



# Investigating the role of stakeholder engagement for more resilient vaccine supply chains during COVID-19

Yigit Kazancoglu<sup>1</sup> · Muruvvet Deniz Sezer<sup>2</sup> · Melisa Ozbiltekin-Pala<sup>1</sup> · Murat Kucukvar<sup>3</sup>

Received: 28 May 2021 / Revised: 14 September 2021 / Accepted: 13 October 2021 / Published online: 26 April 2022  
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## Abstract

The complexity of the supply chains and the uncertainties in the processes cause business to become more vulnerable in the face of disruptions. Pandemic situations such as COVID-19 cause sudden disruptions in supply chains, causing processes to be disrupted. Especially in multi-stakeholder supply chains, the importance of stakeholder communication, motivation, and regulations i.e. comes to the forefront in order to ensure the resilience of supply chains. As learned with the COVID-19 pandemic, vaccine supply chains are also one of the multi-stakeholder supply chains and are extremely vulnerable to disruptions. In COVID-19 times, the importance of vaccine supply chain management and the resilience in vaccine supply chains increased. To have more resilient vaccine supply chains, stakeholder engagement is an essential issue. Therefore, the Graph Theory Matrix Approach has been used to determine factors of stakeholder engagement in multi-stakeholder vaccine supply chains and to specify the relationships between the factors of project and stakeholder engagement in vaccine supply chains to increase resilience in disruption times. The aim of the study is to identify the factors of project and stakeholder engagement that are necessary to ensure the resilience of multi-stakeholder vaccine supply chains and not be affected by disruptions such as COVID-19 as it is today. As a result of the study, innovativeness of stakeholders is the most important factor of stakeholder engagement in vaccine supply chains.

**Keywords** Vaccine Supply Chain · Stakeholder Engagement · Resilience · COVID-19

## 1 Introduction

Supply chains are increasingly global structures that have complexity in their operations (Van Hoek 2020; Karmaker et al. 2021). The complex structures of supply chains cause supply chains to be vulnerable in the face of disruptions

(Jabbour, et al. 2020; Alam et al. 2021). The COVID-19 pandemic, which emerged unexpectedly in March 2020 and still continues today, affects almost every sector and the supply chain structures of sectors (Frederico 2021; Margherita et al. 2021). Especially, due to the outbreak that started in China and China's position in production, supply chain interruptions are experienced in other countries of the world before the symptoms of the disease are seen (Sarkis et al. 2020; Yu et al. 2021).

Moreover, with many regulations taken to stop the COVID-19 pandemic, such as sudden decisions, closing the transportation between countries, many sectors have faced challenges (Queiroz et al. 2020; Ali et al. 2021). In other words, COVID-19 creates a ripple effect in supply chains (Ivanov & Dolgui 2021; Farooq et al. 2021), causing the supplier business to be unable to sell products with the closure of a factory, and the customer to be unable to supply input, causing disruption in the entire supply chain (Sharma et al. 2020). Generally, traditional supply chain approach aims to minimize costs, reduce stocks and increase asset utilization in supply chains (Crum et al. 2011), and this

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✉ Yigit Kazancoglu  
yigit.kazancoglu@yasar.edu.tr

Muruvvet Deniz Sezer  
deniz.sezer@yasar.edu.tr

Melisa Ozbiltekin-Pala  
melisa.ozbiltekin@yasar.edu.tr

Murat Kucukvar  
mkucukvar@qu.edu.qa

<sup>1</sup> Department of Logistics Management, Yasar University, 35100 Izmir, Turkey

<sup>2</sup> Business Administration Department, Yasar University, 35100 Izmir, Turkey

<sup>3</sup> College of Engineering, Qatar University, Mechanical and Industrial Engineering, Doha, Qatar

focusing on supply chain optimization reduces the resilience of supply chains by eliminating flexibility to meet delays and disruptions (Macdonald and Corsi 2013; Golan et al. 2021). With this perspective, for industries, the COVID-19 pandemic causes many businesses to suffer great damage in their supply chains against global disruptions (Bai and Kumar 2020; Choi 2021). Therefore, with this pandemic, the issue of ensuring the resilience of supply chains comes to the fore (Pettit et al. 2019; Chowdhury et al. 2021).

With another point of view, project and stakeholder engagement in the supply chain comes into prominence, especially in vaccine supply chains (Lemmens et al. 2016). Recently, the resilience of vaccine supply chains is based on effective stakeholder engagement in supply chains (Golan et al. 2020). Especially in multi-stakeholder supply chains such as vaccine supply chains (Lemmens et al. 2016), the necessity of reorganizing operations such as planning and controlling processes in order to ensure the sustainability of supply chains is at the forefront (Shanker et al. 2021).

One of the issues that increase its importance the most with the pandemic is the vaccine supply chain (Castillo et al. 2021). The vaccine supply chain has a very perishable structure due to its cold chain focus (Rastegar et al. 2021). With the COVID-19 pandemic, the importance of effective use of vaccine supply chain management and increasing the resilience in vaccine supply chains in order to deliver vaccines to those in need effectively (Dai et al. 2021; Sinha et al. 2021).

Therefore, it is essential to integrate all stakeholders into the process from the beginning of the vaccine supply chains and to know every stage in the process increases the resilience of the vaccine supply chains and ensures that they are sustainable against disruptions, such as COVID-19 pandemic (Castillo et al. 2021). Hence, it is essential to determine the factors of stakeholder engagement in vaccine supply chains to increase resilience against disruptions (Pettit et al. 2019). The motivation of this study is determining factors of stakeholder engagement in vaccine supply chains and specifying their relations between each other to have resilient vaccine supply chains against disruptions such as COVID-19. As a result, the research question of the study can be summarized as;

- RQ1: What are the factors of stakeholder engagement in vaccine supply chains?
- RQ2: What is the importance of factors of stakeholder engagement in vaccine supply chains?

