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Integrating Halal and Food Safety Indicator Relationships through DEMATEL-ISM-MICMAC Structural Analysis

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Abstract

The food industry's supply chain is both complex and fragmented, which amplifies the risk of contamination; this paper focuses on addressing these challenges. To tackle these challenges, companies need indicators that track their activities from procurement through to returns, as such metrics are essential for supporting decision-making, efficiency, and risk management. This study's goal was to investigate the relationships among operational performance indicators in order to identify priority indicators that may enhance operational performance while integrating halal and food safety certification. The indicators were identified by examining activities within the business process (source, make, deliver, and return). They were then developed based on previous studies and the perspectives of experts panel. The DEMATEL method was used to find cause-and-effect links between indicators; ISM was used to make hierarchical structures; and MICMAC was applied to categorize indicators according to driving power and dependent power. This study shows that there are five hierarchical levels of the 25 identified operational indicators. Indicators such as material quality, cleanliness, defect rate, production rate, and warehouse inventory can be root causes that impact other operational performance indicators. The findings may assist stakeholders in the food industry to identify root causes, strengthen halal and food safety assurance, and significantly improve performance. This study contributes new insights by applying an activity-based approach combined with DEMATEL-ISM-MICMAC, advancing both the theoretical and practical application of performance indicators within the food industry.

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Introduction

The world population in 2025 is projected to reach 8,261,826,758[1],spread across the continents as follows: Asia (59.04%), Africa (18.28%), America (12.86%), Europe (9.24%), and Oceania (0.57% [2]). On the other hand, food products, as a primary human need, have specific characteristics that can pose challenges to meeting this need, for example, high variety (10% common), relatively short shelf life, and seasonality.[3] Food industrialization is a solution to meeting food security. However, the food industry can also cause problems if not managed properly. Millions of people may fall ill or die from consuming unhealthy food.[4] According to the World Health Organization (WHO) (2024), 600.000.000 individuals get sick every year by consuming food that contains contaminants, with 40% being children under five years old, while financial losses of more than US$ 110.000.000.000 are incurred due to unsafe food, especially in nations with poor and medium income.

Due to the dangers of illness and death that can happen when food is not handled properly, it is very important to make sure it is safe.[5] Food safety, according to the WHO, is the set of rules and practices that must be followed during the production, processing, storage, distribution, and preparation of food to make sure it is safe, healthy, and fit for human consumption.[4]

Halalness is one of the requirements that products must meet when Muslims consume them. While food safety is a concept related to protecting consumer health, halalness broadens its scope by demanding compliance with Islamic law. These two concepts are key factors influencing consumers in product selection.[6] By implementing these two concepts in their operations, companies can capture the opportunity of serving the Muslim market, which has the second-largest population in the world, with a total of 2.000.000.000 people.[7]

The integration of halal and food safety certification into operational systems within the food industry is becoming an essential necessity due to the globalization of supply chains. The risk of contamination in this industry is increasing due to the complex network of stakeholders, including farmers, input suppliers, transporters, processing units, wholesalers, distributors, retailers, exporters, importers, and finally, consumers [8]. Furthermore, the fragmentation of supply chains across various regions and even countries contributes to the risk of contamination [9]. Therefore, consumers demand food safety assurance that emphasizes the management of microbiological, chemical, and physical hazards in food [10]. Muslim consumers are pushing regulatory agencies and processing companies to produce products with halal certification [11]. This involves guaranteeing that the processing area is sanitary and that products are free from contamination by pork and its by-products, alcohol, blood, as well as certain types of animals and all types of flesh that have not been slaughtered according to Islamic protocols [12]. Ensuring halal and food safety compliance throughout the supply chain calls for an integrated standard covering all stages, from raw materials to distribution.

According to earlier studies, consumers are willing to pay a premium for goods with food safety and halal certification [13,14]. Therefore, companies having halal certification will positively impact their operations [15]. Likewise, food safety certifications such as HACCP and ISO 22000 provide immediate and enduring benefits for a company's profitability [16]. Compliance with internationally accepted standards is crucial for companies because failure to comply with halal and food safety standards directly impacts their reputation, operational costs, and market confidence [17]. Implementing halal and food safety standards can also positively impact a company's performance to a significant degree [18]. For this reason, it is necessary to identify indicators that influence operational performance, especially in connection with halal and food safety compliance. Furthermore, understanding the relationships between these operational performance indicators is crucial for mapping cause and effect. This mapping can be used to evaluate current policies and develop future policies for the food industry.

DEMATEL, ISM, and MICMAC are the three integrated methods used in this study. The main objective is to systematically build a hierarchical model among performance indicators. The cause-and-effect correlations between the indicators are found and shown using the DEMATEL approach. ISM is subsequently employed to organize the hierarchical structure based on these relationships, resulting in a clear model that illustrates the degree of interconnection and the sequence of influence among the indicators. MICMAC complements the analysis by classifying indicators according to their levels of influence and dependence, enabling the mapping of indicators as drivers, dependents, linkages, or autonomous. In comparison to other methods such as Regression or Structural Equation Modeling (SEM), the DEMATEL-ISM-MICMAC model is more appropriate for exploratory and conceptual purposes, as it does not solely focus on the statistical relationship, but also on the hierarchical structure and indicator dynamics. Therefore, the combination of these three methods provides a strong justification for the development of a model that can effectively illustrate the complexity of the relationship between performance indicators in the context of food safety and halal, as well as produce conceptual insights that can be used as the foundation of business strategy or further research. This model is important to provide an analytical framework, evaluation tools, and useful recommendations for the food industry by knowing the operational performance indicators and modeling the relationships between these indicators for future research.

The food industry has a supply chain that is crucial for human needs, job creation, and economic growth, and also impacts the natural environment [19]. The food supply chain is highly complex and has unique characteristics; if not managed properly, it will cause losses for both consumers and producers [9, 20, 21]. Key characteristics inherent in the food industry include: shelf-life constraints, food safety requirements, long production times, seasonality in production results, special features such as sensory properties flavor, color, size and shape), conditioned transportation and warehousing, and the impact of natural conditions on the quantity and quality of agricultural products [3].

To overcome these distinctive challenges, the Supply Chain Operations Reference (SCOR) Model offers a comprehensive framework for assessing and managing operations. SCOR is the first cross-industry framework designed to assess and improve supply chain performance and management across companies [9]. Although the SCOR model is often used in non-food industries, it can also facilitate an in-depth study of the complex performance measurement indicators applied in agribusiness production systems and related supply chains [22]. The basis of every supply chain is the ‘chain’ of source, make, and deliver [23,24]. Because supply chains are not only related to companies but also to consumers, there is the additional ‘return’ activity, i.e., products being returned after delivery to consumers [25]. Apart from business process activities, in the SCOR framework, there are performance attributes such as reliability, responsiveness, agility, cost, and assets [26].

Besides quality and food safety, one of the consumers’ needs that companies with a majority Muslim consumer base must address is the assurance of halal products. For example, Indonesia, a nation with a Muslim majority, has implemented legislation that ensures things are halal, as specified in Law No. 33 of 2014. The importance of halal assurance stems from the commandment of Muslims to only consume halal food, as stated in Surah Al-Baqarah, verse 168. According to the Indonesian Ulema Council (MUI), there are three main criteria for halal certification: the halalness of the raw materials used, the methods of obtaining them, and the processes of processing them. For example, when slaughtering, a halal slaughterer must recite a prayer before carrying out the slaughtering process, complying with halal slaughtering regulations [11]. The challenge of maintaining these three main criteria is multidimensional and difficult to contextualize holistically, because they are all interdependent and equally important [27].

