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Typical traceability barriers in the Indonesian vegetable oil industry

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Abstract

Purpose – A traceability system is a key success factor in global food trade, but implementing it in vegetable oil industry is one of the most difficult undertakings in food supply chain management. This study aims to (1) identify typical operational barriers in the implementation of bulk-liquid traceability system in the Indonesian vegetable oil industry by considering the perspective of experts and (2) model the relationship between the barriers structurally in order to improve the reliability of the traceability system.

Design/methodology/approach – To do so, data from in-depth interviews with experts were examined by using content analysis. Then the authors used a combination of decision-making trial and evaluation laboratory (DEMATEL), interpretive structural modelling (ISM) and matrice d'impacts croisés multiplication appliqué un classement (MICMAC) to construct the hierarchical model and to cluster the typical barriers based on their driving power and dependence power.

Findings – In total, 20 typical traceability barriers along the internal chain (supplier-input-process-output-customer) were identified. The interrelationships between these barriers were modeled in a hierarchical structure, seeking to answer why it is difficult to implement a traceability system and what actions should be taken to remove these barriers.

Practical implications – The model can shed light on how to manage barriers in bulk-liquid food commodity industry, especially in the vegetable oil industry. An action map has been proposed to overcome the operational barriers. This model will also help tracing the critical points of the traceability system.

Originality/value – Compared to other food commodities, operational barriers in vegetable oil chain has never been studied specifically. In fact, there are many operational aspects that hinder traceability. The Indonesian context entails social, economic and environmental factors as well, so it can inform decision-makers in formulating an action map.

Keywords Bulk-liquid food industry, Traceability system, Typical operational barrier

Paper type Research paper

1. Introduction

Vegetable oil, especially palm oil and coconut oil, is widely consumed around the world. Indonesia's export of these two commodities is among the largest globally. It also contributes to 4% of the Indonesia's gross domestic product (Alika, 2019). However, vegetable oil market is prone to food safety issues including the contamination of harmful chemicals such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polybrominated biphenyl ethers (PBDEs) as well as pesticides (Roszko *et al.*, 2012). To compete with substitute products e.g. soybean oil, rapeseed oil, peanut oil, cottonseed oil and olive oil, both industries must be able to guarantee the safety and the quality. However, testing food safety in Indonesia as basic as checking the PAH parameter could be costly, especially for small and medium enterprises (SMEs). Moreover, the Indonesian vegetable oil

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industry can only schedule testing on a semiannual or annual basis. Product samples are often insufficient and do not accurately represent production in such a long period. These two factors have caused control on food safety become weak. A reliable traceability system, therefore, is needed.

The European Union (EU), one of the biggest importers of Indonesian vegetable oil, has issued an embargo because of food safety and sustainability issues (Rifin *et al.*, 2020). This has impacted the socioeconomic conditions of the stakeholders along the value chain. To negotiate on the embargo lifting, the industry needs to improve the traceability systems. However, assuring the quality and safety of food products in a complex food chain is difficult (Wowak and Boone, 2015). Vegetable oil supply chain is not only complex but also consists of changes in product forms and perception of quality and safety throughout the supply chain. In the upstream, stakeholders pay more attention to food quality (Engelseth *et al.*, 2011); while toward the downstream, they shift the focus to food safety (Pant *et al.*, 2015). This illustrates how vegetable oil industry is an intersection between the commodity-focused and the consumer-driven value chain (Dani, 2015). A market that categorizes vegetable oil as a value-adding product demands its traceability to ensure the food safety, but for a commodity-focused market, this is not a major concern.

Technically, a traceability system allows for backtracing of a product's footprints and forward tracking of a distributed product to determine the product's location and quantity when there is a problem that necessitates a recall (Wowak *et al.*, 2016). Besides that, the system may also be used to ensure sustainability (Leegwater and van Duijn, 2012). However, to build a reliable traceability, there are many barriers, such as the high start-up cost and the supply chain complexity (Regan *et al.*, 2015). Such barriers may become an excuse for food industry not to put a traceability system in place.

Previous studies have identified barriers in a traceability system establishment. Skilton and Robinson (2009) proposed a theoretical model that illustrates the connectedness of the barriers in a food chain. Miao *et al.* (2011) identified the barriers by looking at the country's context. Regan *et al.* (2012) categorized barriers into managerial issues, social issues and technical issues. Likewise, Bosona and Gebresenbet (2013) categorized barriers into resource limitation, information limitation, standard limitation, capacity limitation and awareness limitation. Meanwhile, Morana (2016) categorized 17 barriers into organizational barrier and technological barrier.

Each food chain has its own specificity, which must be considered when designing a traceability system. Engelseth *et al.* (2014) stated that there is no traceability model that is suitable for all types of food chain. Dediu *et al.* (2016) and Hardt *et al.* (2017) identified barriers in the fishery sector and seafood sector, but the results were inconclusive. Therefore, no practical implication could be drawn. Meanwhile, at the organizational level, challenges in building a traceability system emerge at the operational level (Gunawan *et al.*, 2019). Regan *et al.* (2012) have identified the technical barriers at this level, but they were oversimplified. This is not sufficient because without valid identification, food industry will not be legally obliged to implement an excellent traceability system.

Bulk food is classified into four forms: liquid, powder, crystal and grain (Comba *et al.*, 2013; Charlebois and Haratifar, 2015). Thakur and Hurburgh (2009) and Comba *et al.* (2013) emphasize that implementing a traceability system in food industry that manages and trades its products in bulk is a hard work; especially if it is in the liquid form (Skoglund and Dejmek, 2007; Acierno *et al.*, 2011). However, Sharma (2019) argues that it is more feasible to implement a traceability system for a liquid food product such as milk that has shorter shelf life, direct consumption pattern and segmented distribution systems.

To date, only few studies have specifically identified typical operational barriers faced by a traceability system in a vegetable oil industry that involves experts' judgment. Filling this gap is important for the development of a traceability system for bulk-liquid food. However, a contextual relationship among them must be drawn first. Therefore, the current study will review the barriers and their relationships by considering experts' judgment.

Data were collected from a systematic literature review, interviews with experts and questionnaires based on decision-making trial and evaluation laboratory (DEMATEL). We also used interpretive structural modelling (ISM) to map out the relationships among the identified barriers and matrice d'impacts croisés multiplication appliqué un classement (MICMAC) to classify the typical barriers based on their driving power and dependence power. The ISM approach has been tested in many food chain systems. Mor *et al.* (2018) used a combination of ISM and MICMAC to map out the relationship between barriers in an Indian dairy supply chain. Ra *et al.* (2018) also used the ISM to model the interaction of barriers in agricultural product supply chain. Kamble *et al.* (2019) used a combination of ISM and DEMATEL to model barriers interaction in the implementation of IoT (Internet of things) at the food retailer level.

The current study uses a combination of the DEMATEL–ISM–MICMAC. The hypothesis is that interactions between typical operational barriers can be a basis to develop a model that contributes to the creation of an action map to solve potential problems in the relevant industries.

2. Literature review

2.1 The overview of Indonesian vegetable oil industry

In 2015/2016, Indonesia's palm oil production reached 33.5 million tons, and its export met 35% of the world's needs. Meanwhile, the coconut oil production reached 970,000 tons, and its export met 23% of the world's needs. However, the sustainability of the Indonesian vegetable oil industry is at a critical stance as demands from India, the largest importer of Indonesian palm oil, continue to decline (Yahya and Gunawan, 2019). The EU's recent updates that require food safety standards have become a trade barrier for Indonesian vegetable oil (Suwastoyo, 2020). Through its General Food Law (EU 178/2002), required all food business operators to be able to do one-step-tracing and one-step-tracking of their products. The EU is the third largest importer of Indonesian vegetable oil. Therefore, research on Indonesian vegetable oil industry will contribute not only to the development of the nation's industry but also the global trade.

Contamination by hazardous chemicals is a major issue in global vegetable oil trade (Shi *et al.*, 2016), which can happen in the production process or anywhere in the supply chain. For example, glycidyl fatty acid esters (GE), 3-monochloropropanediol (3-MCPD) and 2-monochloropropanediol (2-MCPD) and their fatty acid esters may form during refining process at a high temperature (EFSA, 2016). Other hazardous chemicals include mycotoxins (aflatoxins, ochratoxin A, fusarium-toxins and patulin), metals (cadmium, lead, mercury and inorganic tin), dioxins and PCBs, polycyclic aromatic hydrocarbons (PAHs) and nitrates. These chemicals are genotoxic and carcinogenic and may cause cancer.