These research questions are aimed to determining the factors of stakeholder engagement in vaccine supply chains and analysing the relationships between the factors of stakeholder engagement in vaccine supply chains. For this purpose, to achieve these research questions, after determining factors

of stakeholder engagement in vaccine supply chains with the help of literature review and by using graph theory method, relationships between the factors of stakeholder engagement in vaccine supply chains are analysed.

To find answers to these questions, a detailed literature review about resilience of supply chains and stakeholder engagement in supply chains are conducted. In the literature review, factors of stakeholder engagement are determined. After literature review, graph theory matrix approach is implemented to find relationships between the factors of stakeholder engagement in vaccine supply chains.

This study aims to identify the factors of project and stakeholder engagement that are necessary to ensure the resilience of multi-stakeholder vaccine supply chains and not be affected by disruptions such as COVID-19 as it is today. As will be mentioned later, when the literature is examined, it has been seen that the most critical of these factors are identified and specifying the relationships between the factors of project and stakeholder engagement in vaccine supply chains to increase resilience in disruption times as a research gap and uniqueness of the study.

As a summary, the main contribution of the study is to determine factors of project and stakeholder engagement in multi-stakeholder vaccine supply chains and the second contribution is specifying the relationships between the factors of project and stakeholder engagement in vaccine supply chains to increase resilience in disruption times. Moreover, as a contribution, it is crucial to understand these factors and to highlight these relationships between each other to find permanent solutions to increase resilience in multi-stakeholder vaccine supply chains. It is aim to find permanent solutions to cope with sudden disruption by increasing resilience in multi-stakeholder vaccine supply chains by using graph theory matrix approach.

The remainder of the paper is structured as follows. Section 2 covers stakeholder engagement in vaccine supply chains and determining factor of stakeholder engagement in vaccine supply chains. Section 3 consist of methodology of the study and Sect. 4 covers implementation and results. Section 5 highlights the discussions and implications. Section 6 concludes of the study.

In the following section, stakeholder engagement in vaccine supply chains are explained in details.

## 2 Stakeholder engagement in vaccine supply chains

Stakeholders are defined as individuals or groups that directly affect or are affected by supply chain performance in a supply chain structure (Hussain et al. 2019). In other words, stakeholders in the supply chain are a broader and more complete group, from suppliers of materials and

services to delivery and logistics, and customers and consumers (Masfield et al. 2021). Increasingly complex supply chain processes are transforming into a multi-stakeholder structure (Qiuchen et al. 2021). One of the most important in multi-stakeholder supply chains is ensuring the resilience of supply chains against disruptions (Kar et al. 2021). Providing stakeholder engagement in supply chains ensures the elimination of risks in the supply chain process, the development of operations, the emergence of new business models, new actors, and the continuation of interposes communication (Pettit et al. 2019). With the effective stakeholder engagement, supply chains are being more resilient against sudden disruptions (Golan et al. 2020).

Moreover, considering the spreading rate of COVID-19, it becomes very important to deliver vaccines to the most points at the maximum usable speed (Barbieri et al. 2020). Therefore, the most important point is accurate planning and stakeholder engagement (Marrucci et al. 2021). Stakeholders are expected to be involved in the process in harmony and in an integrated manner for an effective project management especially in vaccine supply chains because of its vulnerable structure (Jarrett et al. 2020).

As mentioned before, it is more difficult to ensure the resilience of supply chains in multi-stakeholder supply chains. Due to its vaccine supply chain structure, it consists of a multi-stakeholder supply chain (Castillo et al. 2021). The vaccine supply chain consists of many processes in its supply chains such as development of vaccine, allocation process, validation and certification, distribution, monitoring process, dose tracking, cold chain management process, inventory management, storage i.e. (Rastegar et al. 2021). Therefore, the stakeholders of vaccine supply chain include providers, manufacturers, distributors and governments as shown in Fig. 1. (Schlosser 2021).

To have effective stakeholder engagement in vaccine supply chains, firms should make strategic stakeholder analysis, determine stakeholder characteristics, make capability analysis, develop action plans for their operations (Van Ostrand et al. October 26, 2020). However, having effective stakeholder engagement in multi-stakeholder structure is rough in complex and uncertain supply chains (Liang et al. 2021). In this point, it is essential to have effective communication and coordination between stakeholders (Yan et al. 2020), commitment of stakeholders on projects, high level training and knowledge of stakeholders, being resistant to changes in conditions, risk management capabilities i.e. (Golan et al. 2020). Therefore, determining of these factors that affects stakeholder engagement in vaccine supply chains in the context of project management is crucial to have more resilient vaccine supply chains against disruptions.

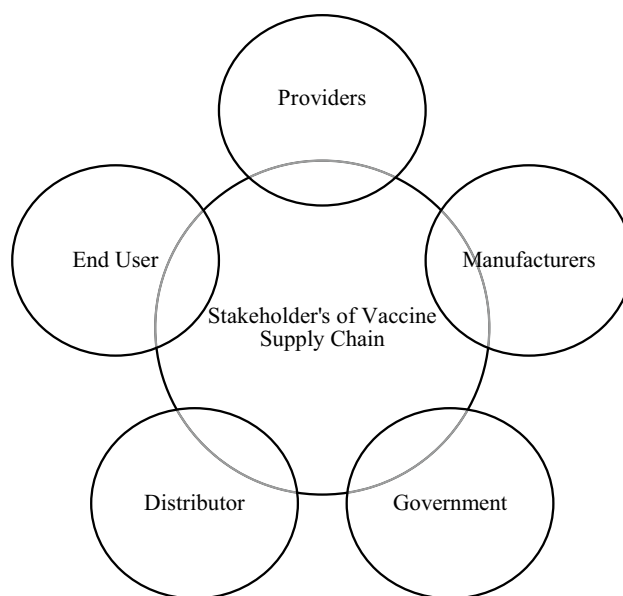


Fig. 1 Stakeholders in vaccine supply chain

In the following section, determined factors that affects stakeholder engagement in vaccine supply chains are explained in details.

