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Selection supplier for Textile and Garment enterprises in Vietnam using association rules

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ABSTRACT

The research aims to investigate the support suppliers' decision making for Textile and Garment Vietnamese Enterprises based on using association rules mining. In order to increase the competitive advantage over other enterprises, Vietnamese enterprises are gradually shifting their production methods from CMT (Cut-Make-Trim) to FOB (Free On Board), ODM (Original Design Manufacturing), and OBM (Original Brand Manufacturing). One of the important steps for this transformation is to be self-sufficient in sourcing raw materials from selected suppliers with sufficient capabilities, meeting the requirements of price, and CSR (corporate social responsibility) to enable Vietnamese enterprises to enjoy tax incentives. The Vietnamese Enterprises participate in the textile and garment production process through importing raw materials from other countries such as China, Korea, etc. Therefore, the selection supplier issue is very important to them to enhance their business products. This study researches on finding positive ARs and negative ARs in Textile and Garment data domain via three scenarios to define the relationship of alternative criteria for selection suppliers. By using alternative method of ARM (Association Rule Mining), the experimental results show that Textile and Garment enterprises in Vietnam appreciate the CSR factor highly. This is completely in line with the previous survey research on the new factor in the supplier selection criteria of Textile and Garment enterprises in Vietnam. In another word, in this field, the CSR plays as an important role to reflect company's image and it is the first of decision choice. The other criteria are considered after including Cost, Quality, and Delivery respectively. The remain factors of Service, Capability, Relationship, and Sourcing Country are not highly evaluated via the experiments. With different scenarios along with the association rules mined, they reflect different sets of criteria that textile and garment enterprises use to select their suppliers. Furthermore, the rare rules show situations that are very unlikely but have high reliability in reality. Based on the findings, the factors will show the essentials for suppliers to improve themselves to meet the requirements.

1. Introduction

In supply chain management, members play an important role in providing raw materials for the production process or services for the business called suppliers. The supplier selection process can be understood as the screening process to aid the manager's final decision. It typically includes several steps such as identifying a potential supplier pool, proposing criteria for evaluating that pool, and propose a screening, selection and evaluation process aligned with previously defined criteria. In today's competitive conditions, searching, collecting,

screening and selecting a good supplier list for the business is one of the extremely important factors helping the business to achieve its goals. In the screening process, the searching and evaluating steps can be seen as the essential ones to decide the quality of the suppliers. Searching for suppliers can be easily assisted by current search tools such as social networks, or suppliers' own marketing. The evaluation stage can be seen as the most important one for businesses in order to select the optimal list of suppliers that fulfill the requirements for both raw materials and costs. From the supplier's perspective, clearly identifying the factors that the business needs (selection criteria) is one of the success factors in

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applying for the company's supplier selection process. Moreover, suppliers can improve themselves to enhance their own competitiveness. To do so, they need to fully understand the company's supplier selection process, participate in these processes themselves in the role of partners, share information and data with the company to gain deep insights into the criteria of the evaluation process.

Data mining techniques, and specifically association rule mining, is known as an effective tool to support managers in the selection and decision-making process (Jain et al., 2017; Lin et al., 2009; Olson, 2020). In the supplier selection problem, association rule mining can be applied by analyzing transaction data. If customers frequently choose a specific supplier for their products, the system will discover the relationship between the products and the corresponding suppliers. From the obtained set of suppliers, through the evaluation stage in the above process, managers can select suitable suppliers for their company. In addition to analyzing transactions to identify suppliers for specific products, association rule mining can also identify rules linking products in the shopping cart. If customers frequently purchase certain products together, a relationship between those products can be formed, which can be used to build and supplement the set of suppliers providing those linked products. Another way to build the set of suppliers for selection is to analyze transaction characteristics. If a supplier frequently appears in transactions with values above a threshold or in transactions of potential customer groups, the system will establish a relationship between the supplier and these characteristics. As a result, managers will have more data and choices for the evaluation stage to select the appropriate suppliers. Therefore, understanding the specific process and evaluation criteria for supplier selection is crucial. With a clear understanding of the process, suppliers can know how to make improvements and upgrades in order to become strong candidates and enhance their competitiveness in the selection process from businesses.