Given the characteristics of the food industry mentioned above and the need to meet halal requirements, operational management is crucial for managing supply uncertainty and maintaining product quality, safety, and halal certification. Therefore, the goal of operational management in the food industry is not only to ensures that procedures are functional and efficient but also to prioritize protecting consumers.

Table 1: The operational performance indicators in the food industry based on supply chain activities

Activities	KPI Code	Indicator	Source	Description
	(1)	Sufficient employee	Interview results	Have a food safety coordinator & halal supervisor and for RPH have at least one halal slaughterer.
	(2)	Employee knowledge evaluation[31,32,25]	Literature	Employees know, understand, and initiate actions related to halal and food. Requirements Knowledge related to: Halal and food safety mind-set, knowledge, motivation.
	(3)	Sufficient raw materials[25,32]	Literature	Raw materials must be available in sufficient quantities according to industrial demands.
	(4)	Number of materials not contaminated by non-FSH substances[25,27,33,32,34,35]	Literature	Raw materials must be free from direct or indirect contact, mixing, or interaction with anything that is categorized as unclean or haram according to Islamic law.
Source	(5)	Operational cost[22,25,33,36,37]	Literature	All expenses incurred in running a business on a day-to-day basis. These costs are important to monitor because they directly impact a company's profitability.
	(6)	Availability of Sanitation[25,38,39]	Literature	Sanitation is crucial, especially in the food industry, to ensure product safety and employee health. This includes access to adequate facilities and hygienic conditions in the work environment.
	(7)	Suppliers with halal, HACCP/ISO 22000 certification[40,41,42]	Literature	Suppliers with ownership of documents are needed to ensure that the supplier has met standards in terms of halal and food safety aspects.
Make	(8)	Percentage of employee awareness (cleanliness)[28,43,31,39,44,45,46,47]	Literature	Employees are objects that have significant potential to carry contaminants. The lower the percentage of employees who do not comply with hygiene regulations, the better.
	(9)	Percentage of compliance in product handling & animal welfare[34,48,49,50,51]	Literature	A crucial aspect of industries involving are animals. This indicator focuses on how animals managed from the farm to the finished product.
	(10)	Percentage of compliance with facility cleanliness inspection results[49,50]	Literature	Number of Violations
	(11)	Number of defective FSH products (WIP)[43,39]	Literature	% of defective products Number of defective products Food safety & Halal.
	(12)	Separation of halal and non-halal facilities[50]	Literature	Segregation of halal facilities is an essential physical element to guarantee the complete elimination of contamination during manufacturing.
	(13)	Documentation[47,49,52,53]	Literature	Documentation related to food safety implementation and its availability for assessment are factors to consider. Thorough documentation and comprehensive record-keeping throughout the HACCP process are essential requirements to ensure compliance with regulatory standards and facilitate traceability.

	(14)	Production Rate[54,55,56,57]	Literature	Looking at the productivity of a process in optimizing resources, costs and maintaining quality. Percentage of output to input.
	(15)	Compliance with storage facility specifications[58,59,50]	Literature	Product storage facility specifications can be represented by the percentage of damaged products (damaged packaging, crushed, wet) during the storage process.
Delivery	(16)	Number of warehouse facility inspections	Interview results	Reducing the risk of contamination and damage to stored goods. Demonstrating compliance with food safety and halal standards.
	(17)	Percentage of product stock shortages	Interview results	Controlling the number of products to prevent overstock or understock.
	(18)	On-Time Delivery Rate[30,60,61,62]		Literature This indicator measures how often product shipments arrive at their destination on or before the promised time to customers. It measures the percentage of correct deliveries (product, quantity, and condition) and on-time deliveries.
	(19)	Percentage of accuracy in order quantity and type[62]	Literature	Measuring the ability to meet customer demand with the right quantity and type.
	(20)	Compliance with halal labelling and clarity of composition[25,33,32,34,35,39,50,63]	Literature	This indicator indicates the company's compliance with food safety and halal regulations.
	(21)	Availability of procedures for handling defective FSH products	Interview results	In the BPJPH standards there is a clause stating that companies must have an SOP for halal failure.
	(22)	Percentage of defective products	Interview results	The level of non-conformity of recalled products needs to be measured based on the product that can be worked on and resold.
	(23)	Number of customer complaints[59]	Literature	One of the company's goals is to meet customer quality standards. If consumers receive a product that doesn't meet their desired quality, complaints will be an indication of inefficiencies in the operational process.
Return	(24)	Availability of traceability system[52,50]	Literature	Traceability is the capacity to monitor and/or trace product movements, encompassing both fresh manufacturing and industrial distribution networks. Traceability denotes the unique identification of items, the documentation of product identity at important stages of manufacturing and distribution, and the systematic collection, processing, and storage of information.
	(25)	Customer Satisfaction Index (CSI) [64,65,66]	Literature	A metric used to measure the overall level of customer satisfaction with a product, service, or experience provided by a company.

Several studies have focused on performance indicators in the food industry and introduced specific indicators related to its characteristics. A framework for assessing the food supply chain performance has been established in previous research. Aramyan *et al* [28] conducted research on the tomato supply chain by collecting expert perspectives to identify performance measurement indicators with three general dimensions: efficiency, flexibility, and responsiveness; and one dimension specifically related to food characteristics, namely food quality. They examined financial and non-financial dimensions, and food safety was one of the things that made up the food quality dimension. Bigliardi and Bottani [29] suggested at the Balanced Scorecard (Financial, Learning and Growth, Internal Processes, and Customer) to develop a performance measurement framework for the food supply chain, and suggested integrating several measurement aspects. To that end, Moazzam *et al* [22] looked at performance indicators from a business process perspective using the SCOR approach with five dimensions (reliability, responsiveness, agility, cost, and assets), where these indicators are derived from activities for operational implementation. To obtain the right strategy, it is necessary to understand the indicators as factors that influence or are influenced by other indicators. Sufiyan [30] examined performance in the food supply chain by examining the relationship between indicators using DEMATEL and Analytic Network Process (ANP). Although many studies have addressed activity-based indicators in the supply chain and developed criteria to address the quality aspects of the food industry, without explicitly addressed halal and food safety requirements. This leaves a gap in understanding how compliance with halal and food safety standards translates into operational performance outcomes. To address this gap, the present study applies the DEMATEL-ISM-MICMAC approach to analyze the interrelationships among indicators, thereby providing a structured framework that integrates halal assurance and food safety into operational performance measurement. Informed by past research, this study addresses the gap through the following research questions:

RQ 1 – What indicators reflect operational performance integrated with halal and food safety requirements?

RQ 2 – What is the relationship between operational performance indicators integrated with halal and food safety requirements?

The results of this study can assist the food industry in establishing effective and efficient systems that comply with food safety and halal requirements. Using a qualitative approach, operational performance indicators were explored. The researchers used SCOR, which focuses on operational business process activities (source, make, deliver, return) to explore and categorize the operational performance indicators. The indicators identified from the characteristics in the food industry (covering halalness and food safety) are listed in Table 1, and their mapping is presented in Table 2.

Table 2: Indicators derived from halal, food safety, and operational characteristics in the food industry

	Source	Make	Delivery	Return
Employees and training	KPI 1 KPI 2	KPI 8		
Raw material	KPI 3 KPI 4			
Production process	KPI 5 KPI 6	KPI 9 KPI 12 KPI 11 KPI 10	KPI 15 KPI 16	KPI 22
Documentation	KPI 7	KPI 13		KPI 21
Finished product		KPI 14	KPI 17 KPI 18 KPI 19	KPI 23 KPI 25
Packaging and Labelling			KPI 20	
Traceability				KPI 24

Materials and Methods

The objective of this research was to determine the indicators impacting operational performance within the food industry and analyze the hierarchical relationships between them. The ISM method is often used in research to create a hierarchical structure model that illustrates the causal relationships between indicators and classifies indicator variables to understand the interdependencies within a complex system[67,68]. Systems with many elements are more comprehensible when depicted through a hierarchical structure than a network structure[69]. Food supply chains are complicated, so the ISM approach is suitable for identifying and analyzing the relationship of operational performance indicators within the food industry, as validated by a panel of experts.