A traceability system functions as a parameter to ensure that food industry monitors and controls its product quality and safety (Kher *et al.*, 2010). It makes each stage transparent so that quality and safety can be controlled properly. Therefore, traceability has become mandatory in many countries (Olsen and Borit, 2018), including Indonesia. The National Agency of Drug and Food Control of Republic Indonesia (NADFC) requires all food industries to use a traceability system through a regulation no. 22 in 2017.

2.2 Traceability at operational level

Traceability is a multi-disciplinary (Alfaro and Sebrek, 2015) and multi-dimensional topic (Souza-Monteiro and Caswell, 2009). The term is first coined in automotive industry in the 1970s (Karlsen and Olsen, 2016), but currently it is more associated with food safety (Alfaro and Sebrek, 2015). According to Codex Alimentarius Commission (2006), traceability is "an ability to follow food movement through specified stages of production, processing and distribution". Thus, traceability is not a tool to improve food safety, but it is a part of food safety management system. Hobbs (2004) defines traceability system as an information technology to record and display information of every constituent part of a product at each manufacturing stage. Kvarnstörm and Ogazhi (2008) define the system more broadly, namely a combination of process information and material flow model in a production. Technically, a traceability system consists of several tracing methods to record changes in material properties and operations throughout a production process. If the process has a large number of possible combinations, creating a traceability system will require more efforts.

Van der Vorst (2006) mentioned that product traceability at the factory level is as important as at the supply chain level. Donelly *et al.* (2009) argues that the former often involves material transformation. This occurs because the procedures involve combination, transfer, addition and splitting to produce the final food product. Dupuy *et al.* (2005) developed a batch dispersion model to trace such transformation processes. Riden *et al.* (2007) developed a mixing model to improve traceability in fruit packaging industry. In that study, fruit was regarded as a bulk product that flows continuously. Thakur and Hurburgh (2009) then proposed an information technology framework for a bulk grain traceability system, followed by Thakur *et al.* (2010) with their multi-objective optimization model. However, all these operational models were built upon a bin system approach because the product is solid. For a liquid product, this approach will not deliver because transporting a liquid product through pipelines and storing it in high capacity tanks makes batches separation nearly impossible. Such separation is only possible after a cleaning or flushing procedure. Therefore, liquid food industry generally follows a large dynamic batch sizing.

In the dairy industry, Skoglund and Dejmek (2007) proposed a fuzzy traceability system, a batch identification approach using a virtual batch concept. Liu *et al.* (2014) also developed a similar model in the dairy industry by minimizing the number of raw material batches of the finished product. However, the form of a dairy product material does not change from start to finish, and there are no derivative products along the production process. In a more complex liquid food industry such as vegetable oil, operational models of traceability from previous studies will not suffice because it involves not only liquid food characteristics but also material transformation. The aim of the current study is to fill such a gap.

2.3 Typical operational barriers in improving traceability system in bulk-liquid industry

A qualitative approach is needed to discover hidden barriers. Previous research by Bertolini *et al.* (2006) used the failure mode effect and critical analysis (FMECA) to analyze activities in durum wheat pasta production, but this did not fully capture the traceability. In some other studies, e.g. Regan *et al.* (2012), Bosona and Gebresenbet (2013) and Morana (2016), barriers were categorized to allow for a more focused analysis.

In this work, we used the SIPOC concept (supplier, input, process, output and customer) to explore and categorize typical operational barriers because it can cover all the main stages at the operational level. The identified barriers can be seen in Table 1.

These barriers stem from the characteristics of the vegetable oil industry, i.e. a commodity product, in liquid form, traded in bulk and categorized as a process industry. In the current study, the identified barriers from start to finish are analyzed and correlated in a structural model. The mapping of the identified barriers and the characteristics of vegetable oil industry can be seen in Table 2.

3. Methodology

According to Saaty and Vargas (2006), there are two approaches in analyzing causal influences. One is traditional deductive logic and the other is a holistic approach that

Table 1. List of typical operational barriers in bulk-liquid food commodity industry

Stage	Code	Typical operational barriers	Description	Reference
Supplier	S1	Multi-sourcing	Vegetable oil industry needs supplies from multiple sources because supply capacity is usually far less than production capacity. Besides, suppliers for main raw materials and supporting materials are usually different. This multi-sourcing can lower the traceability system's accuracy in tracing backward	Trienekens and Zuubier (2008), Gunawan *et al.* (2017, 2018)
	S2	Multi-layered sourcing	In vegetable oil chain, there are several layers of trade before it reaches the processor: plantations, collectors, small/local traders, wholesalers and brokers. Indonesian plantations are categorized into smallholder plantations, state large plantations and private large plantations. Besides, there is a business concept called cooperative, which acts as a collector but only takes small profit margins because it is not profit oriented. Indonesian vegetable oil industry can decide which material from which layer to take. However, the more layers, the greater chance of loss of information	Gunawan *et al.* (2018, 2019)
	S3	Preprocessing method	Palm fruit and copra (dried coconut) as raw materials of vegetable oil undergo preprocessing such as stripping or drying before being sold, especially at the plantation level. Plantations have their own methods depending on the local culture and the production scale. This also potentially obscures material information	Expert opinion
Input	I1	Blending process	In the vegetable oil industry, materials from many suppliers will be blended with certain composition to meet the needs of production and quality standard. Materials may consist of main raw materials and supporting materials such as bleaching earth (powder), phosphoric acid (liquid) and activated carbon (powder). Vegetable oil materials often consist of many physical states that need "blending" instead of only "mixing". The blending process will cause loss of the historical information of each material	Saltini and Akkerman (2012)
	I2	Nonuniform quality	The quality of raw materials (palm fruit and copra) cannot be controlled due to the influence of various natural factors and preprocessing methods. The vegetable oil industry generally focuses on the quantity of raw material to achieve the economies of scale. The nonuniform quality of raw materials will increase the complexity of the traceability system because there are customized treatments in production process	Thakur *et al.* (2010)
	I3	Various physical states	The main raw materials and supporting materials generally have different physical states such as solid (copra and palm fruit), liquid (crude coconut oil (CCNO), crude palm oil (CPO), phosphoric acid, and hexane) and powder (bleaching earth and activated carbon). The end products also have different physical states such as liquid (olein) and semisolid (stearin). Various physical states of materials cause difficulty in deciding the unit of measurement	Trienekens *et al.* (2014)

(*continued*)

Stage	Code	Typical operational barriers	Description	Reference
Process	P1	Alternating divergent and convergent processes	In the vegetable oil industry, there are two possibilities in producing convergent results (many-to-one: many types of material processed into single product) or divergent (one-to-many: single material processed to produce many derivative products). For example, CPO, activated carbon, phosphoric acid and bleaching earth can be processed into refined bleached deodorized palm oil (RBDPO) and palm fatty acid distillate (PFAD). Then, RBDPO can be processed into olein and stearin. This condition may lead to difficulty in tracing raw material or in finding the root problem along the process. The results are usually intermediate products that must be stored. Orzechowski (2019) stated that tracking information on intermediate products is very important in a traceability system	Trienekens *et al.* (2014)
	P2	Outsourcing	The vegetable oil industry often outsources its production to other places or purchases semifinished products due to limited capacity or to reduce production costs. For example, the vegetable oil industry can produce refined bleached deodorized coconut oil (RBDCNO) from either copra or CCNO. Products or services supplied by third parties will increase the complexity of the traceability system	Ringsberg (2014)
	P3	Dynamic batch sizing	The vegetable oil moves in a continuous flow from pipe to storage tank so there is no standard batch size	Comba *et al.* (2013)
	P4	Batch definition	From the bulk materials: copra, CPO and CNO to the finish products: olein, stearin and RBDCNO; the physical batch separation does not exist	Engisch and Muzzio (2015)
	P5	Coordination	In a refinery, a process operator never sees raw material, work in process or a finished product although coordination among departments is essential to manage the process. Lack of coordination often mean misleading information or losing traceability information at all	Golan *et al.* (2004)
Output	O1	Quality degradation	Vegetable oil stored in bulk is more perishable so the quality often degrades in the storage period. Solutions to this include downgrading, reprocessing and redirecting for other use. The more changes in a product's status, the more vague the product history records	Trienekens *et al.* (2014); Expert opinion
	O2	Mixing	Product mixing is normally conducted in the materials (copra, CCNO and CPO) and in the finished products (RBDCNO and olein) to meet customer specification. Mixing a final product may obscure the product's history if the traceability system cannot manage it	Comba *et al.* (2013)
	O3	Batch separation	Improper storage planning may result to batch separation issue. In fact, a clear separation between batches is needed to prevent cross-contamination	Trienekens *et al.* (2014)
	O4	By-products	In the case of one-to-many production process (divergent process), raw material will be processed into a main product and some derivative products which are called "by-products". These products can be categorized as valuable products or waste. Managing derivative products will increase the complexity of traceability system	Trienekens *et al.* (2014)

(*continued*)

Table 1.