According to supplier selection in sector-based distribution of publications in Yildiz and Yayla (2015), almost publications concentrated to hypothetical examples (28 %), electrical-electronics sectors (20 %), automotive sector (16 %), etc. However, there is only 2 % of publication mentioned to Textile and Garment sector. In Vietnam, textile and garment enterprises participate in the garment supply chain, which includes processes like fabric production and design. They often import raw materials from countries such as China, Taiwan, and Korea (Virac, 2016). Therefore, selecting the right suppliers is crucial for these enterprises, as it impacts their products. A supporting decision system based on established supplier criteria by using scientific method should be developed.

The Vietnamese Textile and Garment industry characterized by four production methods such as CMT (Cut-Make-Trim), ODM (Original Design Manufacturing), OBM (Original Brand Manufacturing), OEM/FOB (Original Equipment Manufacturing/Free On Board) (Vitas, 2015).

Currently, according to BSC (2016), for Vietnamese textile and garment enterprises, the CMT method accounts for the majority, about 30 % of enterprises are implementing the OEM/FOB method, and only 5 % are using the ODM and OBM methods. By using OEM/FOB method, the enterprises will have higher profit compared to the others because they can control the selection of raw materials from different suppliers, be self-sufficient in the production process, packaging, and transportation to the partner. Therefore, the selection and evaluation of suppliers is also extremely important for these enterprises. However, the supplier selection criteria currently used by Vietnamese textile and garment enterprises are seldom available (Nong & Ho, 2019).

The purpose of this study is to build and discover relationships or rules related to factors in the evaluation stage of business supplier selection through association rule mining. Identifying important factors contributing to supplier selection from the perspective of the business in order to provide suggestions or additional information to suppliers regarding these important criteria. Based on that, they can make appropriate business decisions to meet the selection requirements from the business perspective. The main academic contribution is the use of

positive ARs and negative ARs, which are often not considered when developing exploration rules to find rare information in the dataset. This is also a proposal method to experiment with traditional data survey methods using the PLS or SEM model. Regarding the contribution to industrial contexts, the supplier selection criteria catalogue using the proposed method is completely appropriate and consistent with previous publications. Therefore, the validity of these criteria is reinforced. Additionally, the new method has found that the CSR factor is the most important among the supplier selection criteria for Vietnamese textile and garment enterprises. Besides that, the different association rules mined reveal different sets of criteria that textile and garment enterprises use to select their suppliers. Furthermore, the rare rules show situations that are very unlikely but have high reliability in reality. Based on the findings, the factors will show the essentials for suppliers to improve themselves to meet the requirements.

The rest of the paper is organized as follows: Section 2 – Literature Review presents related studies. The factors affecting the choice of chain supplier of Textile and Garment enterprises are mentioned in Section 3. Section 4 describes the data set and introduces the experimental methods and procedures carried out in this study. The experimental results and discussion are presented in Section 5. Finally, Section 6 are discussion and conclusions.

2. Literature review

Using data mining techniques for selecting the right suppliers for an enterprise is interested by many researches in supply chain management field (Olson, 2020). The selection of suppliers is primarily carried out through data mining techniques such as clustering to group suppliers into different groups (Parmar et al., 2010; Zhao & Yu, 2011), using decision trees and neural networks (Zhao & Yu, 2011), or combining clustering and classification methods (Chen et al., 2012). Regarding the use of association rule mining in data mining techniques, Xu and Lin (2009) demonstrate the combination of using rules in hierarchical tree structures to establish a supplier selection process, while Li et al. (2008) use grey theory based on fuzzy set theory to enhance the certainty of supplier selection. According to Le et al. (2013), the association rule mining method is used to support decision-making in sharing transaction data between retailers and suppliers by constructing association rules algorithms for removing sensitive data before releasing database. Haery et al. (2008) used association rule mining to discover relationships between variables such as quality system outcome, claims, on-time delivery, and response to claim using the Apriori algorithm (SPSS Clementine). The publication confirmed that association rule mining can help make decisions even in incomplete datasets. Lin et al. (2009) used association rule mining in combination with set theory to identify key suppliers. Initially, association rules were used to classify suppliers into different groups, such as primary and secondary. Based on set theory, availability values were measured to determine the ability to meet the required demand from manufacturers. Jain et al. (2017) proposed an association rule algorithm called i-PM for finding correlations among suppliers in a pre-qualification dataset. Criteria such as organizational strength and performance capabilities showed high weights in the rules. They also confirmed that association rule mining faces the challenge of providing uncertain rules alongside effective ones. They suggested using fuzzy rules to make the rules more explainable.