Operational performance indicators were determined using a thorough literature review and interviews with the members of the panel. To guarantee the integrity of the Delphi results, the Delphi procedure included a panel of seven carefully selected panelists, each possessing over five years of expertise in halal, food safety, and food company operations. The panel consisted of both practitioners and academics. Panelists were chosen using a non-probability selection method referred to as snowball sampling, to ensure that only experts with direct experience [68]. This organized and iterative methodology guaranteed the systematic use of the Delphi technique, integrating varied knowledge to produce robust and credible results. The Delphi technique was used to manage, compile, and analyze expert comments, as well as to evaluate the relevant literature through the perspectives of the experts' [67,70]. DEMATEL is a structural approach that understands the interaction between indicators of a system through causal diagrams[71,72]. This study employed the Delphi procedure within the DEMATEL framework to achieve consensus without in-person meetings, therefore mitigating social contact and pressure that may influence the panelists' responses [69]. This study applied the Delphi technique over two iterations. During the first iteration, the panelists responded to questionnaires for approximately 40 minutes, assisted by the researchers via Zoom. In the second iteration, they conducted a review after receiving the average answer scores from the first iteration. During this process, no panelist changed their answers. The list of panelists can be observed in Table 3.

Table 3: Panelist profiles

NO	Status	Education	Work Experience (Years)	Field	Job Title
1.	Professional & Academic	Doctoral Degree	16	Halal & Food Safety	Lecturer & Manager of Halal Inspection Agency
2.	Professional & Academic	Doctoral Degree	28	Halal	Lecturer & head of Halal Inspection Agency
3.	Professional	Bachelor's Degree	15	Halal & Food Safety	Lead Auditor Food Safety Halal Assessor
4.	Professional	Bachelor's Degree	10	Halal & Food Safety	Manager of Quality Control
5.	Professional	Bachelor's Degree	10	Halal & Food Safety	Auditor of Food safety & Halal
6.	Professional	Master's Degree	15	Halal	Auditor of Food safety & Halal
7.	Professional	Master's Degree	12	Halal & Food Safety	Auditor of Food safety & Halal

Gunawan [69] integrated DEMATEL and ISM to structurally model the interaction among barriers in a traceability system. As a comprehensive methodology, DEMATEL consolidates group knowledge to construct structural models that reveal causal links among complex indicators. ISM complements this by structuring and visualizing the indicators in a directional graph (diagram), with its procedure necessitating the development of the structural self-interaction matrix (SSIM) questionnaire to generate group assessments[73]. Meanwhile, DEMATEL enables the Delphi technique, which enables the drawing of comparable conclusions without the necessity of formal meetings. The use of the Delphi technique in the DEMATEL questionnaire can combine expert consensus with causal relationship analysis, making it more efficient. The integration of DEMATEL and ISM is achieved when the total relationship matrix from DEMATEL is transformed into the initial reachability matrix required by ISM. The final reachability matrix (ISM) then serves as the basis for the MICMAC analysis, which is vital for system development. MICMAC enriches and sharpens the analysis [69]. This data processing series is assisted by Excel for calculations and Visio for depicting the hierarchy chart. The DEMATEL-ISM-MICMAC procedure is outlined below:

Designing the Questionnaire

The questionnaire is designed from a list of indicators according to the literature review and expert perspectives. A sample can be seen in Table 4. This questionnaire contains $F = \{f_1; f_2; ... ; f_n\}$, arranging the relationship between the indicators. The questionnaire was assessed by the experts by adding the value of each relationship between the indicators from the f_i indicator to the f_j indicator using an integer scale of 0 to 4: 0 = not having an influence; 1 = low influence; 2 = moderate influence; 3 = highly influence; 4 = very strong influence.

Sufficient employees (1) has ____X___ influence on ____Y____

Table 4: The questionnaire sample

Indicator (X)						
0	**1**	**2**	**3**	**4**	**KPI Code**	**Indicator (Y)**
					2	Employee knowledge evaluation
					3	Sufficient raw materials
					4	Number of materials not contaminated by non-FSH substances
					5	Operational cost
					6	Availability of sanitation
					7	Suppliers with halal, HACCP/ISO 22000 certification
					8	Percentage of employee awareness (cleanliness)
					9	Percentage of compliance in product handling & animal welfare
					10	Percentage of compliance with facility cleanliness inspection results
					11	Number of defective FSH products (WIP)
					12	Separation of halal and non-halal facilities
					13	Documentation
					14	Production Rate
					15	Compliance with storage facility specifications
					16	Number of warehouse facility inspections
					17	Percentage of product stock shortages
					18	On-Time Delivery Rate
					19	Percentage of accuracy in order quantity and type
					20	Compliance with halal labelling and clarity of composition
					21	Availability of procedures for handling defective FSH products
					22	Percentage of defective products
					23	Number of customer complaints
					24	Availability of traceability system
					25	Customer Satisfaction Index

Table 5: Initial direct-relation matrix

F	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0	0.25	0.875	0	1	0.125	0	0	3.625	0	0	1	0	0	0.875	1	0.875	2.625	0.875	0	0	2	0	0	0
2	0.375	0	0	1.75	2	0.25	0	2.125	2.25	1	4	2	0	2	3.625	1.75	0.875	1	2	3	2	1	0.125	0	0
3	0.875	3	0	4	4	0	4	1.75	0	0	0	3.5	0	0	3.625	0.25	0.125	0	2.625	0	0	3	0	0.125	0
4	0.25	3	2.75	0	0	3.625	4	3	0	0	4	4	0	0	4	0	0	0	0	0	0	0	0	0.125	0
5	2.875	2.875	3.5	3.25	0	3	3.625	0.875	3.75	1.875	3.75	4	1	3.125	2	2.125	3.75	1.875	2.75	3.625	1.875	1.875	2	0	0.75
6	0.125	0.25	0	0	4	0	0	0.125	3.5	0.125	0	0	0	0	1.875	0	0	0	0	0	0	0.125	0.25	0	1.25
7	0	0	0	0	4	0	0	0	3.5	0	0	0	0.125	0	0	0	1.75	0	0	0	0	1	0	0	0
8	0	4	0	0	2	1.125	0	0	2.625	0	0	2	0	1.75	0.875	0.875	2.625	0	0	0	0	0	0	0	0
9	1.25	2.75	4	4	4	2	4	1	0	1.375	0	3	0	0	0	0	1.75	0	0	0	0	0.125	3	0.125	0
10	0	2	0	0	0	1.125	0	3.75	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	2.75	4	2.25	0	1	2.375	1	4	1.75	0	3	0	3.5	0	0.125	0	0	0	0	0	0	0	0	0.625
12	0	2.625	0.5	0	4	0	0	0	4	0	0.125	0	0	0.25	1.25	0	0	0	0	0	0	0	0	0	1.25
13	0.125	2.75	3.5	2.5	1	1	4	2	3.5	4	1	3	0	3	2.875	4	2	2	4	4	4	2	2	0.125	1.75
14	1	2	3.5	2	0	1	2.625	1	4	1.25	4	1.875	0	0	4	0.125	4	0	1	1	0	4	0.125	2	0
15	0	2	0.125	0	4	0.875	0	0	0.875	0	0	3	2.625	0	0	0	0	0	0	0	0	0.125	0	0	0.125
16	0.125	0.875	1.375	0.75	1	0	0.875	0	3	2.25	0.875	0	0	2.625	4	0	1	1.75	1.75	0	0	0.125	0	0	0.5
17	1	0	3.75	1.875	0	0	0	0	1	0.125	4	0	0	4	1.75	0.875	0	0.125	0	0	0	0	0	0	0
18	0.25	0	1.5	0.875	0	0	0.5	0	2	0.125	1	0	0	4	0	0	4	0	4	0	0.875	4	1	0	0.75
19	0	2.625	0.875	0.75	0	0	0	0	3.625	0.25	0.875	0	2	4	0.875	4	2	0	0	0	0	0	2	0	0.125
20	4	3	0	2.75	0	3	4	0	3.75	4	2.25	4	3.5	0	2.25	3.125	0	0	0	0	4	0	0	4	1.875
21	0	3	0.25	0.375	1	0	0	0	2.625	0	0.25	0	4	3	0	0	0	0	0	0	0	4	1	0	1.875
22	0	3	1.75	1.25	0	0.25	1.75	0	3.625	1	4	1	0	1.875	1	1.75	0	0	4	0	0	0	0.125	0.125	0.125
23	0	0	0	0	0	0	0.375	0	3.75	0	1	0	0	1.875	1	0	4	4	4	4	1	2.75	0	0.125	0.5
24	0	3	0	0.25	4	0	4	0	3	0	0	4	4	1.875	0	0	0	0	0	0	4	0	3	0	4
25	0	0	0	0	0	0	2.75	0	3.625	0	1	4	0	1.875	1	0	4	4	4	4	2	2.75	4	3.75	0