## 2.1 Determining factors of stakeholder engagement in vaccine supply chains

As mentioned before, vaccine supply chains have multi-stakeholder structure. Therefore, it is essential to be aware of affecting factors of stakeholder engagement and being successful in project management processes (Golan et al. 2020). Hence, by considering literature review, stakeholder engagement factors in vaccine supply chains are determined as follows (Table 1).

The explanations of these factors are given as follows;

*Stakeholder's Motivation and Loyalty ( $F_1$ ):* In order for a supply chain to be resilient to disruptions, to be able to act on time and to be successful in terms of project management, every stakeholder in the supply chain must be motivated (Chandra and Kumar 2021). Since the vaccine supply chain consists of a structure that must run flawlessly, the motivation of the stakeholders and their commitment to the project are extremely important in order to increase the resilience of the supply chain (Hussain et al. 2019).

*Knowledge and Experience of Stakeholders ( $F_2$ ):* The fact that the stakeholders in the supply chain have knowledge and experience in process and operational meaning affects the durability of supply chains in the face of sudden disruptions (De Boeck et al. 2019). Knowledge and experience at every stage of the vaccine supply chain ensure that the process runs effectively (Chandra and Kumar 2021). As

**Table 1** Factors of Stakeholder Engagement in Vaccine Supply Chains

Factors	Author(s)
Stakeholder's Motivation and Loyalty (F1)	(Hussain et al. 2019; Chandra and Kumar 2021)
Knowledge and Experience of Stakeholders (F2)	(De Boeck et al. 2019; Chandra and Kumar 2021)
Transparency of Stakeholders (F3)	(Antal et al. 2021; Baah et al. 2021; Labaran and Hamma-Adama 2021)
Risk Management Capabilities of Stakeholders (F4)	(Sudarmin and Ardi 2020; Yong et al. 2020)
Being Resistant to Changes in Conditions (F5)	(Hussain et al. 2019; Burgos et al. 2021)
Management Policies and Regulations for Vaccine Supply Chain (F6)	(Chandra and Kumar 2021; Dai et al. 2021)
Communication and Coordination Between Stakeholders (F7)	(Jarrett et al. 2020; Golan et al. 2020)
Innovativeness of Stakeholders (F8)	(Golan et al. 2021; Okafor et al. 2021)

mentioned before, every process of the supply chain must be managed very well, and effective supply chain management also depends on the knowledge and experience of the stakeholders (De Boeck et al. 2019). Having information in every process enables fast actions to be taken in the face of problems that may arise.

*Transparency of Stakeholders (F<sub>3</sub>):* Supply chain transparency is defined as the degree to which supply chain members can access information on product, process and capital flow without any deterioration, loss or delay (Baah et al. 2021). Stakeholder transparency ensures rapid access to information and permanent and rapid solutions to any sudden disruptions that may occur (Antal et al. 2021). Especially in vaccine supply chains, as seen with COVID-19, operational excellence can be achieved in supply chains with the transparency of stakeholders (Labaran and Hamma-Adama 2021).

*Risk Management Capabilities of Stakeholders (F<sub>4</sub>):* The increasing complexity of supply chains or sudden disruptions increase the risks arising from the supply chain (Jabbour et al. 2020). Although most of the risks that arise in the supply chain are caused by sudden disruptions, problems such as stakeholder's risk management capabilities cause risks on the resilience and sustainability of the supply chain (Sarkis 2020; Sudarmin and Ardi 2020). The risk management capabilities of stakeholders become an important factor in vaccine supply chain operations, which are becoming more important especially in pandemic conditions such as COVID-19 (Yong et al. 2020).

*Being Resistant to Changes in Conditions (F<sub>5</sub>):* The flexibility of supply chains against sudden disruptions and changes depends on the resilience of stakeholders in the supply chain against changes (Baba et al. 2021). As learned especially with COVID-19, resilience to changes such as the increasing importance of the vaccine supply chain, increasing demands (Chandra and Kumar 2021) and complexity of supply chain processes depends on the ability of stakeholders to show the same resistance among themselves (Hussain et al. 2019).

*Management Policies and Regulations for Vaccine Supply Chain (F<sub>6</sub>):* Especially in pandemics such as COVID-19, it is one of the most important factors to deliver vaccines to the most points at maximum speed (Chandra and Kumar 2021). The error-free planning required for this should be done with management policies and regulations (Dai et al. 2021). Management policies and regulations to be made for stakeholders in vaccine supply chains ensure that the process runs fast and effectively (Chandra and Kumar 2021).

*Communication and Coordination Between Stakeholders (F<sub>7</sub>):* Communication and coordination between stakeholders is extremely important in terms of sustainability and resilience of the processes in supply chains and minimizing operational errors (Li and Chen 2019; Jarrett et al. 2020). Especially in vaccine supply chains, which consist of a vulnerable supply chain structure and where every process should be integrated with each other, communication and cooperation between stakeholders should be close to flawless (Golan et al. 2020; Irfan et al. 2021).

*Innovativeness of Stakeholders (F<sub>8</sub>):* Keeping pace with the changing conditions of supply chains and sustaining resilience against sudden disruptions depends on the innovativeness of the stakeholders in the supply chain (Okafor et al. 2021). Stakeholder innovation facilitates adaptation to new processes and applications and increases the resilience of the supply chain (Golan et al. 2020).

Through the literature review and expert opinions, 8 different stakeholder engagement factors are determined in the vaccine supply chains. This study aims to analyse the relations between these factors and to determine the priorities of the factors. The research methodology is described in the next section.