Table 1. Typical traceability barriers

Stage	Code	Typical operational barriers	Description	Reference
Customer	C1	Customer demand	In the commodity focused chain, the customers only care about product specification. Thus, not all customers require traceability as long as the product specification is met. This condition causes food industry not obliged to build a traceability system	Liu and Batt (2011)
	C2	Transaction model	There are several transaction models used in commodity trading, namely spot market, relational contracts, simple contracts, long-term contracts and vertical integration. Each transaction model impacts on different needs on traceability information	Vo *et al.* (2016)
	C3	Customer willing to pay traceability for food commodity	Developing and maintaining a traceability system will have an impact on increasing costs. If customers perceive vegetable oil as a food commodity, they do not want to spend more money to buy products with traceability information	Ringsberg (2014)
	C4	Trust	Trust will eliminate the thought that one party will be taken advantage by another. Therefore, mutual trust between companies enables information sharing that plays an important role in the traceability system. Lack of trust among the players in business to business (B2B) transaction will be a barrier in developing an excellent traceability system	Ringsberg (2014)
	C5	Indirect sales	Sales do not always occur directly between the vegetable industry and the end users. Sales can occur through distributors or brokers. Indirect sales will interrupt traceability information flow. Consequently, the vegetable industry cannot track products up to the end user	Gunawan *et al.* (2018) Golan *et al.* (2004)

Code	Typical operational barriers	Source of the barriers in vegetable oil chain Food commodity	Bulk	Liquid	Process industry
S1	Multi-sourcing	✓			
S2	Multi-layered sourcing	✓			
S3	Preprocessing method	✓			
I1	Blending process				✓
I2	Nonuniform quality	✓			
I3	Various physical states				✓
P1	Alternating divergent and convergent processes				✓
P2	Outsourcing	✓			
P3	Dynamic batch sizing		✓		
P4	Batch definition			✓	
P5	Coordination				✓
O1	Quality degradation		✓		
O2	Mixing		✓		
O3	Batch separation			✓	
O4	By-products				✓
C1	Customer demand	✓			
C2	Transaction model	✓			
C3	Customer willing to pay traceability for food commodity	✓			
C4	Trust	✓			
C5	Indirect sales	✓			

Table 2.
Source of the barriers

organizes all the factors involved in the hierarchy. We used the second approach to avoid logical fallacies. Then, we used ISM to create a hierarchical model from the correlated barriers. To reduce the cognitive loads, a complex system needs to be decomposed into several subsystems and hierarchical structures (Lin *et al.*, 2019; Simpson and Simpson, 2014). If a system has many elements, a hierarchical structure is more accommodating than a network structure. Effective data presentation such as this is more on target to seek solutions and overcome the problems. Additionally, the outcomes of the ISM are presented in a graphical model for easy reading.

The system elements were obtained from a systematic literature review and interviews with experts. The system decomposition was done by a pair-wise comparison through a group judgment such as brainstorming, focus group discussion, nominal group technique, Delphi technique, etc. (Poduval *et al.*, 2015). In this study, we chose Delphi technique in the DEMATEL approach to reach consensus without face-to-face meetings to avoid social interaction and pressure that could potentially lead to bias (Einhorn *et al.*, 1977). The Delphi technique was run in two rounds. In the first round, seven professionals and academics were selected by criterion sampling and asked to fill out a pair-wise comparison questionnaire individually in 45–60 minutes. These experts were chosen based on their work experience in related field and their willingness to participate. In the second round, each expert was given a chance to change opinions or judgments after being presented with the group response's mean in the first round. The list of experts involved in this study is presented in Table 3.

The integration of DEMATEL and ISM was proposed by Zou *et al.* (2006). DEMATEL is considered a comprehensive method for gathering group knowledge in order to construct a structural model involving causal relationships among complex factors. Then, ISM structured and visualized the complex factors in a directional graph (diagraph). While ISM's procedure requires developing a structural self-interaction matrix (SSIM) through expert face-to-face meetings to produce group judgment, DEMATEL allows the Delphi

No	Status	Work experience	Location	Field	Job title
1	Professional	5–10 years	East Java	Palm and coconut oil industry	Quality Assurance Manager
2	Professional	5–10 years	East Java	Palm and coconut oil industry	Marketing Manager
3	Professional	>10 years	East Java	Palm and coconut oil industry	Technical Advisor
4	Professional	5–10 years	East Java	Palm oil industry	Safety, Health, Environment and Quality Manager
5	Professional	>10 years	North Sulawesi	Palm and coconut oil industry	Plant Manager
6	Professional	>10 years	Central Java	Coconut oil industry	Quality Assurance Manager
7	Academics	>10 years	East Java	Agro-industrial technology	Lecturer and researcher

Table 3.
Group of experts

technique to draw similar conclusions without meeting in person. This will save resources while increasing the accuracy above 50% (Rowe and Wright, 1999). DEMATEL and ISM integration, technically, occur when the total matrix relationship from DEMATEL is translated into the initial reachability matrix of the ISM.

The ISM's final reachability matrix can be the basis for calculation, the driving power and the dependence power of the MICMAC analysis, which is influential and essential for the system evolution. In this study, MICMAC was not only used to enrich and sharpen analysis but also to validate the structural model generated by ISM (Mor *et al.*, 2018). The DEMATEL–ISM–MICMAC procedures are discussed below:

Step 1: Designing the questionnaire

A system containing a set of elements $F = \{f_1, f_2, \ldots, f_n\}$ is arranged in a pair-wise comparison. The pair-wise comparison scale is set at a four-level score. Score 0 represents "no influence", score 1 represents "weak influence", score 2 represents "medium influence", score 3 represents "strong influence" and score 4 represents "very strong influence". Then, the experts filled out the pair-wise comparison from element f_i to element f_j using the four-level score in accordance with his or her beliefs. The questionnaire sample can be seen in Figure 1.

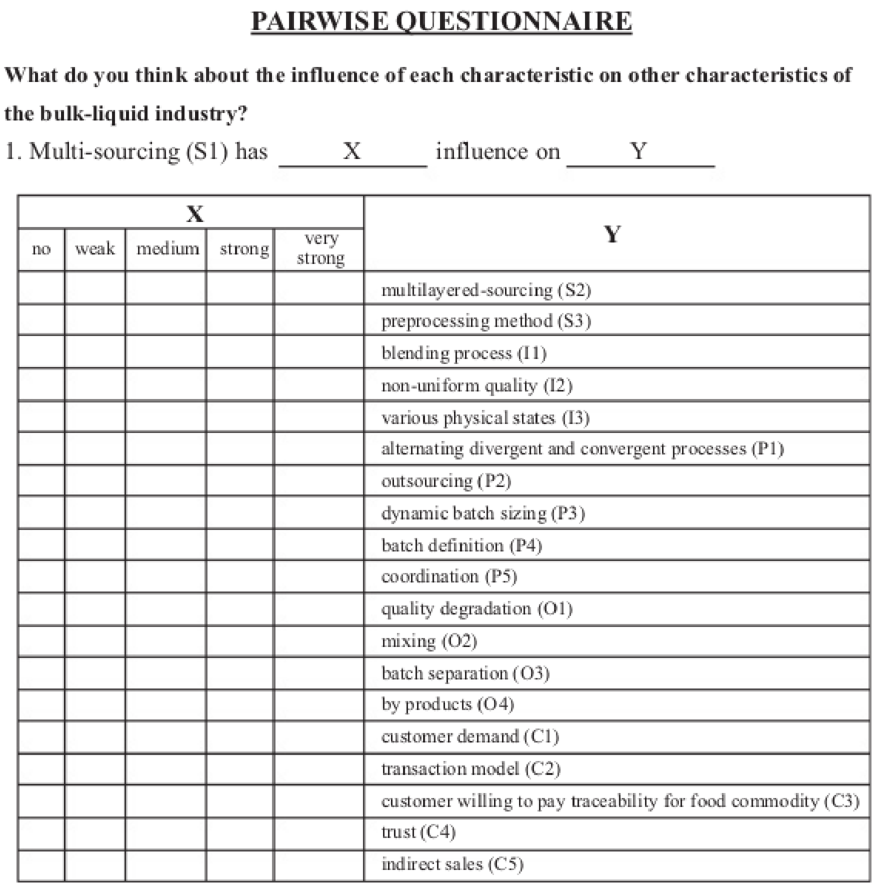
Step 2: Building initial direct-relation matrix (A)

There are H experts and n element to be considered. Each expert will produce a $n \times n$ nonnegative matrix $X^k = [x^k_{ij}]_{n\ x\ n}$, with $1 \leq k \leq H$. Then, the $n \times n$ average matrix A is calculated, which covers all experts' opinions by averaging their scores. The average matrix A is called initial direct-relation matrix. This matrix indicates the initial direct influence of each element given to and received from other element. In this study, there were seven experts and 20 elements involved, so the initial direct-relation matrix became as shown in Table 4.