Based on the criteria sets, related publications also indicate that the decision to choose a supplier also depends on the evaluation criteria they emphasize on the level of influence through surveys. For example, with the technology usage criteria in the production process, the research group of Mondragon et al. (2021) proposed 12 factors to select suppliers such as: technologies used by suppliers, technologies used by customers, etc. The factor analysis results indicate that 5 important factors affecting the supply chain performance were identified in decreasing order: on-time delivery/customer service level, return on investment, recruitment and training of employees, reducing environmental impact, rapid

prototyping and tooling.

By using the criteria of distance range from the company to the supplier, the research group of Mahmoudifard et al. (2018) proposed 8 potential criteria affecting supplier selection: cost, credit and finance, distance and convenience, delivery, loyalty, production capability and reliability, management and service, technology and quality (on Likert scale) in selecting customers. In addition, this study also shows that company characteristics also affect supplier selection.

In Vietnam, there are not many publications on the application of machine learning, specifically association rule mining, in supplier selection in supply chain management. The research focuses mainly on surveys to assess satisfaction between suppliers and businesses. For example, to assess satisfaction with the logistics service environment of suppliers, the research group of Huynh-Xuan et al. (2024) surveyed 200 logistics enterprises operating in Ho Chi Minh City and determined satisfaction affected by 6 factors: Quality of infrastructure related to trade and transportation, convenience of competitively priced shipment arrangements, efficiency of customs clearance procedures, ability to track status of goods after shipment, logistics service capabilities and quality, and on-time delivery. Studying the cooperation between retailers and suppliers, the research group of Pham and Nguyen (2018) surveyed staff and managers working in business departments at supermarkets in Ho Chi Minh City. Data from 328 survey forms with 29 observed variables distributed into 7 factors: Value-added benefits, cooperation benefits, economic benefits, relationship outcomes, trust, commitment, long-term collaborative relationship. Thereby the research group concluded that Positive impacts of trust and commitment create long-term business partnerships; Relationship benefits are the main impacts on trust/commitment and create long-term strategic partnerships.

This points out that there is still a large gap in research with factors affecting supplier selection using machine learning based on criteria where they are built based on identifying factors influencing supplier selection decisions from businesses in Vietnam.

In summary, supplier selection is an interesting topic in supply chain management. However, many publications focus on improving the steps within the selection process to predict the output (key suppliers) rather than explaining the methods for choosing these suppliers and the implications after the prediction process. Sometimes, in the set of rules obtained from association rule mining, it may not be possible to fully explain why one supplier is chosen over another due to the lack of direct and sufficiently strong rules (with high support) influencing the selection decision. Additionally, the set of rules may not reveal all the deeply hidden (rare) pattern information present in the original dataset. The research aims to leverage the techniques of association rule mining to detect and predict reputable suppliers with clearer explanations for the selection process by using fuzzy set theory to discover rare (infrequent) rules. Consequently, it identifies the set of important attributes for selection from the perspective of the enterprise, helping suppliers understand what they need to change or enhance to become significant candidates in the enterprise's selection process.

3. Factors/criteria for evaluating supplier

There are some existing groups of criteria for selecting the supplier such as Dickson's criteria (Dickson, 1966), Olsen's criteria (Olsen & Ellram, 1997), Weber's criteria (Weber et al., 1991). Each industry has its own characteristics, so the criteria for selecting suppliers are also different. In the Textile and Garment industry, there are some groups of criteria including model of Gary and Jaramillo (2005) with five criteria and 19 sub-criteria, Kopru and Albayrakoglu (2007) added an innovation criterion to this model. In 2012, Vijayvagy (2012) proposed set of 18 criteria, and especial Fallahpour et al. (2017) built a set of criteria based on three aspects: economic, environmental, and social. This set of criteria includes 13 criteria with 46 sub-criteria. In Vietnam context, basing the result of interview, Nong and Ho (2019) divided criteria to

select the supplier for Textile and Garment businesses into three groups including: Organizational factors, performance metrics, and sourcing country.

3.1. Performance metrics

3.1.1. Quality

Businesses need the product/service of the supplier to be able to do good business. Therefore, the supplier must ensure that the quality of the product/service provided meets the requirements of the business. Sub-criteria to evaluate the quality of a supplier include: Conformance to requirement, Quality certificates, Defect and scrap ratio, Country of origin, Continuous quality improvement programs.

