart supplier selection.

2 Literature review

2.1 Smart supplier selection

The transformation of the classical supply chain into an intelligent supply chain requires the recent deployment of advanced intelligent technologies (the Internet of Things (IoT), blockchain, CPS (Cyber-Physical System), large data analysis, virtual and augmented reality (VR and AR) and artificial intelligence (AI) techniques. All actors of the supply chain will be perceptible, intelligible, transparent, and optimized, through this transformation.[11]. The digital supply chain challenges the option of suppliers through dynamic order allocation and offers new possibilities by using digital data to improve purchasing decisions [1].

When we mention the supplier, it refers to all parties directly and indirectly engaged by the manufacturer [12]. Supplier selection is an intensively researched process due to its impact on supply chain purchasing management[13]. Indeed, suppliers play an essential role in supply chain management. It focuses on evaluating supplier selection and ensuring a productive relationship between different segments of the supply chain [12]. Therefore, the careful selection of the right supplier for the right mission is essential for improved performance [5, 6].

The issue of partner selection in the supply chain is the subject of several kinds of research. Previous studies have shown that the evaluation and selection of suppliers cannot be based on a single criterion, and therefore they use multi-criteria decision-making techniques (MCDM). To classify a set of suppliers in an intelligent logistics environment,[8] have developed a decision support system to integrate and process imprecise heterogeneous data in a unified framework. [14] adopted a multi-agent systems (MAS) approach to handling the process of evaluating and selecting sustainable suppliers in order to provide an appropriate communication channel, structured information exchange, and visibility among suppliers and manufacturers. To identify smart supply chain management practices, [11] present a new framework for supplier selection criteria in a sustainability context. Its proposed approach is a hybrid approach that combines the approximate and fuzzy DEMATEL-TOPSIS method for selecting sustainable suppliers for an intelligent supply chain. [1] developed a hybrid approach combining simulation and machine learning. This author examines its applications to data-based decision support in the selection of suppliers in a resilience context.[15] used the approach of the analytical hierarchy model (AHP) to analyze the supply chain 4.0 risks. The authors examined Supply Chain Risk Factors 4.0 and categorized them into 11 risks under five major risk factors. Other researchers used other techniques like Artificial intelligence (AI), methods based on cost, or mathematical programming methods (MP) to evaluate and select suppliers [16]. However, papers dealing with the analysis of supplier selection criteria while considering the integration of resilience and digitalization are not undertaken.

2.2 Supplier selection method

Since the nineties, there has been an evolution in the role and structure of the purchasing function, and the supplier selection problem has become one of the crucial issues for

establishing an efficient supply chain system [17]. Supplier selection is a strategic process for organizations due to the high firms' dependency on the purchasing process. The supplier selection process is based on the selection of suppliers with the highest potential to meet the needs of a manufacturer and with acceptable overall performance. The selection of the right supplier from a large number of possible suppliers depending on various levels of capabilities and potential becomes a difficult task.[18]. Indeed, each process of supplier selection is different due to many factors that are taken into consideration when making that selection, such as the needs of the manufacturer, the type of product, the type of industry, etc. Companies must intelligently delineate their supply chain strategy, considering the value of the supplier selection. There is no best way to select the right supplier. However, several methods and approaches are used by decision-makers for the selection process. There are many methods for supplier selection and evaluation according to the literature. [17].

Table 1. Classification of the supplier selection methods

	Supplier selection method	References
Statistical approach	Cluster Analysis (CA)	[19, 20]
	Multi-Nominal Logit (MNL)	[21]
	Utility Theory (UT)	[22]
	Factor Analysis (FA)	[23]
	Interpretative Structural Modelling (ISM)	[24, 24, 25]
Multi-Criteria Decision Making (MCDM) or Multi-Attribute Decision Making (MADM)	Analytical Hierarchy Process (AHP)	[15, 26–29]
	DEMATEL	[5, 6, 30]
	Analytic Network Process (ANP)	[31–34]
	Technique for the Order Performance by Similarity to Ideal Solution (TOPSIS)	[35–37]
	Multiple Attribute Utility Theory (MAUT)	[38]
	Outranking Methods (ELECTRE, PROMOTHEE)	[39]
	Fuzzy set theory	[11, 40, 41]
Methods based on cost	Activity Based Cost (ABC)	[42]
	Total Cost of Ownership (TCO)	[43, 44]
Mathematical Programming models	Linear Programming (LP)	[45]
	Multi-Objective Linear Programming (MOLP)	[46–50]
	Goal Programming	[51–53]
Artificial intelligence	Case Based Reasoning (CBR)	[54]
	Artificial Neural Network (ANN)	[55, 56]
Combined approaches	Fuzzy+AHP	[57, 58]
	Fuzzy+TOPSIS	[59–61]
	ANP+TOPSIS	[62, 63]
	Fuzzy Neural Network	[3]
	Fuzzy DEMATEL-TOPSIS	[64]
	AHP+MOLP	[65]