Table 6: Normalized direct-relation matrix

F	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0.003	0.014	0.023	0.010	0.025	0.006	0.010	0.003	0.066	0.004	0.008	0.024	0.002	0.009	0.020	0.019	0.021	0.041	0.021	0.003	0.002	0.035	0.005	0.001	0.002
2	0.014	0.027	0.020	0.043	0.048	0.016	0.020	0.040	0.065	0.026	0.075	0.054	0.010	0.047	0.071	0.035	0.027	0.019	0.039	0.050	0.036	0.025	0.009	0.005	0.006
3	0.019	0.067	0.015	0.071	0.079	0.011	0.074	0.034	0.029	0.007	0.019	0.073	0.006	0.015	0.071	0.014	0.015	0.005	0.050	0.008	0.006	0.052	0.006	0.003	0.004
4	0.007	0.062	0.050	0.011	0.025	0.060	0.069	0.050	0.025	0.005	0.067	0.076	0.004	0.010	0.072	0.005	0.008	0.003	0.006	0.005	0.003	0.007	0.003	0.003	0.004
5	0.054	0.081	0.083	0.077	0.036	0.062	0.086	0.029	0.110	0.044	0.085	0.096	0.026	0.074	0.064	0.047	0.079	0.038	0.061	0.065	0.039	0.049	0.041	0.008	0.021
6	0.007	0.014	0.010	0.009	0.068	0.007	0.011	0.005	0.063	0.006	0.007	0.013	0.003	0.007	0.034	0.004	0.009	0.004	0.007	0.006	0.004	0.007	0.010	0.002	0.020
7	0.005	0.009	0.011	0.010	0.066	0.006	0.010	0.003	0.062	0.005	0.009	0.010	0.004	0.008	0.006	0.004	0.033	0.003	0.006	0.005	0.003	0.019	0.005	0.001	0.002
8	0.005	0.070	0.012	0.011	0.042	0.023	0.010	0.006	0.055	0.006	0.013	0.042	0.003	0.036	0.026	0.018	0.047	0.003	0.006	0.006	0.004	0.006	0.005	0.002	0.003
9	0.026	0.061	0.074	0.074	0.081	0.040	0.077	0.025	0.029	0.026	0.018	0.066	0.004	0.014	0.021	0.008	0.040	0.008	0.013	0.011	0.006	0.014	0.049	0.004	0.004
10	0.002	0.038	0.004	0.005	0.009	0.020	0.004	0.058	0.039	0.002	0.004	0.036	0.001	0.004	0.006	0.002	0.005	0.001	0.002	0.003	0.002	0.002	0.002	0.000	0.001
11	0.005	0.059	0.073	0.048	0.021	0.023	0.052	0.025	0.080	0.031	0.013	0.064	0.002	0.059	0.018	0.006	0.012	0.003	0.009	0.006	0.003	0.010	0.006	0.003	0.012
12	0.006	0.050	0.019	0.012	0.070	0.007	0.013	0.005	0.073	0.006	0.012	0.015	0.003	0.012	0.028	0.005	0.010	0.005	0.008	0.008	0.005	0.007	0.007	0.002	0.021
13	0.014	0.082	0.080	0.065	0.049	0.032	0.091	0.046	0.106	0.075	0.044	0.082	0.015	0.074	0.076	0.075	0.056	0.040	0.081	0.072	0.071	0.053	0.043	0.011	0.036
14	0.022	0.058	0.074	0.050	0.028	0.026	0.062	0.026	0.091	0.028	0.078	0.056	0.008	0.018	0.079	0.011	0.070	0.004	0.027	0.021	0.006	0.069	0.010	0.032	0.006
15	0.005	0.042	0.013	0.010	0.070	0.019	0.011	0.005	0.030	0.007	0.010	0.057	0.041	0.010	0.011	0.007	0.009	0.005	0.009	0.009	0.007	0.008	0.006	0.001	0.006
16	0.006	0.029	0.034	0.023	0.029	0.008	0.026	0.007	0.062	0.038	0.024	0.017	0.005	0.049	0.071	0.005	0.026	0.029	0.034	0.005	0.003	0.011	0.006	0.003	0.009
17	0.018	0.015	0.069	0.040	0.012	0.007	0.015	0.007	0.030	0.007	0.068	0.016	0.002	0.066	0.039	0.016	0.008	0.004	0.006	0.003	0.001	0.009	0.002	0.002	0.002
18	0.008	0.018	0.040	0.027	0.010	0.006	0.022	0.006	0.053	0.008	0.033	0.014	0.004	0.075	0.015	0.009	0.071	0.003	0.070	0.005	0.015	0.069	0.021	0.004	0.013
19	0.005	0.055	0.031	0.027	0.014	0.008	0.017	0.008	0.076	0.013	0.029	0.017	0.032	0.073	0.032	0.065	0.043	0.007	0.012	0.009	0.005	0.011	0.036	0.003	0.005
20	0.065	0.076	0.023	0.059	0.035	0.057	0.086	0.015	0.101	0.072	0.050	0.091	0.064	0.022	0.057	0.057	0.018	0.011	0.016	0.013	0.072	0.017	0.015	0.063	0.040
21	0.005	0.062	0.021	0.021	0.027	0.008	0.019	0.008	0.064	0.010	0.021	0.019	0.062	0.058	0.017	0.010	0.014	0.007	0.016	0.012	0.009	0.071	0.023	0.005	0.032
22	0.004	0.063	0.042	0.034	0.017	0.012	0.042	0.009	0.077	0.022	0.071	0.033	0.004	0.042	0.030	0.033	0.011	0.003	0.067	0.005	0.003	0.008	0.009	0.004	0.005
23	0.008	0.020	0.019	0.017	0.013	0.009	0.023	0.005	0.082	0.010	0.033	0.018	0.008	0.047	0.029	0.011	0.073	0.062	0.071	0.063	0.022	0.052	0.009	0.008	0.012
24	0.008	0.070	0.021	0.023	0.082	0.011	0.083	0.010	0.085	0.013	0.020	0.085	0.068	0.050	0.021	0.012	0.024	0.013	0.021	0.020	0.072	0.021	0.059	0.007	0.068
25	0.010	0.029	0.023	0.021	0.024	0.011	0.065	0.007	0.096	0.012	0.037	0.083	0.014	0.054	0.034	0.013	0.080	0.066	0.076	0.068	0.042	0.058	0.072	0.062	0.011

Determining the initial direct-relation matrix (A)
This study considers H experts and n indicators. Each expert generates an n x n non-negative matrix Xk = [X_ij^k]n x n, with 1 ≤ k ≤ H. The average matrix A, or initial direct-relation matrix, is subsequently derived to capture the collective influence dynamics among the elements. This matrix indicates the initial direct influence of each element given to and received from other elements. Given the involvement of 7 experts and 25 indicators in this study, the resulting initial direct-relation matrix is presented in Table 5.