### 3 Methodology

This study aims to analyse factors of stakeholder engagement in multi-stakeholder vaccine supply chains. Vaccine supply chains has multiple stakeholders due to their

complexity and these stakeholders play a crucial role to manage vaccine supply chain efficiently. Thus, investigating relations factors that affected stakeholder's engagement become important to uncover relations. Through semi structured interview, the eight different factors are identified which are Stakeholder's Motivation and Loyalty, Knowledge and Experience of Stakeholders, Transparency of Stakeholders, Risk Management Capabilities of Stakeholders, Being Resistant to Changes in Conditions, Management Policies and Regulations for Vaccine Supply Chain, Communication and Coordination Between Stakeholders, Innovativeness of Stakeholders. In order to investigate orders of importance for proposed factors, The Graph Theory Matrix Approach are used. Thus, The Graph Theory Matrix Approach are discussed as a research methodology in this study.

The graph theory matrix approach includes three stages which are developing digraph, constructing matrix, and calculating permanent function for each factor to rank them (Kumar et al. 2017).

Graph theory is a graphical representation developed to describe the relationships between proposed factors (Gupta and Singh 2020). In this respect, graph theory provides various advantages by analysing system and presenting pair-wise comparisons between factors to investigate relationships of them. It is useful to determine factors effecting system by decreasing complexity with the matrix representations. Besides, each factor and their relations can be investigated by using digraphs. It is important to see the importance of the factors in order to focus on which factors and to see which ones need improvement to improve the system (Rabbani et al. 2019). With this approach, complex systems can be analysed rapidly, and the relationships between factors affecting the system can be easily revealed. In addition to graphic representation, the relationships revealed by matrix representation can also be investigated (Attri et al. 2020). In the first step, the digraph is used to reveal the relationships of multiple factors in relation to each other (Virmani et al. 2021). A digraph that visually presents the system is advantageous for presenting the model and relationships (Luqman et al. 2021). In the second step, the matrix representation is developed to analyse the graphic representation (Mangla et al. 2019). In the last step, the permanent function determines the importance levels of the factors.

Digraph is showed as a set of finite oriented edges or arcs which are sorted pairs of vertices with a finite set of factors called vertices. Factors and interrelations of them are indicated using nodes and edges. Geetha and Sekar (2016) stated that, a node  $i$  has a relative importance on other node  $j$ , an arrow is drawn from node  $i$  to  $j$  ( $d_{ij}$ ), whereas node  $j$  has a relative importance on  $i$ , then a directed edge is drawn from node  $j$  to  $i$  ( $d_{ji}$ ). Thus, direction of edge is from  $i$  to  $j$ , the factor  $x$  has relative importance than  $y$  and is indicated by  $d_{xy}$ , on the other hand, direction

of edge is from  $j$  to  $i$ , it shows that  $y$  has relative importance than  $x$  and is shown by  $d_{yx}$  (Rao 2007).

The complexity of the digraph is reduced with matrix representation. Matrix representation is performed by considering the relationships between the factors (Darvish et al. 2009). Relative importance is shown between the main factors in diagonal elements called  $R_i$ , on the other hand, in non-diagonal elements called  $a_{ij}$  (Mangla et al. 2019). The matrix is developed as shown in Eq. 1.

$$A = \begin{bmatrix} X_1 & \dots & x_{1m} \\ \vdots & \ddots & \vdots \\ x_{m1} & \dots & X_m \end{bmatrix} \quad (1)$$

Relative importance between factors  $r_i, j$  can be assigned between 0 and 1 through scales as showed in Table 2 (Geetha and Sekar 2016; Rabbani et al. 2019).

Stage 3 includes developing the permanent function of a matrix. It is a function that involves combinatorial computing by Eq. 2. The permanent of a  $n \times n$  matrix  $A$  can be shown below.

$$Perm(A) = \sum_{\sigma} \prod_{i=1}^n \sigma_{i,\sigma(i)} \quad (2)$$

where  $\sigma$  is a permutation over  $\{1, 2, 3, \dots, n\}$ .

The flowchart of methodology is proposed in Fig. 1.

## 4 Implementation and results

The Graph Theory and Matrix Approach is used to investigate the factors of permanent index of stakeholder engagement in vaccine supply chains and to rank of factors. The eight factors of stakeholder engagement in multi-stakeholder vaccine supply chains are used as factors in this study. Table 3 indicate these factors.

Factors of stakeholder engagement in multi-stakeholder vaccine supply chains and pairwise comparisons between them are determined by experts from stakeholders of supply chain who are Procurement and Supply Chain Consultant, Research and Development Director, Supply Chain Management Specialist, Manufacturing Professional, Total

**Table 2** Relative importance of factors

Classification	$a_{ij}$	$a_{ji} = 1/a_{ij}$
Two factors are equally important	0.5	2.000
One factor is important than other	0.6	1.667
One factor is more important than other	0.7	1.429
One factor is quite important than other	0.8	1.250
One factor is extreme important than other	0.9	1.111
One factor is the primary importance	1.0	1.000

**Table 3** Factors of stakeholder engagement in vaccine supply chains

<i>Abbreviation</i>	<i>Factors</i>
F1	<i>Stakeholder's Motivation and Loyalty</i>
F2	<i>Knowledge and Experience of Stakeholders</i>
F3	<i>Transparency of Stakeholders</i>
F4	<i>Risk Management Capabilities of Stakeholders</i>
F5	<i>Being Resistant to Changes in Conditions</i>
F6	<i>Management Policies and Regulations for Vaccine Supply Chain</i>
F7	<i>Communication and Coordination Between Stakeholders</i>
F8	<i>Innovativeness of Stakeholders</i>

Quality Manager, Distribution Manager, Senior Information Technology Manager, Risk Analyst. They have different years of experience, the details of which are shown in Table 4.

Based on the factors discussed in Table 3, the diagram of the algorithm in Fig. 2 are developed. The graph indicates interrelations between factors of stakeholder engagement in multi-stakeholder vaccine supply chains. Each factor has interrelations with each other as indicated Fig. 2.

Data were collected from eight different experts by using semi structured interviews. In terms of pairwise comparisons, the factors among the factors for each enabler were weighted by the experts using a 0–1 scale and permanent levels for each factor are determined by expert using 0–5 value. The data collected based on the level of factors of stakeholder engagement in vaccine supply chains are shown in Table 5, and weights of each factor are collected from the expert opinions shown in Table 6.