3.1.2. Costs

Product/service prices and payment methods are indispensable criteria in the supplier evaluation criteria table. This criterion affects the purchasing power and profitability of business. Obviously, if two suppliers with the same quality and performance of products and services, the one with the cheaper price will bring more profits to the business. Sub-criteria to evaluate the price of a supplier may include: Payment method, Freight cost, Minimum order quantity (MOQ), Discount, Material price.

3.1.3. Delivery

Normally, the delivery is often concerned by the issue of on-time delivery. However, from the survey results for textile and garment enterprises in Vietnam situation, in addition to on-time delivery, the sub-criteria for shipping standards also have short lead-time, delivery quality, and geographic distance between them and suppliers.

3.1.4. Service

The service that the supplier provides to the business supports the delivery of the best product/service. Especially in cases where problems arise such as product defects, quality assurance, lack of orders... Therefore, this is an indispensable criterion in the evaluation and selection of suppliers. When evaluating suppliers, businesses need to collect opinions on the quality of support, the attitude of the supplier and the time to respond to support requests, the qualifications of the support staff, etc. However, in this study sub-criteria to evaluate the service of a supplier include: flexibility to changes, responsiveness, after-sales services, and ease of communication and offering service. In which flexibility to change is the most important criterion that often occur in the fashion industry.

3.2. Organizational features

3.2.1. Relationship

Firms always want to have a long-term cooperation relationship with suppliers, because long-term cooperation will ensure a stable source of goods in terms of quality, quick supply when needed, and help businesses not spend much time in researching suppliers. To evaluate the supplier relationship criterion, it is divided into sub-criteria including: long-term partnership, trust, honesty, and especially, information sharing. In which information sharing criteria are: especially important because it is the factor that helps to improve the business relationship.

3.2.2. Capability (productivity and efficiency)

In the supplier evaluation criteria, it is indispensable for the performance of that supplier to provide products/services to the business. Ensuring the performance of the supplier's product/service delivery determines the business plan of the enterprise. Therefore, suppliers need to ensure and have credibility in the time and quantity of products/services provided. Sub-criteria to evaluate the performance of supplier can include: sample development capacity, production capacity, financial capacity, reputation, human resources, and factories.

3.2.3. CSR

This is one of the criteria to evaluate social responsibility as well as the sustainable development of enterprises. It is applicable to all enterprises in general and enterprises in the textile industry in particular. Normally, CSR is divided into three groups of factors: environment, Social and Governance. In the study of CSR sub-criteria including labor practices and environmental protection, consumer protection and contributions to communities.

3.3. Sourcing country

The selection of suppliers does concern not only with the suppliers' performance and/ or organizational characteristics and capabilities but also with macro factors such as the political and economic stability of sourcing countries, cultural differences, etc. According to the results of the survey, businesses require suppliers to come from countries with stable political and economic status, no labor disputes, and little cultural differences. Because these factors will affect the delivery progress, and thereby affect the productivity and production schedule of enterprises.

4. Data and methods

4.1. Data description (original, objects, descriptive table)

The data set in this study is collected from a survey of enterprises in the Textile and Garment industry for the evaluation criteria to select a supplier for their company. The original dataset is derived from [Nong and Ho \(2019\)](#) which was strictly collected by Axis Research company (according to ICC/ESOMAR international code in market). This set include 38 variables was divided into 8 factors (or criteria) as in [Table 1](#) (the last variable is the output of model). These supplier selection criteria for T&A companies was identified basing on steps including review literature with high impact journal articles, interview with 20 practitioners to explore the criteria for matching theory and practice, conduct a pilot study after revising questionnaire twice, and test to ensure the reliability, the validity and sensitivity of the measures. The number of observations of the data set is 362. After taking the mean value of sub-criteria by each factor, 8 variables/ factor continue were coded as input to the rule mining process.

4.2. Association positive negative rules

The association rule (AR) first introduced by [Agrawal et al. \(1993\)](#) presents a nonlinear relationship or between items in a supermarket sales data basket. Suppose T is a transaction database, $T = \{t_1, t_2, \dots, t_n\}$, where each t_i is a purchase transaction, and T has k items (or data items) $I = \{i_1, i_2, \dots, i_k\}$. An AR over T is a representation of the form $A \Rightarrow B$, where A and B are a subset of data items that do not intersect ($A \cap B = \emptyset$); A and B are called the antecedence and the consequence of the rule, respectively, and so AR is presented as an "if-then".