Normalizing the initial direct-relation matrix (A) into a normalized direct-relation matrix (G)

The score scale used by each researcher can vary. Therefore, the initial direct relationship matrix needs to be normalized with G = [g_{ij}]n x n and 0 < gij < 1. The normalization result is presented in Table 6.

Calculating the total relation matrix (T)
Calculating the total relation matrix is necessary because the normalization process creates a distinction between the elements (g_{ij}) of the matrix of G values. The compilation of the total relation matrix T = [t_{ij}]n x n strengthens the value of each element, so that elements that actually affect each other can be distinguished from elements that have no effect. The total relation matrix can be seen in Table 7.

Table 7: Total relation matrix

F	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
2	0	0	0	1	1	0	0	1	1	0	1	1	0	1	1	1	0	0	1	1	1	0	0	0	0
3	0	1	0	1	1	0	1	1	1	0	0	1	0	0	1	0	0	0	1	0	0	1	0	0	0
4	0	1	1	0	0	1	1	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
5	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0
6	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
8	0	1	0	0	1	0	0	0	1	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0
9	0	1	1	1	1	1	1	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0
10	0	1	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	1	1	1	0	0	1	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
12	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1
14	0	1	1	1	0	0	1	0	1	0	1	1	0	0	1	0	1	0	0	0	0	1	0	1	0
15	0	1	0	0	1	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
16	0	1	1	0	1	0	0	0	1	1	0	0	0	1	1	0	0	1	1	0	0	0	0	0	0
17	0	0	1	1	0	0	0	0	1	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0
18	0	0	1	0	0	0	0	0	1	0	1	0	0	1	0	0	1	0	1	0	0	1	0	0	0
19	0	1	1	0	0	0	0	0	1	0	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0
20	1	1	0	1	1	1	1	0	1	1	1	1	1	0	1	1	0	0	0	0	1	0	0	1	1
21	0	1	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	1
22	0	1	1	1	0	0	1	0	1	0	1	1	0	1	1	1	0	0	1	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1	0	1	1	1	1	0	1	0	0	0
24	0	1	0	0	1	0	1	0	1	0	0	1	1	1	0	0	0	0	0	0	1	0	1	0	1
25	0	1	0	0	0	0	1	0	1	0	1	1	0	1	1	0	1	1	1	1	1	1	1	1	0

Converting the total-relation matrix (T) to the initial reachability matrix (K)

The total-relation matrix represents the complex dependencies among the observed indicators. A meaningful relationship between the fi indicator and the f_j indicator is indicated by t_{ij} greater than or equal to the threshold value. The threshold value (α) is the average value in the total relation matrix. The initial reachability matrix is derived by transforming the total-relation matrix T into a binary matrix K, where values are expressed as 0 or 1 based on the threshold criterion. The conversion process and the resulting matrix K are detailed in Table 8.

Table 8: Initial reachability matrix

F	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Dr
1	0	1	1	1	1	1	1	0	1	0	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	17
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	25
3	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	22
4	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0	20
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	25
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	23
7	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0	22
8	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	23
9	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0	22
10	0	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	1	1	1	0	1	0	0	18
11	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	0	21
12	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0	22
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	25
14	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	23
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	24
16	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	23
17	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	0	0	1	1	1	0	19
18	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	1	1	1	0	20
19	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24
20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	25
21	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	25
22	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	23
23	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24
24	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	25
25	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24
Dp	16	24	24	25	25	25	25	22	25	23	25	25	18	25	25	24	25	19	25	22	22	24	24	16	11	

Checking the transitivity and establishing the final reachability matrix K0

This stage uses Boolean multiplication and the addition theory of sets. The conclusion arises due to some indirect relationships that the concept of transitivity eliminates, for example, if a → b a is related to b and b → c b is related to c, it can be concluded that a → c a is related to c. The final reachability matrix can be seen in Table 9.

Defining the reachability set and the antecedent set Each element's reachability set is composed of specific elements. In the interim, the antecedent set of each element comprises elements that constitute specific elements [74]. In technical terms, the reachability set RS_i of an element system is a collection of elements that correspond to the columns, where all elements in row i of the final reachability matrix are '1'. The antecedent set AS_i of the element system is a collection of elements that correspond to the rows, where all elements in column *i* of the final reachability matrix are '1'. These sets provide the basis for partitioning the elements into distinct levels, and the results for each indicator are summarized in Table 9.

Table 9: Final reachability matri

KPI	Antecedent Set	Reachbility Set	Intersection Set	Level
2	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,17,18,19,20,21,22,23,24,25	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,17,18,19,20,21,22,23,24,25	I
5	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25	
13	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25	2,3,4,5,6,13,14,15,16,17,18,19,20,21,22,23,24,25	2,3,4,5,6,13,14,15,16,17,18,19,20,21,22,23,24,25	
20	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25	2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,19,20,21,22,23,24,25	2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,19,20,21,22,23,24,25	
21	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25	2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,19,20,21,22,23,24,25	2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,19,20,21,22,23,24,25	
24	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25	2,5,8,11,13,14,17,18,19,20,21,22,23,24,25	2,5,8,11,13,14,16,17,18,19,20,21,22,23,24,25	
25	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25	2,5,13,14,15,19,20,21,23,24,25	2,5,13,14,15,19,20,21,23,24,25	
3	1,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	1,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	1,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	II
6	1,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	1,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	1,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	
7	1,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	1,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	1,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	
8	1,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22	3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22	
9	1,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	1,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	1,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	
12	1,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	1,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	1,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	
15	1,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	1,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	1,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	
16	1,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	1,3,4,6,7,8,9,10,11,12,14,15,16,18,19,22,23	1,3,4,6,7,8,9,10,11,12,14,15,16,17,18,19,22,23	
1	4,11,14,17,18,19,22,23	23	23	III
23	1,4,10,11,14,17,18,19,22,23	1,10,11,14,17,18,19,22,23	1,10,11,14,17,18,19,22,23	
18	4,10,11,14,17,19,22	19,22	22	IV
19	4,10,11,14,17,18,19,22	4,10,11,14,17,18,19,22	4,10,11,14,17,18,19,22	
22	4,10,11,14,17,18,19,22	4,11,14,17,18,19,22	4,11,14,17,18,19,22	
4	4,10,11,14,17	4,10,11,14,17	4,10,11,14,17,	V
10	4,11,14,17	4,11,14,17	4,11,14,17	
11	4,10,11,14,17	4,10,11,14,17	4,10,11,14,17	
14	4,10,11,14,17	4,10,11,14,17	4,10,11,14,17	
17	4,10,11,14,17	4,10,11,14,17	4,10,11,14,17	