The matrix representation was developed using the values in Tables 5 and 6, with eight factors for stakeholder engagement in the vaccine supply chain. Expert opinions for each factor are indicated in the diagonal values of the matrix. Other matrix values were created using pairwise comparison values obtained from expert opinions. Relationships between factors were developed using the digraph in Fig. 3. Table 7 shows the matrix developed for the “*Stakeholder's*

*Motivation and Loyalty*” factor for each expert opinions. The same process is conducted for each factor that discuss in Table 3.

The developed matrix was used to calculate the permanent value of each factor, and this value was calculated by Eq. 1. The matrix representations are developed to calculate permanent index for each factor and to rank factors. Developed matrix is solved through Eq. 1 to calculate each permanent function. Index for each factor are obtained in a similar way.

The rank and importance factors for stakeholder engagement in the vaccine supply chain is showed in Table 8.

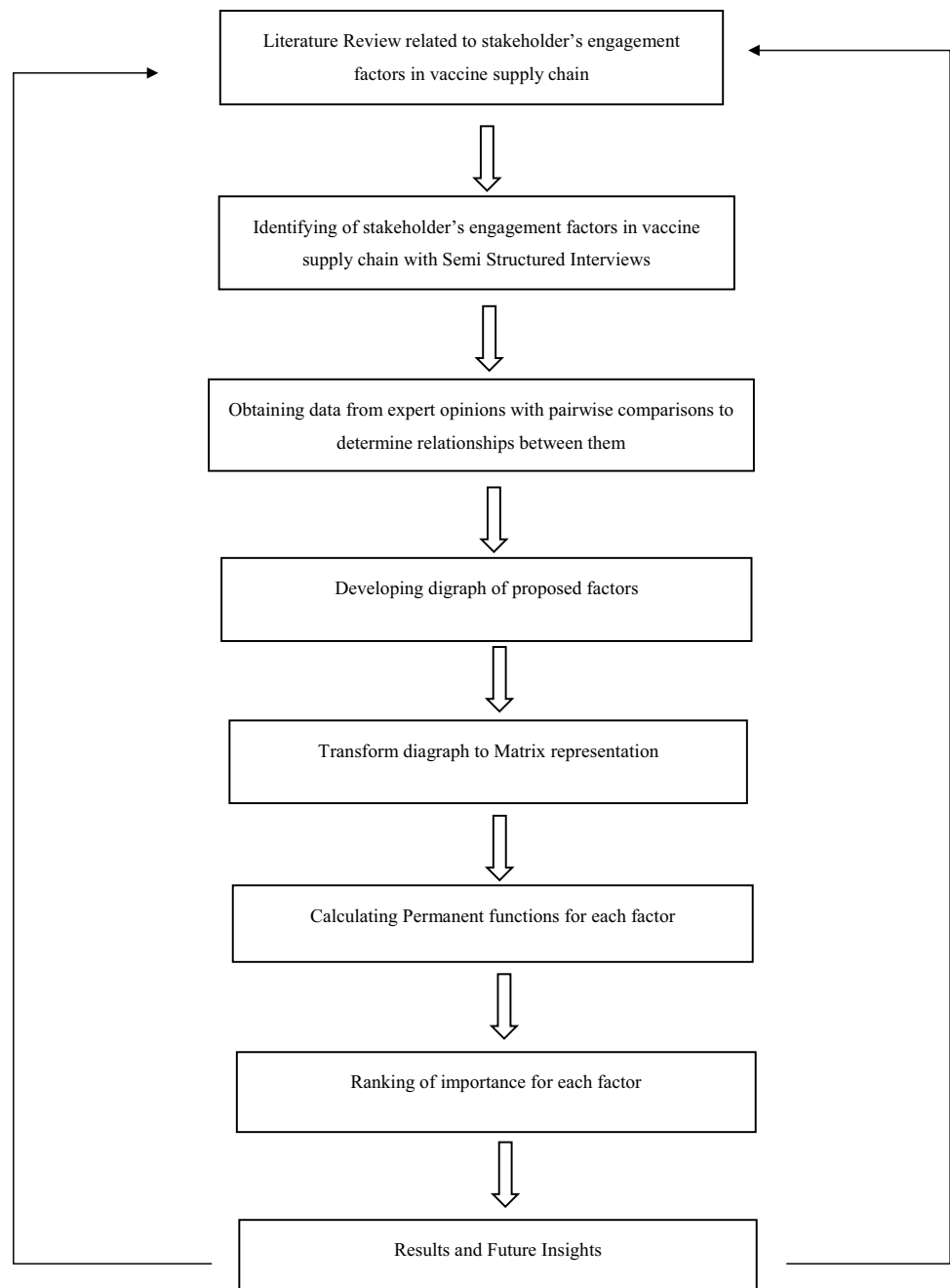
The stakeholder engagement factors in the vaccine supply chain is calculated using Eq. 1 and these factors rank by ascending order to assess the permanent index and prioritize them. The results indicate that, it is the most important factor has been found as an “*Innovativeness of Stakeholders (F8)*”. Two other important factors are “*Risk Management Capabilities of Stakeholders (F4)*” and “*Knowledge and Experience of Stakeholders (F2)*”, respectively. Ranked fourth and fifth are “*Transparency of Stakeholders (F3)*” and “*Management Policies and Regulations for Vaccine Supply Chain (F6)*”. Other enablers are determined as a “*Communication and Coordination Between Stakeholders (F7)*”, “*Stakeholder's Motivation and Loyalty (F1)*” and “*Being Resistant to Changes in Conditions (F5)*”, respectively. Investigating the main factors of project and stakeholder engagement that are necessary to ensure the resilience of multi-stakeholder vaccine supply chains. In multi-stakeholder vaccine supply chains; determining the most important factors that are effective for efficient and sustainable project management and the actions and policies to be taken to achieve these factors is required.