3 Research methodology

To prioritize supplier selection criteria and select the best supplier using the AHP method, we propose the following research methodology. For the research methodology, three main steps are followed to the supplier selection decision model: criteria identification, data collection, and supplier prioritization. Fig.1 shows the structure of the model.

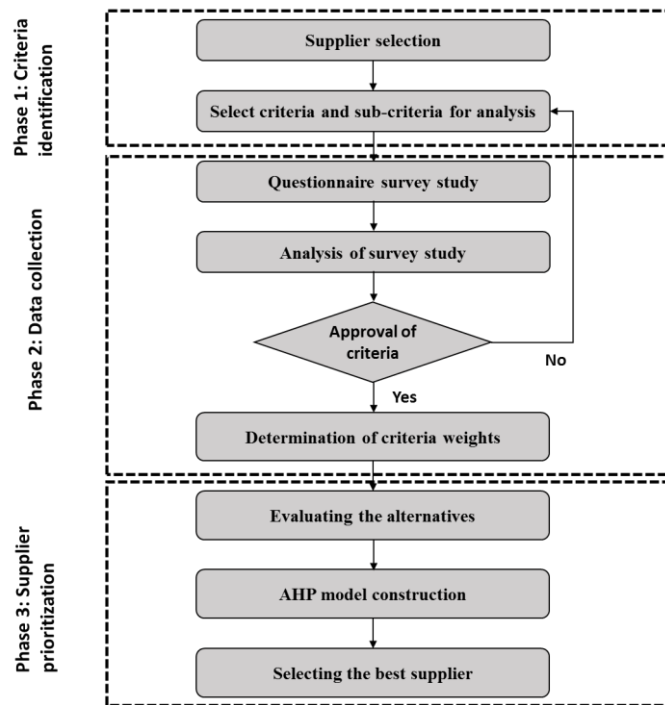


Fig.1. Structure of proposed supplier selection model

4 Criteria identification and data collection

4.1 Criteria identification

The perfect combination of identifying the decision-making criteria and the method used to select suppliers is the main factor determining the growth and competitiveness of a company. The importance of choosing the right supplier has several benefits like reducing purchasing risks, maximizing overall value for the buyer, reducing project delays (on-time delivery), improving customer satisfaction, reducing costs, and developing strategic alliances between supplier and buyer, ultimately leading to competitive advantages. Traditionally, supplier selection has followed a price-based approach. However, companies today have become aware that price, while important, is not enough to achieve a competitive advantage. Indeed, a more comprehensive multi-

criteria approach is needed to solve the problem of selecting appropriate suppliers. In the last decade, companies integrated a new perspective for the supplier selection criteria, such as supplier's resilience, environmental aspect, social aspect, etc. As a result of the literature review regarding the selection of suppliers, 8 main criteria and 14 sub-criteria are presented in the following table. Each criterion is identified by considering the characteristics of the domestic construction industry (e.g., size of the industry, general procurement trends, etc.).

Table 2. Supplier selection main criteria and sub-criteria

Criteria	Sub-criteria
Cost	-
Quality	-
Delivery	-
Flexibility	-
Technological capability	Responsiveness
	Reliability
	Real time data
	Leagility
	Innovation
Resilience	Collaboration
	Viability
	Risk awareness
Ecological concern	Environmental cost
	Environmentql management
	Reverse logistic
Social concern	Employee right
	Mutual trust
	Effective communication

4.2 Questionnaire survey

Once the criteria are selected, the next step is to collect the expert opinion to determine the weights of each criterion. The structure of the questionnaire survey includes all the main criteria and sub-criteria, as well as an open-ended question that allows the respondent to introduce additional criteria for selecting suppliers that are important to consider. This question is optional. As a measurement scale, the five-point Likert scale is used to assess the significance of each criterion: (Low importance, less important, important, very important, extremely important).