Table 10: Partitioning levels

F	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0.000	0.004	0.013	0.000	0.015	0.002	0.000	0.000	0.054	0.000	0.000	0.015	0.000	0.000	0.013	0.015	0.013	0.039	0.013	0.000	0.000	0.030	0.000	0.000	0.000
2	0.006	0.000	0.000	0.026	0.030	0.004	0.000	0.031	0.033	0.015	0.059	0.030	0.000	0.030	0.054	0.026	0.013	0.015	0.030	0.044	0.030	0.015	0.002	0.000	0.000
3	0.013	0.044	0.000	0.059	0.059	0.000	0.059	0.026	0.000	0.000	0.000	0.052	0.000	0.000	0.054	0.004	0.002	0.000	0.039	0.000	0.000	0.044	0.000	0.002	0.000
4	0.004	0.044	0.041	0.000	0.000	0.054	0.059	0.044	0.000	0.000	0.059	0.059	0.000	0.000	0.059	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
5	0.043	0.043	0.052	0.048	0.000	0.044	0.054	0.013	0.055	0.028	0.055	0.059	0.015	0.046	0.030	0.031	0.055	0.028	0.041	0.054	0.028	0.028	0.030	0.000	0.011
6	0.002	0.004	0.000	0.000	0.059	0.000	0.000	0.002	0.052	0.002	0.000	0.000	0.000	0.000	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.004	0.000	0.018
7	0.000	0.000	0.000	0.000	0.059	0.000	0.000	0.000	0.052	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.026	0.000	0.000	0.000	0.000	0.015	0.000	0.000	0.000
8	0.000	0.059	0.000	0.000	0.030	0.017	0.000	0.000	0.039	0.000	0.000	0.030	0.000	0.026	0.013	0.013	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.018	0.041	0.059	0.059	0.059	0.030	0.059	0.015	0.000	0.020	0.000	0.044	0.000	0.000	0.000	0.000	0.026	0.000	0.000	0.000	0.000	0.002	0.044	0.002	0.000
10	0.000	0.030	0.000	0.000	0.000	0.017	0.000	0.055	0.030	0.000	0.000	0.030	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.041	0.059	0.033	0.000	0.015	0.035	0.015	0.059	0.026	0.000	0.044	0.000	0.052	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009
12	0.000	0.039	0.007	0.000	0.059	0.000	0.000	0.000	0.059	0.000	0.002	0.000	0.000	0.004	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.018
13	0.002	0.041	0.052	0.037	0.015	0.015	0.059	0.030	0.052	0.059	0.015	0.044	0.000	0.044	0.043	0.059	0.030	0.030	0.059	0.059	0.059	0.030	0.030	0.002	0.026
14	0.015	0.030	0.052	0.030	0.000	0.015	0.039	0.015	0.059	0.018	0.059	0.028	0.000	0.000	0.059	0.002	0.059	0.000	0.015	0.015	0.000	0.059	0.002	0.030	0.000
15	0.000	0.030	0.002	0.000	0.059	0.013	0.000	0.000	0.013	0.000	0.000	0.044	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.002
16	0.002	0.013	0.020	0.011	0.015	0.000	0.013	0.000	0.044	0.033	0.013	0.000	0.000	0.039	0.059	0.000	0.015	0.026	0.026	0.000	0.000	0.002	0.000	0.000	0.007
17	0.015	0.000	0.055	0.028	0.000	0.000	0.000	0.000	0.015	0.002	0.059	0.000	0.000	0.059	0.026	0.013	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.004	0.000	0.022	0.013	0.000	0.000	0.007	0.000	0.030	0.002	0.015	0.000	0.000	0.059	0.000	0.000	0.059	0.000	0.059	0.000	0.013	0.059	0.015	0.000	0.011
19	0.000	0.039	0.013	0.011	0.000	0.000	0.000	0.000	0.054	0.004	0.013	0.000	0.030	0.059	0.013	0.059	0.030	0.000	0.000	0.000	0.000	0.000	0.030	0.000	0.002
20	0.059	0.044	0.000	0.041	0.000	0.044	0.059	0.000	0.055	0.059	0.033	0.059	0.052	0.000	0.033	0.046	0.000	0.000	0.000	0.000	0.059	0.000	0.000	0.059	0.028
21	0.000	0.044	0.004	0.006	0.015	0.000	0.000	0.000	0.039	0.000	0.004	0.000	0.059	0.044	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.059	0.015	0.000	0.028
22	0.000	0.044	0.026	0.018	0.000	0.004	0.026	0.000	0.054	0.015	0.059	0.015	0.000	0.028	0.015	0.026	0.000	0.000	0.059	0.000	0.000	0.000	0.002	0.002	0.002
23	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.055	0.000	0.015	0.000	0.000	0.028	0.015	0.000	0.059	0.059	0.059	0.059	0.015	0.041	0.000	0.002	0.007
24	0.000	0.044	0.000	0.004	0.059	0.000	0.059	0.000	0.044	0.000	0.000	0.059	0.059	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.059	0.000	0.044	0.000	0.059
25	0.000	0.000	0.000	0.000	0.000	0.000	0.041	0.000	0.054	0.000	0.015	0.059	0.000	0.028	0.015	0.000	0.059	0.059	0.059	0.059	0.030	0.041	0.059	0.055	0.000

Compiling the Hierarchical Structure

Partition levels are obtained from the reachability set (RS), the antecedent set (AS), and the final reachability matrix. The RS of an attribute is the set an indicators in the row with a value of '1', including the indicator itself. The US for an indicator is an indicator that is in the column with a value of '1', including the indicator itself. Thus, the intersection set IS is identified by selecting the same indicator from the US and the RS. The RS and IS attributes are the same, occupying the top position in the ISM model. The indicator that occupies the top level is then separated from that level, and the same process is continued to obtain the position of the other indicators. The iteration process is shown in Table 10.

Generating the Diagram

A diagram is drawn based on the final reachability matrix. The indicators placed above are indicators that are at level 1. Indicators that are at level 2 are below the level 1 indicators and are therefore at the next level. The Operational Performance Indicator Model is illustrated in Figure 1.

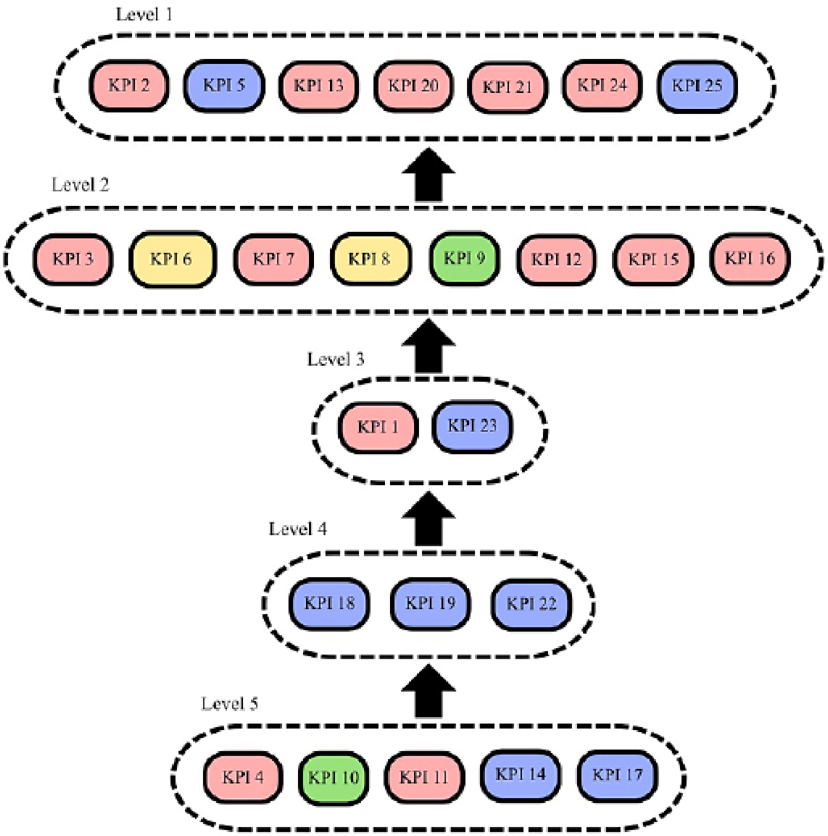

Fig. 1: Hierarchical model

Determining the Value of Driving Power and Dependence Power using the MICMAC diagram