## 5 Discussion and implications

Increasingly complex and uncertain supply chains become vulnerable to sudden disruptions and it threatens to resilience of supply chains. The globalization of supply chains causes complexity of operations, which makes control in

**Table 4** Details of experts

<b>Experts</b>	<b>Position</b>	<b>Years of Experience</b>
1	Procurement and Supply Chain Consultant	10
2	Research and Development Director	9
3	Supply Chain Management Specialist	7
4	Manufacturing Professional	6
5	Total Quality Manager	4
6	Distribution Manager	12
7	Senior Information Technology Manager	7
8	Risk Analyst	14

**Fig. 2** Flowchart of research methodology**Table 5** Pairwise comparisons factors of stakeholder engagement in vaccine supply chains for expert 1

Expert 1	<i>F1</i>	<i>F2</i>	<i>F3</i>	<i>F4</i>	<i>F5</i>	<i>F6</i>	<i>F7</i>	<i>F8</i>
<i>F1</i>	1	0,7	0,9	0,5	0,8	0,5	0,9	0,6
<i>F2</i>	1,429	1	0,7	0,6	0,9	1	0,6	0,5
<i>F3</i>	1,111	1,429	1	0,9	0,6	0,7	0,7	0,9
<i>F4</i>	2,000	1,667	1,111	1	0,9	0,5	0,8	0,7
<i>F5</i>	1,250	1,111	1,667	1,111	1	0,5	0,6	0,9
<i>F6</i>	2,000	1,000	1,429	2,000	2,000	1	0,5	0,6
<i>F7</i>	1,111	1,667	1,429	1,250	1,667	2	1	0,8
<i>F8</i>	1,667	2,000	1,111	1,429	1,111	1,667	1,250	1

**Table 6** The permanent levels for each factors of stakeholder engagement obtained from each expert

	<i>F1</i>	<i>F2</i>	<i>F3</i>	<i>F4</i>	<i>F5</i>	<i>F6</i>	<i>F7</i>	<i>F8</i>
<b>Expert 1</b>	4	5	4	5	3	4	2	5
<b>Expert 2</b>	4	3	5	4	5	4	5	2
<b>Expert 3</b>	5	4	4	3	3	5	3	4
<b>Expert 4</b>	5	4	3	4	5	4	5	2
<b>Expert 5</b>	5	4	5	2	4	3	4	4
<b>Expert 6</b>	5	3	5	4	5	4	3	2
<b>Expert 7</b>	4	4	3	5	5	4	5	4
<b>Expert 8</b>	4	4	4	3	5	5	4	2

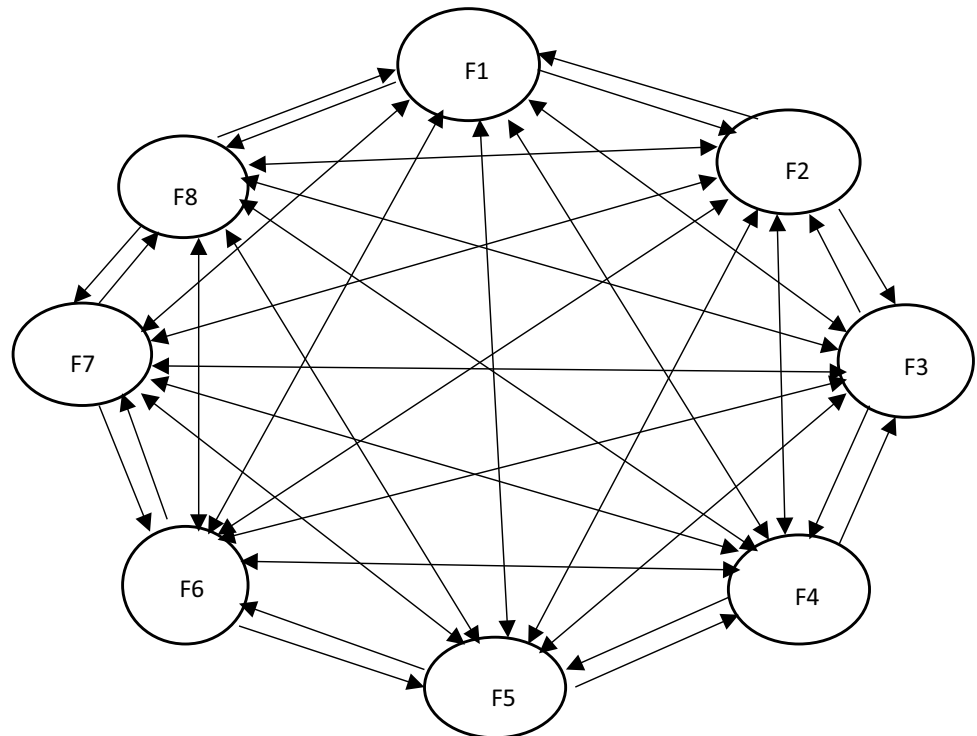
supply chains difficult (Jabbour et al. 2020). With the current pandemic situation, COVID-19, the importance of the vulnerable nature of supply chains has become more critical (Sarkis et al. 2020). Especially in multi-stakeholder supply chains, such as vaccine supply chains, it is extremely important that stakeholders act together for the control of operations, effective project management and sustainability (Pettit et al. 2019).

With the COVID-19 pandemic, the importance of the vaccine supply chain has increased enormously. Sudden increases in demand and complexity of processes affect the effectiveness and sustainability of operations (Schlosser 2021). Multi-stakeholder vaccine supply chains have many processes to be controlled to have effective project management and cover more than one stakeholder (Rastegar et al. 2021). Furthermore, multi-stakeholder vaccine supply chains need integrated stakeholder engagement. Therefore,

it is essential to determine factors stakeholder engagement in vaccine supply chains to have more resilient and sustainable supply chains.