The questionnaire is addressed to 250 professionals in the industrial sector. The target professionals for this survey are project managers, site managers, and purchasing managers of different sectors. The sectors chosen for this study are the aeronautics, automobile, electronics, and textile sectors. 81 answers out of 250 questionnaires are obtained, 21 of them are removed for lack of information (incomplete questionnaire). The analysis was made based on information from 60 surveys. The distribution of survey participants by sector is shown in the figure. Verification of the validity and reliability

of the 60 surveys was done through the use of the SPSS software. Indeed, correlation analysis and a coefficient are obligatory to determine the reliability of the study. To verify the reliability of the study, SPSS uses Cronbach's alpha value, which is between 0 and 1. To be considered highly reliable, the value must be between 0.8 and 0.9. [66].

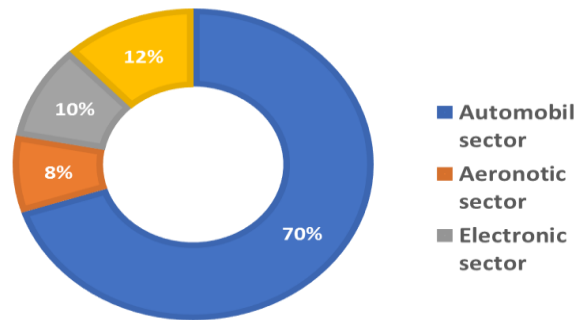


Fig.2. Distribution of survey participants by sectors

5 Supplier selection prioritization with AHP method

The Analytical Hierarchical Process (AHP) was introduced by Thomas L. Saaty in 1980 and is recommended for solving complex problems. Indeed, AHP is a decision-making method that allows factors to be structured in a hierarchical way when multiple criteria have to be considered when making a decision. Deconstructing a problem is usually done through three different levels that include objective, qualitative or quantitative criteria, and alternative.

5.1 Developing the AHP model

To develop an AHP model, it is necessary as a first step to formulate a hierarchy containing the objective, the factors, and the choices, as shown in the figure. The first level concerns the objective of the study, which is the selection of a suitable supplier. The second level consists of the criteria that we will use for decision-making. Thus, we determine nine criteria for decision support, namely: cost, quality, delivery, flexibility, technological capacity, resilience, reliability, environmental concern, social concern. The third level of this hierarchy consists of the results. In other words, it is the choice of suppliers.

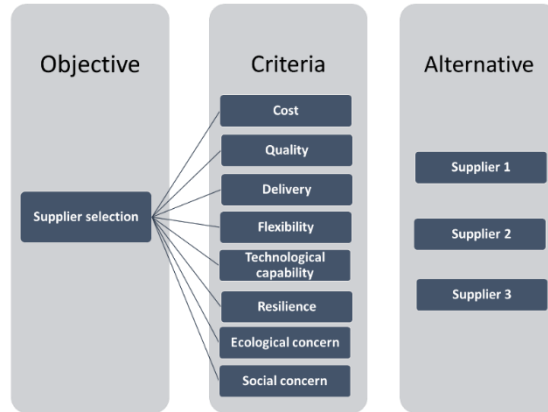


Fig. 3. Hierarchy of supplier selection

5.2 Weights Evaluation and pair-wise comparison

The AHP presumes that the criteria do not have the same importance. Therefore, it is mandatory to determine the relative priorities of the criteria (the weights). To generate the weights of the criteria, the paired comparison decision matrix must be developed. Then to determine the relative importance of each alternative, a pair-wise comparison must be made for each criterion. In this way, decision-makers express their preferences. AHP generally uses a nine-point numerical scale, called the Saaty scale, used for translating human judgment to make criteria comparisons. The weights of the alternatives reflect the relative importance of the criteria in achieving the objective of the hierarchy[17]. The values of the AHP pair-wise comparisons are determined by Saaty's (1980) scale. Table 3 presents the corresponding comparison matrix between the considered criteria.