Step 3: Normalizing the initial direct-relation matrix (A) into normalized direct-relation matrix (G)

The score scale used by each researcher may vary. Therefore, the initial direct-relation matrix needs to be normalized to a normalized direct-relation matrix $G = [g_{ij}]_{n \times n}$ with $0 \leq g_{ij} \leq 1$. The normalization result is presented in Table 5.

Step 4: Calculating total relation matrix (T)



PAIRWISE QUESTIONNAIRE

What do you think about the influence of each characteristic on other characteristics of the bulk-liquid industry?

1. Multi-sourcing (S1) has ____X____ influence on ____Y____

X					Y
no	weak	medium	strong	very strong	
					multilayered-sourcing (S2)
					preprocessing method (S3)
					blending process (I1)
					non-uniform quality (I2)
					various physical states (I3)
					alternating divergent and convergent processes (P1)
					outsourcing (P2)
					dynamic batch sizing (P3)
					batch definition (P4)
					coordination (P5)
					quality degradation (O1)
					mixing (O2)
					batch separation (O3)
					by products (O4)
					customer demand (C1)
					transaction model (C2)
					customer willing to pay traceability for food commodity (C3)
					trust (C4)
					indirect sales (C5)

Figure 1.
Pair-wise questionnaire sample

The normalization process makes the difference between the elements (g_{ij}) of the matrix G insignificant. The compilation of the total relation matrix $\mathrm{T} = [t_{ij}]_{n \times n}$ amplifies each element value, so that elements that actually influence each other can be distinguished from the elements that do not have influence. The total relation matrix can be seen in Table 6.

Step 5: Converting the total-relation matrix (T) into initial reachability matrix (K)

Matrix T represents relationship among the observed elements. The relationship between element f_i and element f_j is indicated by t_{ij} that is greater than or equal to the threshold value. A threshold value (α) is an average value in the total-relation matrix. Initial reachability matrix (K) is used to indicate the relationship from element f_i to element f_j expressed in $\{0,1\}$. Therefore, the conversion of matrix T into matrix K is shown in Table 7.

Step 6: Checking transitivity and establishing final reachability matrix (K′)

The concept of transitivity mediates the exchange of logical information and empirical data during the system structuring process (Simpson and Simpson, 2014). In ISM procedure, transitivity is explained as if f_1 is related to f_2 and f_2 is related to f_3, then f_1 is related to f_3 then, $k_{13} = 1$. After all, $k_{ij} = 0$ transitivity is checked, and a final reachability matrix (K′) is formed. The final reachability matrix can be seen in Table 8.

Table 4. The initial direct-relation matrix

F	S1	S2	S3	I1	I2	I3	P1	PP2	P3	P4	P5	O1	O2	O3	O4	C1	C2	C3	C4	C5
S1	4	2.43	3.71	3.57	3.43	2.14	0.86	1	1.29	2.71	0.71	0	1.71	2	0	0.43	0.86	0	0	0
S2	2.71	4	0.86	3.71	2.57	0	0	0	0	1.71	0	0	1.14	0.57	0	0	0	0	0	0
S3	0	0	4	3.86	3.71	0.29	0	0.57	2.29	2.14	1.14	3.71	2.29	1.14	3.14	0	0.29	0	0	0
I1	0.43	0.14	0.57	4	2.43	0.29	0.29	0.71	3.71	3.86	1.86	1.57	0	3.43	1.71	2.14	0.86	0	0	0.29
I2	0.14	0	0.14	4	4	0	0.43	2.86	3.43	1.43	1.43	0.86	0.43	0	0.43	0	0	0	0	0
I3	0.29	0	0	3	0	4	0.43	0	0.86	3	0.43	1.43	0	0	0	0	0	0	0	0
P1	0	0	0	3.86	0	0	4	0.43	1.71	4	0.86	0	0	0.57	4	0	0	0	0	0
P2	2	1.71	1.29	2.43	3.86	0	0	4	2.14	3.57	3.43	1.71	3.57	4	0.86	0	0	0	0	0
P3	0	0	0	2.14	0.14	0.43	0	0	4	4	0.86	0.29	3.57	4	2.57	0	0	0	0	0
P4	0.86	0.57	0	3.57	0	2.43	3.29	0.71	4	4	2.14	0	4	3.43	3.43	0	0.57	0.57	0	0
P5	0	0	0	1.86	0	0	0.43	1.43	0	2.29	4	0	0	0.86	0	0	0	0	1	0.29
O1	0	0	0	0	0	0	0	0	0	0	0	4	4	3.43	0	0	1.86	0	0.43	1
O2	0.14	0	0	0.43	0.43	0	0	0.43	3.71	4	0	4	4	4	0.86	1.57	2	2	0.43	1
O3	0.43	0	0	2.29	0	0	0	1.14	3	3.57	0.43	1.57	3.43	4	3.43	3.43	3.43	3.29	3.43	1.43
O4	0	0	0.14	0	0	0	1.71	0.43	3.14	3.43	0	0	1.71	3.71	4	0	0	0	0	0
C1	0	0	0	0.86	0	0	0	0	0	0.71	0	0	2.43	3.43	0	4	3.86	4	2.14	3.43
C2	0	0	0	1.57	0	0	0	0	0	1.57	0	0.57	2.71	3.57	0	3.86	4	4	3.29	4
C3	0	0	0	0.29	0	0	0	0	0	1.57	0	0	2.71	3.43	0	4	4	4	4	1
C4	0	0	0	0.29	0	0	0	0	0	0	1.43	0	0.14	3.14	0	3.14	3.29	4	4	1.43
C5	0	0	0	1.43	0	0	0	0	0	0.43	0.29	0	1.86	0.86	0	3.86	4	2.86	3	4