The value of an AR can be measured through its support and confidence quantities. More specifically, the mining of ARs is to find all the

rules $A \Rightarrow B$ such that $\text{supp}(A \Rightarrow B) \geq \text{minsup}$ and $\text{conf}(A \Rightarrow B) = \text{Sup}(A \cup B) / \text{Sup}(A) \geq \text{minconf}$, where $\text{supp}(A \Rightarrow B)$ and $\text{conf}(A \Rightarrow B)$ respectively are called the support and confidence of the rule $A \Rightarrow B$ and are defined as follows: $\text{Sup}(A \Rightarrow B) = \text{Sup}(A \cup B) / |T|$ and $\text{Conf}(A \Rightarrow B) = \text{Sup}(A \cup B) / \text{Sup}(A)$, where $\text{Sup}(A)$ is the frequency of occurrence of the set of data items A in the transaction database T , minsup and minconf are user-defined values and are called minimum support and confidence respectively. Such found ARs are called good (or valid) rules.

In ARs, if the antecedence and consequence sections contain only the items that appear in the purchase transactions, it is called positive ARs (or PARs), whereas, ARs have an antecedent or consequence containing at least one item that doesn't appear in the purchase transaction is called negative ARs (or NARs), and $\neg A$ is denoted for negative of item A . The data item that appears in the transaction is called a positive data item, otherwise it is called a negative data item.

The positive association rules reflects situations where items concurrency appear in transactions. For example, items in purchase invoices show customers' consumption habits, thereby suggesting strategies for businesses to arrange and display items together on shelves. Meanwhile, the positive-negative association rules not only reflects the appearance a and/or absence of items in transactions but it can also reflect the increase or decrease and simultaneous relationship of many factors when analyzing correlations. For example, positive-negative association rules can reveal the impact of macroeconomic factors on unemployment rates or stock indexes. Therefore, positive-negative association rules can be widely applied in socio-economic problems.

In this study, the DPNARMiner algorithm was used to discover the positive-negative association rules applied to the problem of choosing chain suppliers ([Thanh et al., 2023](#)). This algorithm is built on the concept of equivalence class and support-confidence framework. It can mine all the positive-negative association rules as defined above with a rather large search cost. The algorithm has been proven the soundness and the completeness as well as the complexity in theory and experiment. As mentioned above, this algorithm mining positive-negative association rules can be applied to association analysis for many socio-economic problems. Moreover, it can be easily implemented with small data sets and has special meanings for problems with rare data domains. More detail can be seen in [Thanh et al. \(2023\)](#)

4.3. Experimental scenarios

In order to find the relationship between the variables with a high level of confidence, thereby building a suitable case for the business and supporting in suggestions and advice to select the suitable logistics supplier, this study propose experimental scenarios based on dividing thresholds for the following criteria described as in the [Table 2](#).

In this empirical process, 3 scenarios were built. Here, the threshold values for negative items have meaning as follows: requirement for criteria is at a very low level (0→2.4), low level (0→3.4), and medium (0→3.9), respectively. Whereas the threshold values for positive items have meanings corresponding that is: requirement for criteria is at a medium level (2.5→5), high level (3.5→5), and very high level (4→5). With the minsup parameter, its threshold value is selected from the smallest value 0.05 (corresponding to the rare rule) to the highest value 0.95 (corresponding to the common rule), while the minconf parameter

Table 1
Data set in the study.

Index	Factor	Description	Value	Variable
1	QA	Quality	1 → 5	A1
2	CO	Cost	1 → 5	A2
3	DE	Delivery	1 → 5	A3
4	SE	Service	1 → 5	A4
5	CA	Capability	1 → 5	A5
6	PR	Relationship	1 → 5	A6
7	CS	CSR – Corporate Social Responsibility	1 → 5	A7
8	SC	Source Country	1 → 5	A8
9	SD	Supplier Decision	1 → 5	D

Table 2
Scenarios for experiment.