According to results of the study, similar with Okafor et al. (2021), innovativeness of stakeholders are the most important factors in stakeholder engagement in vaccine supply chains. Especially in pandemic conditions, being innovative and ready for sudden changes in vaccine supply chains are vital for continuity of project management to have resilient supply chains. Xie et al. (2021) state that it is needed to promote the production and innovation of vaccine product and to increase their social benefits. Besides, stakeholders should support by incentives to improve R&D innovations and the societal benefits of the process (Xie et al. 2021). Moreover, similar with Yong et al. (2020) risk management capabilities of stakeholders are determined as the second important factor of stakeholder engagement in vaccine

**Fig. 3** The diagram of the factors of stakeholder engagement in vaccine supply chains





**Table 7** Values for calculating permanent index of “Stakeholder’s Motivation and Loyalty” considering experts opinions

	<i>F1</i>	<i>F2</i>	<i>F3</i>	<i>F4</i>	<i>F5</i>	<i>F6</i>	<i>F7</i>	<i>F8</i>		<i>F1</i>	<i>F2</i>	<i>F3</i>	<i>F4</i>	<i>F5</i>	<i>F6</i>	<i>F7</i>	<i>F8</i>
<i>F1</i>	0	0,7	0,9	0,5	0,8	0,5	0,9	0,6	<i>F1</i>	4	0,7	0,9	0,5	0,8	0,5	0,9	0,6
<i>F2</i>	1,429	5	0,7	0,6	0,9	1	0,6	0,5	<i>F2</i>	1,429	5	0,7	0,6	0,9	1	0,6	0,5
<i>F3</i>	1,111	1,429	4	0,9	0,6	0,7	0,7	0,9	<i>F3</i>	1,111	1,429	4	0,9	0,6	0,7	0,7	0,9
<i>F4</i>	2,000	1,667	1,111	5	0,9	0,5	0,8	0,7	<i>F4</i>	2,000	1,667	1,111	5	0,9	0,5	0,8	0,7
<i>F5</i>	1,250	1,111	1,667	1,111	3	0,5	0,6	0,9	<i>F5</i>	1,250	1,111	1,667	1,111	0	0,5	0,6	0,9
<i>F6</i>	2,000	1,000	1,429	2,000	2,000	4	0,5	0,6	<i>F6</i>	2,000	1,000	1,429	2,000	2,000	4	0,5	0,6
<i>F7</i>	1,111	1,667	1,429	1,250	1,667	2	2	0,8	<i>F7</i>	1,111	1,667	1,429	1,250	1,667	2	2	0,8
<i>F8</i>	1,667	2,000	1,111	1,429	1,111	1,667	1,250	5	<i>F8</i>	1,667	2,000	1,111	1,429	1,111	1,667	1,250	5
	<i>F1</i>	<i>F2</i>	<i>F3</i>	<i>F4</i>	<i>F5</i>	<i>F6</i>	<i>F7</i>	<i>F8</i>		<i>F1</i>	<i>F2</i>	<i>F3</i>	<i>F4</i>	<i>F5</i>	<i>F6</i>	<i>F7</i>	<i>F8</i>
<i>F1</i>	4	0,7	0,9	0,5	0,8	0,5	0,9	0,6	<i>F1</i>	4	0,7	0,9	0,5	0,8	0,5	0,9	0,6
<i>F2</i>	1,429	0	0,7	0,6	0,9	1	0,6	0,5	<i>F2</i>	1,429	5	0,7	0,6	0,9	1	0,6	0,5
<i>F3</i>	1,111	1,429	4	0,9	0,6	0,7	0,7	0,9	<i>F3</i>	1,111	1,429	4	0,9	0,6	0,7	0,7	0,9
<i>F4</i>	2,000	1,667	1,111	5	0,9	0,5	0,8	0,7	<i>F4</i>	2,000	1,667	1,111	5	0,9	0,5	0,8	0,7
<i>F5</i>	1,250	1,111	1,667	1,111	3	0,5	0,6	0,9	<i>F5</i>	1,250	1,111	1,667	1,111	3	0,5	0,6	0,9
<i>F6</i>	2,000	1,000	1,429	2,000	2,000	4	0,5	0,6	<i>F6</i>	2,000	1,000	1,429	2,000	2,000	0	0,5	0,6
<i>F7</i>	1,111	1,667	1,429	1,250	1,667	2	2	0,8	<i>F7</i>	1,111	1,667	1,429	1,250	1,667	2	2	0,8
<i>F8</i>	1,667	2,000	1,111	1,429	1,111	1,667	1,250	5	<i>F8</i>	1,667	2,000	1,111	1,429	1,111	1,667	1,250	5
	<i>F1</i>	<i>F2</i>	<i>F3</i>	<i>F4</i>	<i>F5</i>	<i>F6</i>	<i>F7</i>	<i>F8</i>		<i>F1</i>	<i>F2</i>	<i>F3</i>	<i>F4</i>	<i>F5</i>	<i>F6</i>	<i>F7</i>	<i>F8</i>
<i>F1</i>	4	0,7	0,9	0,5	0,8	0,5	0,9	0,6	<i>F1</i>	4	0,7	0,9	0,5	0,8	0,5	0,9	0,6
<i>F2</i>	1,429	5	0,7	0,6	0,9	1	0,6	0,5	<i>F2</i>	1,429	5	0,7	0,6	0,9	1	0,6	0,5
<i>F3</i>	1,111	1,429	0	0,9	0,6	0,7	0,7	0,9	<i>F3</i>	1,111	1,429	4	0,9	0,6	0,7	0,7	0,9
<i>F4</i>	2,000	1,667	1,111	5	0,9	0,5	0,8	0,7	<i>F4</i>	2,000	1,667	1,111	5	0,9	0,5	0,8	0,7
<i>F5</i>	1,250	1,111	1,667	1,111	3	0,5	0,6	0,9	<i>F5</i>	1,250	1,111	1,667	1,111	3	0,5	0,6	0,9
<i>F6</i>	2,000	1,000	1,429	2,000	2,000	4	0,5	0,6	<i>F6</i>	2,000	1,000	1,429	2,000	2,000	4	0,5	0,6
<i>F7</i>	1,111	1,667	1,429	1,250	1,667	2	2	0,8	<i>F7</i>	1,111	1,667	1,429	1,250	1,667	2	0	0,8
<i>F8</i>	1,667	2,000	1,111	1,429	1,111	1,667	1,250	5	<i>F8</i>	1,667	2,000	1,111	1,429	1,111	1,667	1,250	0

supply chains. As stated in this study, in sudden disruptions, risks grow and threats the sustainability and resilience of supply chains (Sudarmin and Ardi 2020). Golan et al. (2021)

discussed importance of developing more resilience vaccine supply chain with the risk management approaches. They proposed that risk mitigation and efficiency is needed to