Table 5.
The normalized direct-relation matrix

F	S1	S2	S3	I1	I2	I3	P1	P2	P3	P4	P5	O1	O2	O3	O4	C1	C2	C3	C4	C5
S1	0.081	0.049	0.075	0.072	0.069	0.043	0.017	0.020	0.026	0.055	0.014	0.000	0.034	0.040	0.000	0.009	0.017	0.000	0.000	0.000
S2	0.055	0.081	0.017	0.075	0.052	0.000	0.000	0.000	0.000	0.034	0.000	0.000	0.023	0.011	0.000	0.000	0.000	0.000	0.000	0.000
S3	0.000	0.000	0.081	0.078	0.075	0.006	0.000	0.011	0.046	0.043	0.023	0.075	0.046	0.023	0.063	0.000	0.006	0.000	0.000	0.000
I1	0.009	0.003	0.011	0.081	0.049	0.006	0.006	0.014	0.075	0.078	0.038	0.032	0.000	0.069	0.034	0.043	0.017	0.000	0.000	0.006
I2	0.003	0.000	0.003	0.081	0.081	0.000	0.009	0.058	0.069	0.029	0.029	0.017	0.009	0.000	0.009	0.000	0.000	0.000	0.000	0.000
I3	0.006	0.000	0.000	0.061	0.000	0.081	0.009	0.000	0.017	0.061	0.009	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
P1	0.000	0.000	0.000	0.078	0.000	0.000	0.081	0.009	0.034	0.081	0.017	0.000	0.000	0.011	0.081	0.000	0.000	0.000	0.000	0.000
P2	0.040	0.034	0.026	0.049	0.078	0.000	0.000	0.081	0.043	0.072	0.069	0.034	0.072	0.081	0.017	0.000	0.000	0.000	0.000	0.000
P3	0.000	0.000	0.000	0.043	0.003	0.009	0.000	0.000	0.081	0.081	0.017	0.006	0.072	0.081	0.052	0.000	0.000	0.000	0.000	0.000
P4	0.017	0.011	0.000	0.072	0.000	0.049	0.066	0.014	0.081	0.081	0.043	0.000	0.081	0.069	0.069	0.000	0.011	0.011	0.000	0.000
P5	0.000	0.000	0.000	0.038	0.000	0.000	0.009	0.029	0.000	0.046	0.081	0.000	0.000	0.017	0.000	0.000	0.000	0.000	0.020	0.006
O1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.081	0.081	0.069	0.000	0.000	0.038	0.000	0.009	0.020
O2	0.003	0.000	0.000	0.009	0.009	0.000	0.000	0.009	0.075	0.081	0.000	0.081	0.081	0.081	0.017	0.032	0.040	0.040	0.009	0.020
O3	0.009	0.000	0.000	0.046	0.000	0.000	0.000	0.023	0.061	0.072	0.009	0.032	0.069	0.081	0.069	0.069	0.069	0.066	0.069	0.029
O4	0.000	0.000	0.003	0.000	0.000	0.000	0.034	0.009	0.063	0.069	0.000	0.000	0.034	0.075	0.081	0.000	0.000	0.000	0.000	0.000
C1	0.000	0.000	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.014	0.000	0.000	0.049	0.069	0.000	0.081	0.078	0.081	0.043	0.069
C2	0.000	0.000	0.000	0.032	0.000	0.000	0.000	0.000	0.000	0.032	0.000	0.011	0.055	0.072	0.000	0.078	0.081	0.081	0.066	0.081
C3	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.032	0.000	0.000	0.055	0.069	0.000	0.081	0.081	0.081	0.081	0.020
C4	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.029	0.000	0.003	0.063	0.000	0.063	0.066	0.081	0.081	0.029
C5	0.000	0.000	0.000	0.029	0.000	0.000	0.000	0.000	0.000	0.009	0.006	0.000	0.038	0.017	0.000	0.078	0.081	0.058	0.061	0.081

F	S1	S2	S3	I1	I2	I3	P1	P2	P3	P4	P5	O1	O2	O3	O4	C1	C2	C3	C4	C5
S1	0.099	0.062	0.094	0.143	0.106	0.061	0.035	0.042	0.089	0.130	0.043	0.031	0.089	0.108	0.041	0.037	0.047	0.023	0.018	0.015
S2	0.069	0.093	0.028	0.118	0.077	0.009	0.009	0.012	0.035	0.076	0.015	0.015	0.051	0.047	0.020	0.015	0.014	0.010	0.008	0.007
S3	0.006	0.003	0.091	0.129	0.100	0.015	0.014	0.030	0.106	0.108	0.047	0.110	0.102	0.091	0.106	0.023	0.033	0.020	0.016	0.014
I1	0.017	0.007	0.017	0.134	0.067	0.017	0.022	0.032	0.134	0.147	0.064	0.055	0.057	0.144	0.077	0.077	0.053	0.030	0.025	0.026
I2	0.010	0.005	0.008	0.122	0.103	0.007	0.019	0.076	0.114	0.078	0.053	0.035	0.043	0.047	0.035	0.014	0.014	0.010	0.008	0.007
I3	0.010	0.002	0.002	0.088	0.007	0.094	0.019	0.005	0.043	0.093	0.021	0.041	0.021	0.028	0.017	0.009	0.010	0.006	0.005	0.005
P1	0.005	0.003	0.003	0.117	0.009	0.009	0.104	0.019	0.080	0.137	0.036	0.011	0.033	0.060	0.122	0.015	0.014	0.011	0.009	0.007
P2	0.058	0.047	0.039	0.118	0.112	0.013	0.018	0.111	0.116	0.159	0.106	0.071	0.144	0.168	0.065	0.033	0.036	0.030	0.025	0.018
P3	0.006	0.003	0.002	0.082	0.011	0.019	0.015	0.011	0.136	0.145	0.036	0.028	0.125	0.148	0.093	0.027	0.028	0.025	0.020	0.014
P4	0.028	0.018	0.006	0.134	0.015	0.066	0.092	0.032	0.153	0.172	0.072	0.028	0.146	0.155	0.126	0.034	0.047	0.043	0.025	0.018
P5	0.004	0.003	0.002	0.061	0.007	0.005	0.017	0.039	0.020	0.075	0.099	0.008	0.019	0.045	0.015	0.012	0.012	0.011	0.031	0.013
O1	0.002	0.001	0.001	0.016	0.003	0.002	0.003	0.005	0.023	0.030	0.005	0.104	0.120	0.114	0.015	0.027	0.070	0.028	0.032	0.040
O2	0.010	0.003	0.002	0.050	0.017	0.010	0.014	0.021	0.129	0.148	0.017	0.112	0.155	0.167	0.057	0.078	0.093	0.087	0.046	0.051
O3	0.018	0.005	0.004	0.100	0.012	0.011	0.017	0.039	0.125	0.157	0.034	0.063	0.155	0.193	0.118	0.139	0.143	0.135	0.126	0.073
O4	0.005	0.003	0.005	0.032	0.005	0.008	0.052	0.018	0.109	0.123	0.014	0.015	0.078	0.129	0.121	0.020	0.022	0.020	0.016	0.011
C1	0.004	0.001	0.001	0.048	0.005	0.004	0.006	0.007	0.030	0.060	0.011	0.018	0.105	0.141	0.021	0.145	0.144	0.144	0.096	0.113
C2	0.005	0.002	0.002	0.069	0.006	0.006	0.008	0.009	0.036	0.085	0.015	0.034	0.118	0.155	0.026	0.150	0.155	0.151	0.126	0.129
C3	0.004	0.002	0.001	0.036	0.004	0.005	0.007	0.007	0.031	0.079	0.013	0.019	0.111	0.144	0.023	0.144	0.146	0.145	0.134	0.061
C4	0.003	0.001	0.001	0.029	0.003	0.002	0.004	0.006	0.019	0.033	0.041	0.011	0.043	0.121	0.015	0.117	0.121	0.135	0.129	0.063
C5	0.003	0.001	0.001	0.056	0.005	0.003	0.004	0.005	0.022	0.045	0.017	0.014	0.082	0.078	0.015	0.136	0.139	0.114	0.107	0.121

Table 6.
The total-relation matrix

Table 7.
The initial reachability matrix

F	S1	S2	S3	I1	I2	I3	P1	P2	P3	P4	P5	O1	O2	O3	O4	C1	C2	C3	C4	C5
S1	1	1	1	1	1	1	0	0	1	1	0	0	1	1	0	0	0	0	0	0
S2	1	1	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
S3	0	0	1	1	1	0	0	0	1	1	0	1	1	1	1	0	0	0	0	0
I1	0	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0
I2	0	0	0	1	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0
I3	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
P1	0	0	0	1	0	0	1	0	1	1	0	0	0	1	1	0	0	0	0	0
P2	1	0	0	1	1	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0
P3	0	0	0	1	0	0	0	0	1	1	0	0	1	1	1	0	0	0	0	0
P4	0	0	0	1	0	1	1	0	1	1	1	0	1	1	1	0	0	0	0	0
P5	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
O1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0	0	0
O2	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	1	1	1	0	0
O3	0	0	0	1	0	0	0	0	1	1	0	1	1	1	1	1	1	1	1	1
O4	0	0	0	0	0	0	0	0	1	1	0	0	1	1	1	0	0	0	0	0
C1	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	1	1	1	1	1
C2	0	0	0	1	0	0	0	0	0	1	0	0	1	1	0	1	1	1	1	1
C3	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	1	1	1	1	1
C4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1
C5	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	1