Table 3. pair-wise comparison matrix

	C1	C2	C3	C4	C5	C6	C7	C8
C1	1	1	1	5	7	5	9	7
C2	1	1	1	5	5	5	9	9
C3	1	1	1	3	7	5	9	9
C4	1/5	1/5	1/3	1	3	1	5	5
C5	1/7	1/5	1/7	1/3	1	1	5	7
C6	1/5	1/5	1/5	1	1	1	5	7
C7	1/9	1/9	1/9	1/5	1/5	1/5	1	1
C8	1/7	1/9	1/9	1/5	1/7	1/7	1	1
Sum	3,79	3,82	3,89	15,73	24,34	18,34	44	46

To allocate a relative weight to each criterion, it is necessary to standardize the previous comparison matrix. Normalization is done by dividing each value in the table by the total value in the column. At this stage, it is necessary to measure the estimated level of consistency of the vectors. The AHP calculates a Coherence Ratio (CR) comparing the Coherence Index (CI) of the matrix in question to the Coherence Index of a random type matrix (RI) (Saaty, 2012). In our study, $CR = 0,08 < 10\%$ so the vectors are consistent. After developing the pair-wise comparison matrix and calculating the consistency ratio, weights are generated, as shown in table 4.

Table 4. Criteria weights

Criteria	Cost	Quality	Delivery	Flexibility	Technology	Resilience	Ecology	Social
Weight	25%	25%	24%	6%	8%	7%	2%	2%

As shown in table 5, cost, quality, and delivery are the main criteria for selecting a relevant supplier with the following percentages: 25%, 25%, and 24%, followed by technological capability with 8% and resilience with 7%. Then we have flexibility with 6%. Finally, the respondents did not give much importance to ecological and social criteria. These results confirm that, besides the traditional criteria for supplier selection such as cost, quality, and delivery, companies are beginning to be aware of the importance of including the resilience and digital factors as criteria to select a supplier to achieve competitive advantages.

5.3 Case study in automotive sector

A case study was conducted in a company in the automotive sector to prioritize suppliers. To obtain the wheels, the company has to decide which of the three suppliers is the most suitable one, namely supplier "X" supplier "Y" or supplier "Z". This step consists of ranking the three suppliers according to the criteria defined and weighed previously. As was done with the initial group of criteria, it is necessary to assess the relative weights of the criteria for the second level of the hierarchy. This process is conducted in the same way as the evaluation step for the first level of the hierarchy (group of criteria). Having the comparison matrix allows us to compare the different knowledge taking into account the criteria defined in step 2. After this, we calculate the matrix by inserting the average solutions after normalization in the first column and the decision criteria in the first row. Thus, we can rank supplier "X" as the most relevant taking into account the nine criteria with a percentage of 69% followed by supplier "Y" which represents 24%, and supplier "Z" which represents 7%.

According to table 5, the most relevant supplier is determined according to the score of each criterion. The most relevant supplier is Supplier "X" due to its openness, in addition to the traditional economic criterion such as cost reduction, quality increase, and on-time delivery, to other criteria that allow increasing its competitiveness and ability to face the crises. The criteria of resilience, technological capacity, and flexibility enable the realization of a digital supply chain. Besides, the supplier "X" expresses his interest in ecological criteria and social criteria. Combining economic with

ecological and social criteria enables the supplier to join the sustainability. The supplier “Y” is not relevant due to its only interest in some traditional criteria such as reducing cost, increasing quality, and technology. Not considering the criterion of on-time delivery is one of the reasons for the dysfunctionality of the supply chain. Supplier “Y” does not consider the resilience criteria. Yet, these criteria allow the supply chain to deal with uncertain events. The digitalization of the supply chain and its ability to deal with crisis contexts are two complementary elements.

Table 5. Supplier alternative rankings

	Cost	Quality	Delivery	Flexibility	Reliability	Technology	Resilience	Ecology	Social	Average
Supplier « X »	0,65	0,68	0,75	0,67	0,75	0,67	0,78	0,65	0,65	69%
Supplier « Y »	0,29	0,24	0,18	0,27	0,18	0,27	0,17	0,29	0,29	24%
Supplier « Z »	0,06	0,08	0,07	0,06	0,07	0,06	0,07	0,06	0,06	7%

6 Managerial and researcher implications

The information provided in table 4 is useful for our study. Using the AHP process allowed us to prioritize the criteria according to their importance. The main objective of using the AHP was first to determine the most important criteria to select the relevant supplier in a resilient and smart context. Then, choosing the important criteria in a smart and resilient context is essential for creating a good relationship with suppliers while providing future risks that may be incurred due to market fluctuations.