The MICMAC diagram utilizes the X-axis (Dependence Power) and the Y-axis (Driving Power). The driving power and dependence power values of indicators were used as input to classify the indicators into four groups (Figure 2): The MICMAC diagram utilizes the X-axis (Dependence Power) and the Y-axis (Driving Power). The value-driving power and dependence power of indicators were used as input to classify the indicators into four groups (Figure 2): Autonomous (Quadrant I): Indicators characterized by both low driving power and low dependence power, indicating weak interaction with the system; Dependent (Quadrant II): Indicators with weak driving power but high dependence power, meaning they are primarily influenced by other indicators in the system; Linkage (Quadrant III): Indicators featuring both high driving power and dependence power. These are inherently unstable, as any change in these indicators can trigger feedback loops and affect the entire system; Independent (Quadrant IV): Indicators possessing high driving power but low dependence power. Often referred to as the influence group, these factors serve as the primary drivers of the system.

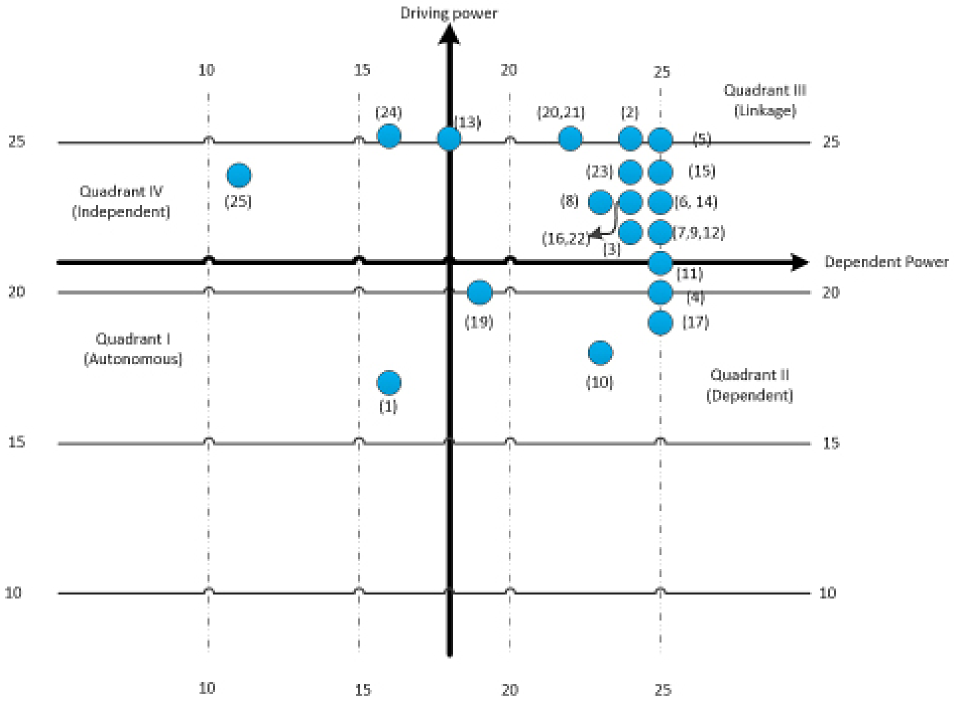

Fig. 2: MICMAC diagram

Results

At the beginning of the collection of indicators through the literature review, the indicators were categorized based on the four main operational processes in the supply chain, namely, source, make, deliver, and return. A total of 25 indicators were obtained, which were then translated into a questionnaire. This questionnaire was given to the panelists to assess the influence of the relationship between the indicators. The questionnaire responses were then analyzed based on the operational processes according to the stages in the methodology.

The model built with the ISM approach produced a relationship between the indicators in the form of a hierarchical structure with five levels. At level 5, there were five indicators: KPI 4 (Number of materials not contaminated by non-FSH substances), KPI 10 (Percentage of compliance with facility cleanliness inspection results), KPI 11 (Number of defective FSH products (WIP)), KPI 14 (Production rate), and KPI 17 (Percentage of product stock shortages). These five indicators affect the indicators above. These indicators can be said to be the root of the problem if there are problems in the company's operational performance.

At level 4, there were three indicators: KPI 18 (On-time delivery rate), KPI 19 (Percentage of accuracy in order quantity and type), and KPI 22 (Percentage of defective products). These indicators are influenced by indicators at previous levels, i.e., KPI 4 (Number of materials not contaminated by non-FSH substances), KPI 10 (Percentage of compliance with facility cleanliness inspection results), KPI 11 (Number of defective FSH products (WIP)), and

KPI 14 (Production rate and percentage of product stock shortages). For example, if the indicator KPI 4 (Number of materials not contaminated by non-FSH substances) is not managed, it will directly affect the indicators KPI 11 (Percentage of defective products) and KPI 18 (On-time delivery rate indicators).

At level 3, there are two indicators, namely KPI 1 (Sufficient employees) and KPI 23 (Number of customer complaints). Both indicators at level 3 are influenced by the indicators at two levels below them and affect the indicators that are two levels above them. If the indicator KPI 18 (On-time delivery rate) is problematic, it will affect the indicator KPI 23 (Number of customer complaints), and in addition to that, it will also affect the indicator KPI 1 (Sufficient employees) to pursue the delivery target.

Level 2 has eight indicators: KPI 3 (Sufficient raw materials), KPI 6 (Availability of sanitation), KPI 7 (Suppliers with HACCP/ISO 22000 halal certification), KPI 8 (Percentage of employee awareness (cleanliness)), KPI 9 (Percentage of compliance in product handling and animal welfare), KPI 12 (Separation of halal and non-halal facilities), KPI 15 (Compliance with storage facility specifications), KPI 16 (Number of warehouse facility inspections). Indicators at level 2 are influenced by the indicators KPI 1 (Sufficient employees) and KPI 23 (Number of customer complaints) at the previous level.

At the final level of the ISM hierarchy, the indicators are: KPI 2 (Employee knowledge evaluation), KPI 5 (Operational cost), KPI 13 (Documentation), KPI 20 (Compliance with halal labeling and clarity of composition), KPI 21 (Availability of procedures for handling defective FSH products), KPI 24 (Availability of traceability system), and KPI 25 (Customer satisfaction index (CSI)). Analysis showed that seven driving indicators accounted for over 25% at the highest position in the hierarchy, where they have the most direct impact on operational performance.

The MICMAC results (Figure 2) show that Quadrant I – *autonomous* (Sufficient employees) includes indicators with limited driving power (influence) and minimal dependency. Further, Quadrant II – *dependent* (Number of materials not contaminated by non-FSH substances, Percentage of compliance with facility cleanliness inspection results, Number of defective FSH products (WIP), Production rate, Percentage of product stock shortages) created a group of indicators with weak influence but dependency. Furthermore, Quadrant III – *interdependent or linkage* (Employee knowledge evaluation, Sufficient raw materials, Operational cost, Availability of sanitation, Suppliers with HACCP/ISO 22000 halal certification, Percentage of employee awareness (cleanliness), Percentage of compliance in product handling and animal welfare, Number of defective FSH products (WIP), Separation of halal and non-halal facilities, Documentation, Production rate, Compliance with storage facility specifications, Number of warehouse facility inspections, Percentage of accuracy in order quantity and type, Compliance with halal labeling and clarity of composition, Availability of procedures for handling defective FSH products, Percentage of defective products, Number of customer complaints) created up of indicators with strong influence. Finally, Quadrant IV – *driving or independent* (Availability of traceability system, Customer satisfaction index (CSI)) consists of elements with strong influence and weak dependency. From the MICMAC diagram, it can be seen that the operational performance indicators are spread across all four Quadrants. This means that there are indicators that have a reciprocal influence, while others function as indicators that trigger or are recipients of influence in one direction.