Scenario index	Value interval for negative item	Value interval for positive item	Minsup	Minconf
S1	0→2.4	2.5→5	0.05; 0.9	0.7→0.95
S2	0→2.9	3→5	0.05; 0.9	0.7→0.95
S3	0→3.9	4→5	0.05;0.9	0.7→0.95

is chosen from 0.7 → 0.9 to ensure there are rules and the mined rules are high confidence.

5. Experiment results

5.1. For 1st scenario with positive item has meaning medium level and negative item has meaning very low level

From the list of popular rules, with threshold minsup = 0.9 and minconf = 0.95, we get 18 rules, in which, the found rules have a confidence of over 99 %. For rules of length 1, that is it only takes one criterion to decide in choosing a logistics supplier. More specifically, with the most popular rule $A7 \rightarrow 1$ (support is 0.972452), it means that as long as the supplier has a social responsibility index at medium level or more, Textile and Garment enterprises will choose to make their supplier. This is completely reasonable because a business with a high CSR index means that this business has a high responsibility to employees, the environment, and the community. So when they are suppliers, Textile and Garment enterprises can completely trust their reputation and service quality. Two criteria with equivalent popularity after the CSR are Cost ($A2 \rightarrow 1$) and Delivery ($A3 \rightarrow 1$) with a support of approximately 0.95. This means, that as long as suppliers have the reasonable cost or high quality of delivery, textile and Garment enterprises will choose them. This can be explained that cost or as well as delivery quality greatly affects the operational efficiency as well as the production progress of enterprises in general and textile enterprises in particular. The final criterion that can stand alone with a rule of length 1 is quality with support of approximately 0.91. And the special thing about these rules of length 1 is that they all have a confidence of 1. This means that these rules have absolute confidence.

For rules of length 2 and 3, they both satisfy popularity and confidence. However, in these rules, we can see that they all contain at least 1 of the criteria in the rule of length 1 above. This means that other criteria are only used as secondary criteria for Textile and Garment enterprises to evaluate their selection of suppliers.

With the table of rare rules obtained, besides the common rules as shown in Table 3, here we get some more rules of length 1 with both negative and positive rules. Specifically, for positive rules, add rules ($A4 \rightarrow 1$), ($A8 \rightarrow 1$), ($A \rightarrow 1$), ($A5 \rightarrow 1$) corresponding to Service, Sourcing Country, Relationship, and Capability can be used as criteria for selecting suppliers. As for the negative rule, there are additional rules ($\neg A4 \rightarrow 1$), ($\neg A5 \rightarrow 1$), and ($\neg A1 \rightarrow 1$) corresponding to the meaning that if one of the Sourcing Country, Capability, or Quality criteria of the supplier has a low evaluating value, textile enterprises can still accept it to choose as a supplier. However, these rules have a very low popularity (0.26; 0.069; and 0.082, respectively), which means that these choices

Table 3
List of popular rules for the 1st scenario.

Index	Popular rules	Support	Confidence
1	$A7 \rightarrow 1$	0.972452	1
2	$A2 \rightarrow 1$	0.958678	1
3	$A3 \rightarrow 1$	0.950413	1
4	$A1 \rightarrow 1$	0.909091	1
5	$A7, A8 \rightarrow 1$	0.947658	0.997101
6	$A2, A7 \rightarrow 1$	0.942149	0.997085
7	$A6, A7 \rightarrow 1$	0.939394	0.997076
8	$A2, A8 \rightarrow 1$	0.933884	0.997059
9	$A3, A7 \rightarrow 1$	0.931129	0.99705
10	$A2, A6 \rightarrow 1$	0.92562	0.997033
11	$A3, A8 \rightarrow 1$	0.92562	0.997033
12	$A2, A3 \rightarrow 1$	0.92011	0.997015
13	$A3, A6 \rightarrow 1$	0.917355	0.997006
14	$A2, A7, A8 \rightarrow 1$	0.917355	0.997006
15	$A6, A7, A8 \rightarrow 1$	0.914601	0.996997
16	$A2, A6, A7 \rightarrow 1$	0.909091	0.996979
17	$A3, A7, A8 \rightarrow 1$	0.906336	0.99697
18	$A2, A6, A8 \rightarrow 1$	0.903581	0.99696

are rare (Tables 4 and 5).