Table 8.
The final reachability matrix

F		S1 1	S2 2	S3 3	I1 4	I2 5	I3 6	P1 7	P2 8	P3 9	P4 10	P5 11	O1 12	O2 13	O3 14	O4 15	C1 16	C2 17	C3 18	C4 19	C5 20	Driving power
S1	1	1	1	1	1	1	1	*1*	*1*	1	1	*1*	*1*	1	1	*1*	*1*	*1*	*1*	*1*	*1*	20
S2	2	1	1	0	1	1	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	0	0	0	16
S3	3	0	0	1	1	1	*1*	*1*	*1*	1	1	*1*	1	1	1	1	*1*	*1*	*1*	*1*	*1*	18
I1	4	0	0	0	1	1	*1*	*1*	*1*	1	1	1	1	1	1	1	1	1	*1*	*1*	*1*	17
I2	5	*1*	0	0	1	1	*1*	*1*	1	1	1	1	*1*	*1*	*1*	*1*	*1*	*1*	0	0	0	15
I3	6	0	0	0	1	*1*	1	*1*	0	*1*	1	*1*	*1*	*1*	*1*	*1*	*1*	*1*	0	0	0	13
P1	7	0	0	0	1	*1*	*1*	1	0	1	1	*1*	*1*	*1*	1	1	*1*	*1*	*1*	*1*	*1*	16
P2	8	1	*1*	*1*	1	1	*1*	*1*	1	1	1	1	1	1	1	1	*1*	*1*	*1*	*1*	*1*	20
P3	9	0	0	0	1	*1*	*1*	*1*	0	1	1	*1*	*1*	1	1	1	*1*	*1*	*1*	*1*	*1*	16
P4	10	0	0	0	1	*1*	1	1	0	1	1	1	*1*	1	1	1	*1*	*1*	*1*	*1*	*1*	16
P5	11	0	0	0	1	*1*	*1*	*1*	0	*1*	1	1	*1*	*1*	*1*	*1*	*1*	*1*	0	0	0	13
O1	12	0	0	0	*1*	0	0	0	0	*1*	*1*	0	1	1	1	*1*	*1*	1	*1*	*1*	*1*	12
O2	13	0	0	0	*1*	0	*1*	*1*	0	1	1	*1*	1	1	1	1	1	1	1	*1*	*1*	15
O3	14	0	0	0	1	*1*	*1*	*1*	0	1	1	*1*	1	1	1	1	1	1	1	1	1	16
O4	15	0	0	0	*1*	0	*1*	*1*	0	1	1	*1*	*1*	1	1	1	*1*	*1*	*1*	*1*	*1*	15
C1	16	0	0	0	*1*	0	*1*	*1*	0	*1*	1	*1*	*1*	1	1	*1*	1	1	1	1	1	15
C2	17	0	0	0	1	*1*	*1*	*1*	0	*1*	1	*1*	*1*	1	1	*1*	1	1	1	1	1	16
C3	18	0	0	0	*1*	0	*1*	*1*	0	*1*	1	*1*	*1*	1	1	*1*	1	1	1	1	1	15
C4	19	0	0	0	*1*	0	0	0	0	*1*	*1*	0	*1*	*1*	1	0	1	1	1	1	1	11
C5	20	0	0	0	1	*1*	0	0	0	*1*	*1*	0	*1*	1	1	0	1	1	1	1	1	12
Dependence		4	3	3	20	14	17	17	6	20	20	17	20	20	20	18	20	20	16	16	16	

Note(s): *The Italic numbers indicate the value after applying transitivity

Step 7: Defining reachability set and antecedent set

A reachability set of each element contains elements made up from certain elements. Meanwhile, an antecedent set of each element contains elements that make up certain elements (Poduval *et al.*, 2015). Technically, the reachability set (RS_i) of the system element is a set of elements corresponding to the columns, where all elements in the i row of the final reachability matrix are 1. The antecedent set (AS_i) of the system element is a set of elements corresponding to the rows, where all elements in the i column of the final reachability matrix are 1. The reachability set and the antecedent set are also presented in Table 8.

Step 8: Compiling the hierarchy structure

Elements that appear both in reachability set and antecedent set are selected as an intersection set (IS_i). The arrangement of the elements starts from level-1, which is placed at the top of the hierarchy. The selected elements are those with the same reachability set and intersection set in the final reachability matrix (K′). For the next iteration, the elements that have entered level-1 are removed from the final reachability matrix (K′). Stopping rule for this iteration process is when the levels of all elements found. The iteration process is shown in Table 9.

Step 9: Generating the diagraph

The levels of the elements along with the final reachability matrix are used as the basis to draw the directional graph (diagraph), which is a visualization of the elements, the contextual relationship among the elements and the compilation of hierarchical levels. A diagraph is also called a map. Therefore, the diagraph is the explanatory model of typical barriers in a bulk-liquid traceability system. The model of the typical barriers is illustrated in Figure 2.

Step 10: Generating MICMAC diagram

MICMAC diagram is used to classify the identified elements into four clusters: autonomous, dependent, linkage and independent. Cluster I, the autonomous, consists of elements with weak driving power and dependence power. Cluster II, the dependent, consists of elements with weak driving power but strong dependence power. Cluster III, the linkage, consist of elements with strong driving power and dependence power. The last, cluster IV, the independent, consists of element with strong driving power but weak dependence power.

Technically, this diagram structure consists of dependence power (X-axis) and driving power (Y-axis). The dependence power of each element is calculated from final reachability matrix by adding all numbers in the corresponding column; whereas the driving power of each element is calculated from final reachability matrix by adding all numbers in the corresponding row. Then, the value of dependence and driving power of each element becomes the position of each element, referring to the X and Y axis in the Cartesian diagram. The MICMAC diagram is depicted in Figure 3.

The diagraph of the operational barriers was sent back to the experts as a prompt to formulate actions to overcome the barriers. The explanatory model of the operational barriers provides guidelines for the problem-solving. The action proposals from each expert were then compiled and aggregated. The ISM procedure structuralized the proposed actions. The contextual relationship chosen to connect these actions is “should precede”. If element f_1 should precede element f_2, the relationship will be 1. However, if element f_1 should not precede element f_2, the relationship will be 0. An action map resulting from the stage can be seen in Figure 4.

4. Result

The analysis resulted in an initial list that consisted of 21 typical barriers in a bulk-liquid traceability system. These were compiled based on the product and industry characteristics: bulk, liquid, commodity and process industry. Then, these barriers were categorized using

Table 9.
Level partitioning

Iteration	Element	Reachability set	Antecedent set	Intersection	Level
1	I1	4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	I
	P3	4,5,6,7,9,10,11,12,13,14,15,16,17,18,19,20	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	4,5,6,7,9,10,11,12,13,14,15,16,17,18,19,20	I
	P4	4,5,6,7,9,10,11,12,13,14,15,16,17,18,19,20	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	4,5,6,7,9,10,11,12,13,14,15,16,17,18,19,20	I
	P5	4,5,6,7,9,10,11,12,13,14,15,16,17	1,2,3,4,5,6,7,8,9,10,11,13,14,15,16,17,18	4,5,6,7,9,10,11,12,13,14,15,16,17	I
	O1	4,9,10,12,13,14,15,16,17,18,19,20	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	4,9,10,12,13,14,15,16,17,18,19,20	I
	O2	4,6,7,9,10,11,12,13,14,15,16,17,18,19,20	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	4,6,7,9,10,11,12,13,14,15,16,17,18,19,20	I
	O3	4,5,6,7,9,10,11,12,13,14,15,16,17,18,19,20	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	4,5,6,7,9,10,11,12,13,14,15,16,17,18,19,20	I
	O4	4,6,7,9,10,11,12,13,14,15,16,17,18,19,20	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	4,6,7,9,10,11,12,13,14,15,16,17,18,19,20	I
	C1	4,6,7,9,10,11,12,13,14,15,16,17,18,19,20	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	4,6,7,9,10,11,12,13,14,15,16,17,18,19,20	I
	C2	4,5,6,7,9,10,11,12,13,14,15,16,17,18,19,20	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	4,5,6,7,9,10,11,12,13,14,15,16,17,18,19,20	I
	C4	4,9,10,12,13,14,16,17,18,19,20	1,3,4,7,8,9,10,12,13,14,15,16,17,18,19,20	4,9,10,12,13,14,16,17,18,19,20	I
2	I2	1,5,6,7,8	1,2,3,5,6,7,8,20	1,5,6,7,8	II
	I3	5,6,7	1,2,3,5,6,7,8,18	5,6,7	II
3	C3	7,18,20	1,3,7,8,18,20	7,18,20	III
	C5	18,20	1,3,7,8,18,20	18,20	III
4	P1	7	1,2,3,7,8	7	IV
5	S2	1,2,8	1,2,8	1,2,8	V
	S3	3,8	1,3,8	3,8	V
	P2	1,2,3,8	1,2,3,8	1,2,3,8	V
6	S1	1	1	1	VI