Discussion

This research analyzed comprehensive operational performance indicators associated with halal and food safety requirements in the food industry. The relationships between the indicators can help identify the key indicators that drive operational performance in the food industry. Indicator mapping with an activity approach to business processes (source, make, deliver, return) can make it easier to identify important indicators within each activity. From the results of the analysis process, 25 indicators were obtained that form a five-level hierarchical structure.

The study also visually presents the results using the DEMATEL-ISM-MICMAC approach to show the most dominant driving indicators in operational performance and the important relationships between these indicators. By knowing the indicators that drive operational performance, we can formulate a model for appropriate and comprehensive strategies and policies to maximize a company's performance.

Five indicators are driving factors (Level 5), KPI 4 (Number of materials not contaminated by non-FSH substances), KPI 10 (Percentage of compliance with facility cleanliness inspection results), KPI 11 (Number of defective FSH products (WIP)), KPI 14 (Production Rate), and KPI 17 (Percentage of product stock shortages). The indicator KPI 4 (Number of materials not contaminated by non-FSH substances) can be one of the root problems in operational performance. Compliance with this indicator is crucial and is the main foundation in maintaining product integrity based on halal and food safety standards[58]. Raw food materials that comply with food safety requirements must be free from chemical, physical, and biological hazards, while food that complies with halal requirements must be free from haram elements such as alcohol, pork, blood, and their derivatives[75]. A sequence of production processes will be implemented to ensure that raw materials undergo the following: if there are materials contaminated with non-FSH materials, there can be disruptions such as production downtime, increased costs due to the need to replace raw materials, and delays in the production and distribution[33], which will indirectly affect the company's performance[58].

Indicator KPI 10 (Percentage of compliance with facility cleanliness inspection results) relies significantly on cleanliness, especially in facilities along halal logistics. Hygiene inspections are part of food safety standards HACCP, ISO 22000, and FSSC 22000, in addition to satisfying the halal and food safety standards, but the implementation of hygiene must also be carried out with a deep understanding and obedience to Sharia requirements[76]. This is because failure to maintain the cleanliness of the facility can result in incompatibilities in the production process, such as cross-contamination between halal and haram ingredients, damp facilities, and pathogenic microbial growth [43]. Moreover, if there is no control of pathogenic microbes to prevent them from reaching the consumer's hands, they may cause infections[31].

Indicator KPI 11 (Number of defective FSH products (WIP)) measures the number of semi-finished products that do not comply with quality, food safety (chemical, physical, and biological), or halal standards. The impact of this important indicator affects other indicators, such as KPI 22 (Percentage of defective products) and KPI 18 (On-time delivery rate). This is due to the disruption of the production schedule due to the additional time needed for product reworking or even product destruction. According to Government Regulation BPOM No. 22 (2025), destruction must be carried out if the product contains toxic, harmful, or hazardous materials that may endanger human health or life; contains contaminants that exceed the maximum threshold; contains materials that are not permitted for use in the manufacture of food activities, or processes, and/or distribution; comprises plant or animal materials that are filthy, rotten, rancid, decomposed, or diseased, materials that come from carcasses, materials that are manufactured in a manner that is not permissible, and/or expired products.

KPI 14 (Production rate) is an indicator that measures the speed of production. It is important to maintain the production rate for smooth operation. An increase in production rate that is not offset by quality control can affect the indicator KPI 22 (Percentage of defective products), so that there is a decrease in quality. Furthermore, this may result in a rise in indicator KPI 23 (Number of customer complaints).

The next indicator is KPI 17 (Percentage of product stock shortages). This indicator measures the sufficiency of product stock against market demand. An imbalance between demand and production can lead to overproduction or a shortage of products [58]. leading to a possibility of affecting the indicators KPI 5 (Operational cost) and KPI 25 (Customer satisfaction index (CSI)).

The MICMAC diagram in Figure 2 illustrates that the indicators in the influence group are KPI 24 (Availability of traceability system) and KPI 25 (Customer satisfaction index (CSI)). These two indicators have a strong influence. Looking at the hierarchical model in Figure 1, it can be seen that both of these indicators are at level 1. At the summit of the hierarchy are the driving indicators, which means they have the greatest direct impact on operational performance. Meanwhile, the other five indicators at level 1 of the hierarchical model – KPI 2 (Evaluation of employee knowledge), KPI 5 (Operational cost), KPI 13 (Documentation), KPI 20 (Compliance with halal labeling and clarity of composition), and KPI 24 (Availability of procedures to deal with defective FSH products) – are in Quadrant III (Linkage), which means that these indicators are the main drivers but are influenced by many indicators below them. Thus, the management of these five indicators needs to be prioritized so that their mutual impact does not cause problems in the company's activities.

It's also important to see how these specific results align with other research on halal certification and food safety laws. Unlike studies that identify automated warehousing and environmentally friendly packaging as important factors for maintaining halal certification based on big data, this study highlights facility cleanliness (KPI 10) and traceability (KPI 24) as crucial components. The DEMATEL-ISM-MICMAC framework, on the other hand, demonstrates a more complex causal relationship between indicators. This method differs from text-based big data capture. This methodological difference highlights the importance of defining interdependencies and explains why indicators such as raw material integrity (KPI 4) are considered a key driver.

Conclusion

This study found that there are 25 indicators that can reflect operational performance and can be integrated into halal and food safety certification, which answers RQ1. Eight indicators are related to operations in general, two indicators reflect food safety aspects, two indicators reflect halal aspects, and fourteen indicators reflect combined halal and food safety aspects. These indicators are spread out over general operations, food safety, halal, and both halal and food safety. From the mapping of these indicators, it can be concluded that the halal and food safety aspects are closely related. The study also answers RQ2 by using the DEMATEL-ISM-MICMAC method to map out causal relationships between indicators and find important points of connection. The results emphasize the importance of two strong driver indicators (Traceability systems and Customer satisfaction) and five connecting indicators (Evaluation of employee knowledge, Operational costs, Documentation, Halal labeling compliance, and Defective product handling procedures), which serve as critical nodes in business processes. Managers must conduct targeted audits and verifications before products reach the market to prevent consumer dissatisfaction and regulatory violations. By embedding these linkage indicators into dashboards and internal audits, managers can anticipate how changes in one area might impact others and intervene early to stabilize operations. In this way, linkage indicators become proactive tools for maintaining halal integrity, ensuring food safety compliance, and maintaining consumer trust, rather than passive measures that only reveal problems after they occur. Organizations can improve the effectiveness of halal food production, minimize risks, and enhance resilience by incorporating these indicators into operational strategies. Future research should focus on developing tailored strategies for each critical indicator in a specific business process, thereby enabling companies to improve their operational performance and competitiveness in the global halal market.

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Conflict of Interest

The author(s) do not have any conflict of interest.

Data Availability Statement

The manuscript incorporates all datasets produced or examined throughout this research study.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Clinical Trial Registration

This research does not involve any clinical trials.

Permission to reproduce material from other sources
Not Applicable

Author Contributions

- **Melati Kurniawati:** Conceptualization, Writing-Original Draft, Introduction, Literature Review, Method, Data Collection, Analysis
- **Patdono Suwignjo**: Introduction, Supervision, Corresponding Author
- **Iwan Vanany**: Conceptualization, Method, Analysis, Supervision
- **Bambang Syairudin:** Analysis, Conclusion, Supervision

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