5.2. For 2nd scenario with positive item has meaning high level and negative item has meaning low level

In this case, there are 12 common rules to be discovered. In which the rules have length 1 with absolute confidence corresponding to Cost, Delivery, and CSR criteria. The rule has the highest popularity is that for the Cost. Thus, in the case of requirement of criteria at a high level, textile and garment enterprises put cost criteria first, and followed by Delivery and CSR criteria. With rules of length 2, similar to the first Scenario, these rules all contain at least one of the previous criteria of length 1. This means that the accompanying criteria are only supplementary to the evaluation and selection of logistics suppliers for Textile and Garment enterprises. In addition, there are rules with length 1 for other standards such as Relationship ($A6 \rightarrow 1$), Sourcing Country ($A8 \rightarrow 1$) and Capability ($A5 \rightarrow 1$), however, these rules have lower support and confidence. The special thing in this case is that there are no rules for Service or Quality criteria. This means that these two criteria are not taken seriously by Textile and Garment enterprises in case of criteria at high level (Table 6).

In the case of mining rare rules, in addition to the rules investigated in popular rules, there are some other rules. Among them, the rules with absolute reliability but low popularity are ($A4 \rightarrow 1$) corresponding to the Service criterion, and ($A1 \rightarrow 1$) corresponding to the Quality criterion. Besides that, the negative rules ($\neg A1 \rightarrow 1$), and ($\neg A4 \rightarrow 1$) also were mined. These rules are completely consistent with those obtained in the popular case where Textile and Garment enterprises do not use Quality or Service as the main/important criteria for selecting suppliers. However, these rare rules also reflect that in reality there are still a very small number of businesses that using/not using Quality or Service as evaluation criteria to choose their logistics supplier.

5.3. For 3rd scenario with positive item has meaning very high level and negative item has meaning medium level

In this case the popular rules do not appear, because when we lower the support level to 0.4, rules start to appear, but these rules are not highly confidence. So in this case we only consider rare rules with high confidence. More detail, the selected thresholds are minsup = 0.05 and minconf = 0.9. The results show that there is only one rule with absolute reliability ($A1 \rightarrow 1$) corresponding to the Quality criterion. This means that when businesses require selection criteria at very high level, supplier quality is given top priority. This is completely reasonable because when the supplier has very good quality, it obviously meets almost requirements of businesses. However, this is a rare rule with a popularity of approximately 0.058, which reflects that not many Textile and Garment enterprises require Quality too high when choosing suppliers (Table 7).

In the list of rare rules, there are also rules where the right-hand side is a negative item, which corresponds to not choosing a supplier.

Table 4
List of rare rules for the 1st scenario.

Index	Rare rules	Support	Confidence
1	$A7 \rightarrow 1$	0.972452	1
2	$A2 \rightarrow 1$	0.958678	1
3	$A3 \rightarrow 1$	0.950413	1
4	$A1 \rightarrow 1$	0.909091	1
5	$A4 \rightarrow 1$	0.730028	1
6	$A8 \rightarrow 1$	0.966942	0.994334
7	$A6 \rightarrow 1$	0.958678	0.994286
8	$A5 \rightarrow 1$	0.922865	0.994065
9	$\neg A4 \rightarrow 1$	0.261708	0.969388
10	$\neg A5 \rightarrow 1$	0.068871	0.961538
11	$\neg A1 \rightarrow 1$	0.082645	0.909091

Table 5

List of popular rules for the 2nd scenario.

Index	Popular rules	Support	Confidence
1	A2→1	0.958678	1
2	A3→1	0.950413	1
3	A7→1	0.914601	1
4	A2, A6 →1	0.922865	0.997024
5	A2, A3→1	0.92011	0.997015
6	A3, A6 →1	0.914601	0.996997
7	A2, A8 →1	0.911846	0.996988
8	A3, A8 →1	0.903581	0.99696
9	A6→1	0.955923	0.994269
10	A8→1	0.944904	0.994203
11	A5→1	0.922865	0.994065
12	A6, A7 →1	0.909091	0.990991

Table 6

List of rare rules for the 2nd scenario.

Index	Rare rules	Support	Confidence
1	A2→1	0.958678	1
2	A3→1	0.950413	1
3	A7→1	0.914601	1
4	A4 →1	0.730028	1
5	A1→1	0.663912	1
6	A6 →1	0.955923	0.994269
7	A8→1	0.944904	0.994203
8	A6→1	0.922865	0.994065
9	¬A1 →1	0.327824	0.97541
10	¬A4 →1	0.261708	0.969388
11	¬A5 →1	0.068871	0.961538

Table 7

List of rare rules for the third scenario.