**Table 8** Rank of stakeholder engagement factors in the vaccine supply chain

	<i>Permanent Index</i>	<i>Rank</i>
Stakeholder’s Motivation and Loyalty (F1)	425,456,88	7
Knowledge and Experience of Stakeholders (F2)	441,690,86	3
Transparency of Stakeholders (F3)	441,021,29	4
Risk Management Capabilities of Stakeholders (F4)	458,419,57	2
Being Resistant to Changes in Conditions (F5)	415,761,43	8
Management Policies and Regulations for Vaccine Supply Chain (F6)	433,081,50	5
Communication and Coordination Between Stakeholders (F7)	430,996,71	6
Innovativeness of Stakeholders (F8)	497,697,86	1

create more resilient supply chain. Therefore, it is meaningful to determine the risk management capabilities of stakeholders as an important factor in stakeholder engagement in vaccine supply chains. Furthermore, according to De Boeck et al. (2019), knowledge and experience of stakeholders are needed for stakeholder engagement in vaccine supply chains similar with this study. Besides, according to Wu and Li (2020), stakeholder engagement in the supply chain is required for both in increasing innovation and in knowledge transfer and performance improvement by developing relationships between stakeholders.

According to results of the study, for managerial implications, innovativeness is one of the essential issues for vaccine supply chains. The vaccine supply chain is one of the most innovative structures. With the COVID-19 pandemic, it has been seen that the innovation processes at every stage of the vaccine supply chain will improve and the resilience of the vaccine supply chain will increase. Therefore, applications such as the adoption of new technologies in the vaccine supply chain and increasing the follow-up of cold chains with technological innovations are required. Digital technologies such as IoT, RFID and Blockchain adaptation provides various advantages by ensuring easily tracking their operations and by obtaining data simultaneously. Increasing transparency of stakeholders in the vaccine supply chain is important to develop security and resilience the supply chain. Besides, these technologies also ensure data analysis, accurate forecasting and optimization of activities to increase risk management capabilities of stakeholders.

Another implication is about knowledge and experience of stakeholders. In order to ensure the stakeholders engagement in the vaccine supply chain, the stakeholders should be constantly informed about the processes and their knowledge of the vaccine supply chain operations should be increased. If there are knowledgeable and experienced stakeholders in the vaccine supply chain structure, the resilience of the vaccine supply chain will increase.

In order to ensure resilience and sustainability in the vaccine supply chain, it is necessary to ensure communication and coordination between stakeholders. Managers should monitor the accuracy and flow of information between stakeholders in vaccine supply chain operations. Therefore, they can keep them under control by carrying out regular meetings and gathering information about the flow.

Moreover, as seen with the COVID-19 pandemic, the vaccine supply chain is extremely important. Every stage, from the production of the vaccine to the delivery to the consumer, must be planned properly. From the policy maker perspective, new policies and regulations should be prepared in order to eliminate the problems that may be experienced between stakeholders and to ensure smooth functioning of the vaccine supply chain process. Stakeholders should be informed and encouraged about the importance of the business.

Furthermore, integrating new technologies in vaccine supply chain will provide improving operations efficiency and new investments in vaccine supply chains. Therefore, in this case, for these new technological adaptations, companies are not only responsible but also government is responsible from the macro perspective.

## 6 Conclusion

The vulnerable nature of the globalized supply chains causes the processes to be disrupted in the face of sudden disruptions. One of the supply chains whose importance has increased with the COVID-19 pandemic has been the vaccine supply chain. Achieving control in multi-stakeholder vaccine supply chains and increasing the resilience of supply chains depends on the stakeholder engagement. Therefore, it is aimed to determine the factors of stakeholder engagement in the vaccine supply chain by using the Graph Theory Matrix Approach in the study. Moreover, the main contribution of the study is to determine factors of project and stakeholder engagement in multi-stakeholder vaccine supply chains and to state the relationships between the factors of project and stakeholder engagement in vaccine supply chains to increase resilience in disruption times.

As a result of the study, it is seen that innovativeness of stakeholders are the most essential factor among the other for stakeholder engagement. Moreover, risk management capabilities of stakeholders and knowledge and experience of stakeholders are the second and third important factors of stakeholder engagement. The ranks of the other factors are transparency of stakeholders, management policies and regulations for vaccine supply chain, communication and coordination between stakeholders, stakeholder's motivation and loyalty, being resistant to changes in conditions, respectively.

As a future work, different factors may arise in the vaccine supply chain that will affect stakeholder engagement factors. This model can be extended to different sectors. Hybrid methods also can be used to improve this study. Moreover, comparative studies can be applied between emerging economies and developed countries.

This study has some limitations. There may be more variables in the vaccine supply chain that affect stakeholder engagement, but the model is not suitable for dealing with too many variables and thus couple of factors can be used in this model. It is not a dynamic model, the relationships between variables are assumed to be static. Moreover, the fact that the study is general and not privatized for specific countries causes general interpretation of the results. Besides, more expert opinions should be sought to generalize the model based on subjective expert opinions.

**Funding** No funding was received to assist with the preparation of this manuscript.

## Declarations

**Conflicts of interest** The authors have no relevant financial or non-financial interests to disclose.

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