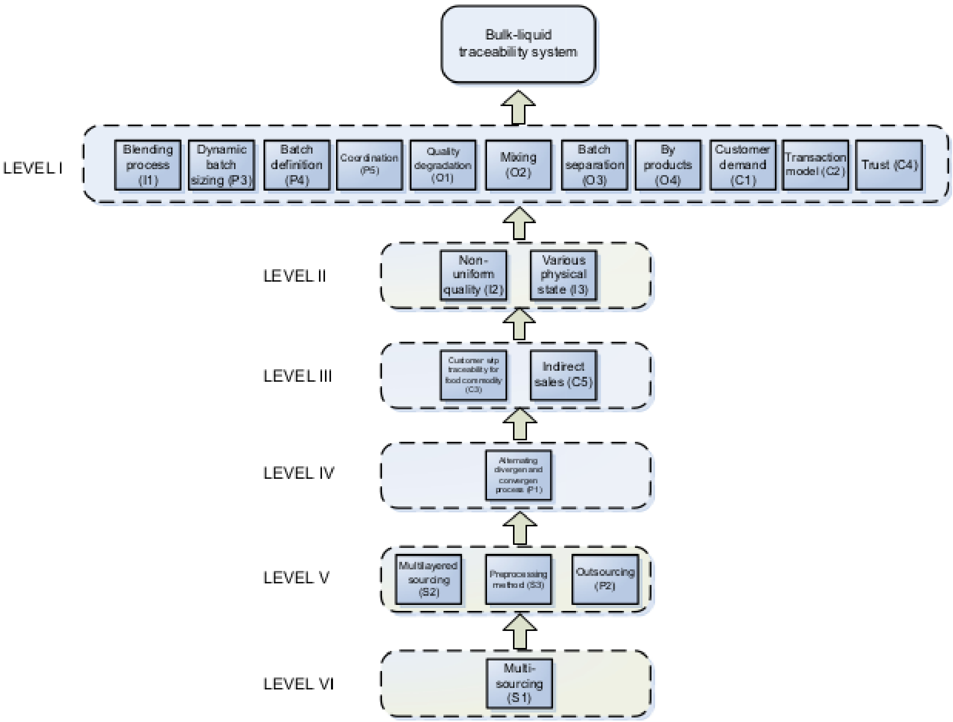


Figure 2.
The hierarchical model

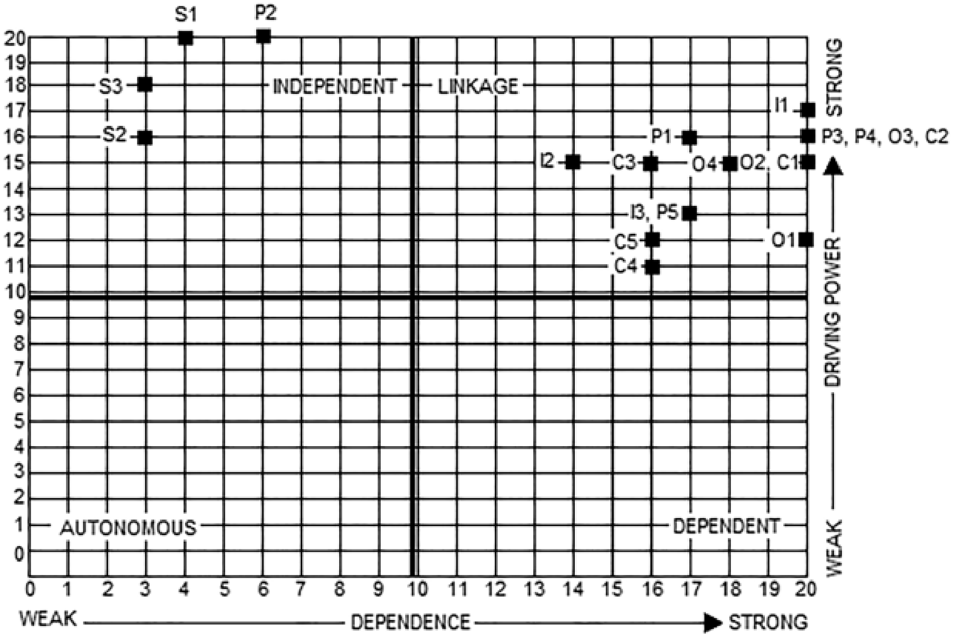


Figure 3.
MICMAC diagram for the typical barriers

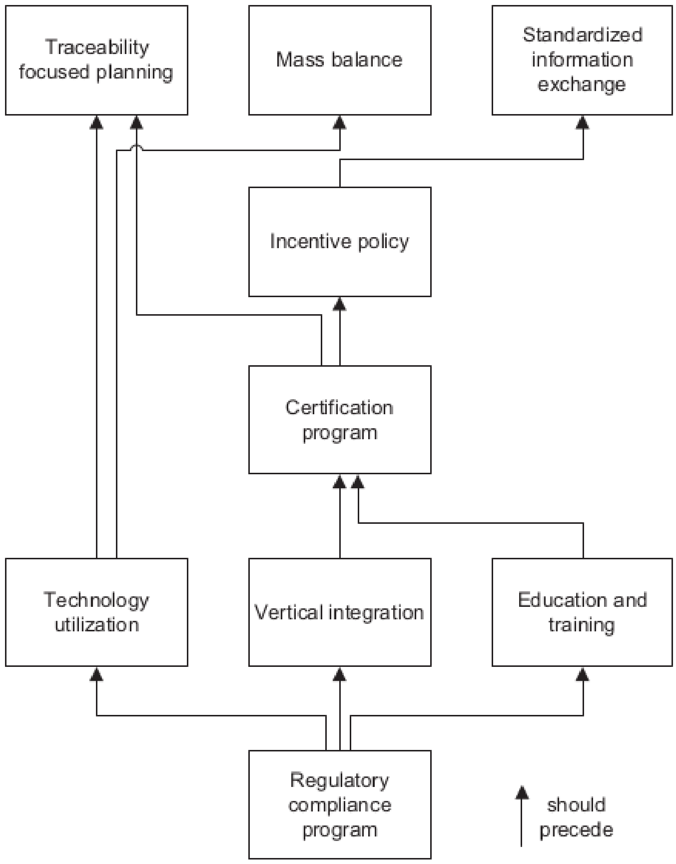


Figure 4.
The action map

the SIPOC concept. At the second stage, the initial list of typical barriers was reviewed by a group of experts. From the review, one barrier was removed because it was not relevant, and another barrier's word choice was adjusted. The final list of the typical operational barriers was then translated into a pair-wise comparison questionnaire to be distributed to the same group of experts. Questionnaires that had been filled out by experts were subsequently processed according to the stages described in the methodology section.

A six-level explanatory model was built by using the ISM procedure. Multi-sourcing (S1) becomes a traceability system barrier at level 6. This barrier has an essential role because it affects all other barriers above it. If described as a tree, multi-sourcing is the root of the problem that hinders the creation of a reliable traceability system in the vegetable oil industry. The involvement of many suppliers in the system is a critical barrier of product tracing.

At level 5, there are three barriers that are directly influenced by the multi-sourcing (S1) barriers: the multi-layered sourcing method (S2), the preprocessing method (S3) and the outsourcing method (P2). First, the relationship between the multi-sourcing method and the multi-layered sourcing method is because the multi-sourcing method allows the industry to receive materials from various tiers of suppliers, such as directly from plantations, small traders, wholesalers or brokers. Second, the multi-sourcing method will affect the kinds of the preprocessing methods of the supplied materials. Third, the multi-sourcing method also allows for procurement of intermediate product supplies by using an outsourcing-like approach. This is because the industry is often unable to meet customer demand due to a limited capacity.

At level 4, there is only one barrier: the alternating divergent and convergent processes (P1), both of which are at the middle level, so they act as the interplay in the internal chain. Empirically, the convergent and divergent process is directly influenced by three barriers at level 5. The vegetable oil industry also produces intermediate products that will be blended with other materials. The industry itself can take a role as a buyer or a seller of any intermediate products. Therefore, the alternating convergent and divergent processes influences indirect sales (C5). There are products that cannot be sold by companies because they do not have competence to sell them, such as the intermediate products or derivatives of nonfood products.