According to table 4, the most important criteria are cost, quality, and delivery with respective weights of 25%, 25%, and 24%. These results mean that companies consider these criteria as determining factors for choosing the right supplier. These criteria allow companies to increase their economic performance. In the second place, we have technological capability criteria with a weight of 8%. Results prove that considering the technological capability, improves the capacity to respond and provide the information on time. Also, it increases their reliability. Considering technologies from industry 4.0 lead managers to an improvement of their economic strategy. Besides the smart criteria, the resilient criteria, being in the third place with a weight of 7%, enable managers to prevent potential blockage in the collaborative supply chain due to market globalization and natural disasters. According to companies, the flexibility criteria is classified in the fourth place with a weight of 6%. This criterion should be considered while choosing the supplier to increase the capacity of the supplier to respond to changing demand. Ecological and social concerns are the last criteria chosen by the companies with a weight of 2% for each criterion. This not means that they don't take into consideration these criteria, that means that they become aware that these criteria are important to the improvement of their sustainability. However, managers have to be careful when they

develop business relationships with suppliers. Because trust and cooperation become critical ingredients in a collaborative supply chain. The information must be collected and shared all along the supply chain in both forward and backward flows. Mutual trust criteria and effective communication combined with technologies from the smart industry provide adequate visibility across both internal supply chain functions and organizational. Suppliers are nowadays obliged to consider the respect for the environment that includes reducing the negative impacts of reverse logistics on the environment and limiting the use of natural resources for a better future.

To better classify the supplier selection criteria, figure 4 presents the criteria classes with sub criteria.

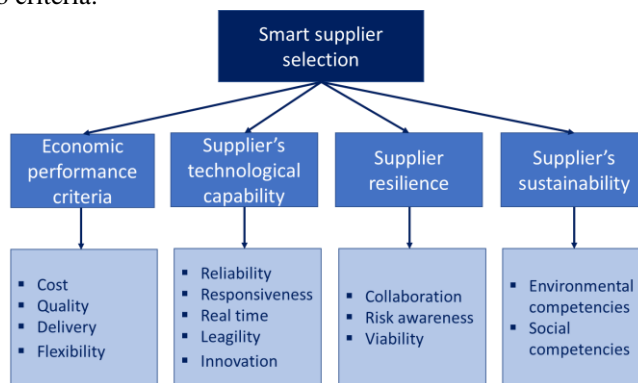


Fig.4. supplier selection criteria and sub-criteria.

7 Conclusion and future works

Choosing the relevant supplier is a crucial task for a manager due to the complexity of the decision-making. Selecting the right supplier for the right mission is the main objective of managers to increase their profitability and performance improvement. Facing multiple supplier selection criteria requires companies to define their supply chain strategy. To do so, our study used the MCDM method, and more particularly the AHP process, to classify the criteria according to their importance.

The AHP is an appropriate method for supplier selection. It helps to solve complex decision issues. In our study, the AHP contributes to prioritize selection criteria and ranking suppliers according to these criteria. In fact, we used an algebra metrics-based mathematical approach to determine the relevance of the eight criteria. First, we used the qualitative approach to convert issues into a hierarchy. Then, based on a quantitative approach, we used the pair-wise comparison strategy to achieve more reliable responses and reliability.

As a practical contribution, this paper proposes an architecture of decision method for supplier selection that will help improve the selection process and choose the appropriate supplier in the digital supply chain. In addition, this study highlights the necessity of considering other criteria that increase organizations' competitiveness such as the 'resilience' and 'smartness' in supplier selection. The findings of this study enable

managers and practitioners to improve the performance of the supply chain by considering the main criteria for selecting the relevant suppliers. However, this study also presents some limits related to the variety of criteria for supplier selection. In fact, our results remain to be discussed and reinforced in future works by introducing new criteria that could affect the process of supplier selection. In addition, it is preferable to review the AHP calculations taking into account the new criteria to be introduced.

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