Rare rules	Support	Confidence
A1→1	0.057851	1
A6,¬A2,¬A4 →0	0.15978	0.935484
A2,¬A3 →0	0.143251	0.928571
A6,A8,¬A2 →0	0.15978	0.920635
¬A2,¬A7 →0	0.14876	0.915254
A2,A4,A7 →1	0.15978	0.90625

Specifically, the law (A6,¬A2,¬A4 →0) reflects that, although the supplying businesses have close relationships and reasonable prices, the Service is only average, and that business is not trustworthy enough for Textile and Garment businesses to choose as suppliers. Similar to the rule (A6, A8, ¬A2 →0) shows that even though the supplier has a very good relationship, the high Sourcing Country Index, and Cost is only average, there are still a small number of Textile and Garment enterprises don't choose them. Rule (¬A2,¬A7 →0) reveals that although suppliers have reasonable prices, however, their CSR index is only average, they are not qualified for Textile and Garment businesses to trust and choose. As for the law (A2,¬A3 →0), it means that when the supplier has very high costs and the Delivery index is at a medium level, there will be a small number of Textile and Garment businesses that do not choose them as their supplier. The special thing in this third experimental case is that except for the absolute confident rule, the other rules are related to the Cost. This means that when the requirements for suppliers are very high, in addition to Quality, Cost will always be considered to determine whether to choose that supplier or not.

6. Discussion and conclusion

In managerial implication, the finding set of criteria is extremely useful for Textile and Garment companies in selecting capable suppliers as partners in the supply chain and reducing their risks and costs. As a result, these companies can increase their current production to a higher

level. For example, they can shift from CMT production method to FOB or from FOB to ODM or OBM. Additionally, identifying the relationships and order of the criteria set can serve as a guideline on the order of criteria for raw material suppliers if they wish to become suppliers for manufacturing enterprises. These suppliers need to be well-prepared on the criteria of quality, cost, delivery, service, capability, relationship, and CSR.

Experimental results with three different scenarios show that for Textile and Garment enterprises in Vietnam if they require criteria at an average level, they will highly appreciate CSR. This means that businesses consider corporate social responsibility as an important factor that fully reflects all aspects of a business, thereby being a basis for selecting suppliers. After this criterion, the other criteria considered include Cost, Quality, and Delivery respectively. This reflects that to select chain suppliers, Textile and Garment businesses are really interested in these criteria. Because it involves the cost problem as well as affects the progress and performance of the business. Therefore, businesses providing chain services need to pay attention to improving these factors to attract and meet the requirements of businesses that need to use their services. Besides that, other criteria including Service, Capability, Relationship, and Sourcing Country although were not highly evaluated, chain suppliers need to be concerned and improve. Because there are still enterprises not select chain suppliers with not good Service or Delivery although they have close relationships or reasonable costs.

In academical implication, this is one of the first studies applying the algorithm mining positive-negative association rules in analyzing and exploring factors affecting the supplier selection of Vietnamese textile enterprises. The proposal applying of positive ARs and negative ARs can be seen as the extension of the use of machine learning techniques in stead of using traditional models in survey data. With the ability to reflect simultaneous and nonlinear relationships, it shows the superior ability of the positive-negative association rule compared to other traditional methods. Moreover, using this algorithm, it not only allows searching for popular rules but also rare rules, in order to detect cases that rarely occur but have high reliability. This helps to reflect and explain more comprehensively the events that occur for practical problems. It is also a suggestion for applied studies in other aspects of supply chain problems as well as in other fields in the future.

CRedit authorship contribution statement

Hung Long Nguyen: Formal analysis, Conceptualization. **Van Thanh Do:** Writing – original draft, Supervision, Conceptualization. **Thi Van Trang Nguyen:** Writing – original draft, Conceptualization. **Thi Thanh Tam Do:** Writing – original draft, Supervision, Conceptualization. **Thi Thu Thuy Nguyen:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Thi Ha Dinh:** Writing – review & editing, Writing – original draft, Software, Methodology.

Declaration of Competing Interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

We understand that the Corresponding Author is the sole contact for the Editorial process (including Editorial Manager and direct

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Declaration of Competing Interest

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