The alternating convergent and divergent process will produce various types of products. Some products are considered food commodities, while others are value-adding products. The implementation of the traceability system will have to cover all of these products and thus increase costs. However, the implementation of a traceability system concerning food commodities is much lower than the value-adding products. As a result, the alternating convergent and divergent process directly influences the customer willingness-to-pay (WTP) for the traceability of a food commodity (C3). At level 2, the nonuniform quality barrier and the various physical state barrier (I3) are directly influenced by the customer's WTP for the food commodity's traceability (C3) and indirect sales (C5). The WTP for traceability information directly influences the nonuniform quality (I2). This means that a majority of buyers' WTP for traceability will increase the bargaining power of the industry against its suppliers. Higher bargaining power will reduce the nonuniformity of the supply quality. The WTP for traceability information may also mean that an additional budget should be allocated for managing material supplies that differ in physical states (I3). Furthermore, pervasive indirect sales (C5) will reduce the motivation of the industry in managing the diversity of the supply quality as well as the material's physical states. The industry will assume that through an indirect sales scheme, the end customer cannot do backward tracing. In other words, an internal traceability system will not have a significant impact.

There are 11 traceability system barriers at the top of the hierarchy (level 1): blending process (I1), dynamic batch sizing (P3), batch definition (P4), coordination (P5), quality degradation (O1), mixing (O2), batch separation (O3), by-products (O4), customer demand (C1), transaction models (C2) and trust (C4). These 11 barriers are directly influenced by the nonuniform quality (I2) and the varying physical states (I3). The 11 barriers will directly influence the implementation of a traceability system.

Most of the identified barriers that directly influence the implementation of a traceability system in the vegetable oil industry indicates that the hypothesis must be accepted: that vegetable oil industry is facing a great challenge in building a reliable traceability system. In the MICMAC diagram (Figure 3), none of the barriers is in the autonomous area or the dependent area. This indicates that all barriers to implement a bulk-liquid traceability system have a significant mutual influence. There are 16 barriers in the linkage area: I1, I2, I3, P1, P3, P4, P5, O1, O2, O3, O4, C1, C2, C3, C4, C5 and C5, which indicate that these 16 barriers not only influence the system actively but also influence each other. In the independent area, there are four barriers: S1, S2, S3 and P2, which actively influence the other barriers but are not influenced by the other barriers.

After studying the hierarchical structure of the operational barriers, the experts were required to propose 3–5 solutions to remove the barriers. The proposed solutions were compiled as a list of nine actions. The constituent element of these actions cannot function optimally when used as a stand-alone solution. Even a company as big as Cargill Indonesia took six years to build an integrated traceable and transparent palm oil supply chain (Cargill, 2020). The actions, therefore, need to be integrated into a roadmap and organized as a hierarchical model. The starting point is at the regulatory compliance program as it can be a strong motivation to increase traceability. The next is technology utilization because it will support traceability-focused planning and mass balance schemes. The third is vertical integration and education and training, followed by a certification program that is buffered by an incentive scheme for traceability-focused planning. This is because incentive policy allows for standardized information exchange along the chain.

5. Discussion

The sustainability of the Indonesian vegetable oil industry is threatened by the declining demands from India, the largest importer of Indonesian palm oil, as well as by the palm oil embargo by the EU due to the food safety and sustainability issue. Indonesia's coconut oil production has also decreased gradually due to the declining supply of the raw materials (Gunawan *et al.*, 2018). All these factors make the Indonesian coconut oil industry unable to maintain its productivity and is unable to compete in the global market.

This issue is exacerbated by the double standards. In the palm oil industry, the problems are often rooted in the downstream of the supply chain; while in the coconut oil industry, problems are at the upstream of the supply chain. A traceability system is needed not only to solve problems along the supply chain but also to increase the customers' confidence in the industry's safety and sustainability. Roundtable on Sustainable Palm Oil (RSPO) certification is a traceability system that can secure the supply of raw materials in a domestic vegetable oil industry. Leveraging this system in the supply chain can generate accurate information that will assist the policy making. However, there are some specific barriers that must be removed before putting a traceability system into practice.

Recently, there has been a shifting focus of attention among players along the supply chain. At the upstream, the players focus on the quality; whereas at the downstream, they focus on the safety. Vegetable oil industry is usually in the middle of the supply chain and is impacted greatly by the shifting focus. Aside from this, the markets are strongly divided as some consider it a food commodity; while others consider it a value-adding product. End consumers and food processors that use vegetable oil for ready-to-eat products demand for a traceability system. This is because liquid products traded in bulk can flow freely and can easily mixed or contaminated with other substances during the storage or shipping.

Based on the ISM hierarchy structure (Figure 2) and the MICMAC diagram (Figure 3), S1, S2, S3 and P3 could be defined as supply barriers as they arise from the supply characteristics. Meanwhile, 11 barriers at the top of the hierarchy: I1, P3, P4, P5, O1, O2, O3, O4, C1, C2 and C4 could be called sales/operations barriers. Next, P1, C3, C5, I2 and I3 could be referred to as connector barriers because they connect the supply barriers and the sales/operations barriers. These simplifications can help the experts understand problems better, so they could formulate actions to solve them. The experts then proposed nine actions to overcome these barriers. Individually, these nine actions have been researched in previous studies, but there has been no unified solution that can holistically tackle the issues in the complex food supply chain. To achieve this, there has to be an integration among these action plans.

There are traceability regulations for food products, but the monitoring of the compliance is low. Therefore, the priority should be improving the regulatory compliance. This is to encourage players in the supply chain to come up with strategies to improve the traceability system by utilizing technology, vertical integration and education and training.

Technology utilization should be the second priority. Advancement in information technology such as automated data collection can accelerate planning (Skoglund and Dejmek, 2007; Tamayo *et al.*, 2009). Advances in information and communication technology will support the improvement of the traceability system such as Radio Frequency Identification (RFID) (Kvarnström *et al.*, 2011), quick response (QR) code (Qian *et al.*, 2017) and blockchain (Galvez *et al.*, 2018) that make continuous processes possible. Technology also supports the use of a mass balance scheme to ensure traceability throughout the production process. The next is vertical integration because a company may not have all resources to develop a traceability system effectively (Sanfiel-Fumero *et al.*, 2012; Engelseth and Hogset, 2016). This should be coupled with education and training because they promote the personnel's understanding of various traceability aspects (Gotel and Morris, 2012). Vertical integration and education and training have been proven to encourage players in the supply chain to take part in a certification program like the one carried out by Cargill Indonesia that encourages its partners to carry out RSPO certification (Cargill, 2020). Technology utilization, vertical integration and education and training are at the same level so they must be done simultaneously. A reward system such as incentive scheme can also be put in place to allow the standardization of information exchange that will eventually ensure consistency in traceability focused planning.

6. Conclusion

Food quality and safety issue in global vegetable chain warrants research on traceability systems in vegetable oil industry. ISO 22005:2007 states that the implementation of a traceability system depends on the technical limitations inherent in the organization and the product characteristics. Technically, the bulk-liquid food commodity industry is identified as not only the most difficult case but also a pressing issue, so identifying the typical operational barriers is imperative.

In this research, 20 typical operational barriers and their contextual relationship in the vegetable oil industry are identified along the internal food chain by using a combination of DEMATEL–ISM–MICMAC. The analysis of the barrier relationship calls for a holistic approach. As visualized in the hierarchical model and the MICMAC diagram, there are three groups of barriers: the supply barriers, the connector barriers and the sales/operations barrier. The industry experts involved in this study acknowledged that the hierarchical model of operational barriers can prompt strategic thinking. They came up with nine solutions, which were then restructured using the ISM approach into an action map to improve the traceability system.

7. Implication of study

The practical implications of this study can be utilized by both practitioners and academics in bulk-liquid traceability systems in the formulation of strategies. By following the hierarchical structure (see Figure 3), experts can sort out the priorities to improve the traceability system in the vegetable oil industry (see Figure 4). These findings will also help tracing the critical points of the traceability system.

8. Limitation and future research

This research has demonstrated the successful application of a methodological approach in explaining the relationship of barriers in the improvement of a traceability system. However, the limitation of this research is on the difficulty in clearly narrating a simple diagraph into a meaningful conclusion. Even though the use of MICMAC is very helpful, the model development using total interpretive structural model (TISM) is recommended in future research. In addition, the strength of relationship between barriers was not captured by the model. The ISM only justifies the relationship as direct and indirect, so the future studies may benefit from the use of structural equation modelling (SEM) to analyze the relationship strength.

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