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ENHANCING RESILIENCE OF OIL SUPPLY CHAINS IN THE CONTEXT OF DEVELOPING COUNTRIES

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Research paper

Abstract: *Oil supply chains play a vital role in the day-to-day functioning of national economies and obstruction in its services can lead to dire consequences. For this purpose, it is imperative for oil supply chains to be on guard against all probable vulnerabilities and develop adequate protection mechanisms. This research study aims to identify the most important vulnerabilities for oil supply chains in the context of Pakistan, a developing country. Subsequently, these identified vulnerabilities were used to design a protection framework, embodying different supply chain capabilities. For this purpose, this study employs a hybrid Multi-Criteria Decision Making approach. Full Consistency Method (FUCOM) has been used to prioritise vulnerabilities and Fuzzy Quality Function Deployment (QFD) has been used to identify those capabilities that can ensure protection against these vulnerabilities. This study utilizes secondary data for the identification of vulnerabilities and capabilities through a comprehensive literature review. In addition, primary data has been incorporated as relevant experts were asked to rate the importance of these identified vulnerabilities and capabilities. Results indicate that crude oil price instability, fuel price shocks, unpredictable demand, and information and communication disruptions are the most important and catastrophic vulnerabilities in the context of Pakistan's oil industry. For mitigation of these vulnerabilities, oil supply chains need to incorporate real-time information sharing, visibility, e-procurement, traceability, and transparency as resilience measures. These recommendations are of considerable importance to Pakistan's oil industry and policy-making authorities. Moreover, this study fulfils the research gap by focusing on enhancing the resilience of Pakistan's oil supply chains, with the aid of MCDM techniques.*

Key words: *Oil Industry, Supply Chain, Resilience, Fuzzy Set Theory, FUCOM, QFD*

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1. Introduction

The oil industry is one of the key contributors to the global and national economies, as it is one of the most significant and commonly dealt products. The worth of the oil development, production, and distribution have a handsome share in a country's economy. Numerous economic sectors count on petroleum products as it drives the generation of electrical energy, transport sector, heating in homes, industrial operations, and fulfils residential needs. Globally, in 2016, it was estimated that global annual and daily consumption of oil stood at 35,442,913,090 and 97,103,871 barrels respectively (worldometers, 2021). The economic worth of a country can be estimated by its production, refinement, transportation, as well as consumption of petroleum products. Pakistan is a developing country, and like other countries, its economic advent also relies on the active role of the oil industry. Its petroleum sector faces frequent disruptions due to various policy, administrative, market-based, and financial issues. The effect of these disruptions is realized in the form of losses to national GDP and deterioration of the quality of life of citizens.

The effective and smooth operations of oil supply chains are often threatened on account of their vulnerabilities, which are exploited by potential disasters. Thus, huge losses to revenue, operations, quality, and other attributes are caused (Ponomarov & Holcomb, 2009). These vulnerabilities are both intrinsic and extrinsic in nature. The disruptions can be realized due to the occurrence of natural disasters, pandemics, epidemics, and internal forces such as failure to incorporate different functions of the supply chain. Moreover, the modern day's turbulent and uncertain business environment has also rendered supply chains more prone to looming disasters. The traditional mechanisms to become profitable supply chains is also exposing companies to new vulnerabilities (Tarei, et al., 2020). The increased number of threats and risks associated with the vulnerabilities can destabilize the entire supply chain. The cascading effect of this destabilization drives the company to a greater extent, and the economic sector to a lesser extent, into chaos (Sheffi, 2005). Recently, the coronavirus pandemic (COVID-19) has posed a serious threat to the sales and market share of each industry. These increased disruptions and vulnerabilities ask for the inclusion of Supply Chain Capabilities (SCCs) to become resilient (Christopher & Lee, 2004). Because if vulnerabilities are not timely mitigated, the consequences could halt the supply chain operations which would, in turn, result in loss of revenue (Ponomarov & Holcomb, 2009). The dilemma of vulnerabilities and disruptions is also existent in oil supply chains. However, due to the crucial role of petroleum products in national and global economies, the implications of these disruptions are more execrable in nature.

The SCCs have the potential to act as resilient features and either prevent disruptions or help the supply chain resume normal operations right after disruptions (Pettit, et al., 2011). The concept of resilient supply chains is a universally accepted and recognized agenda due to the prevalent vulnerabilities and complexities of the global supply chains. The SCCs should be organized in such a way that they not only mitigate risks but also deliver a sufficient amount of petroleum products in a reasonable, reliable, effective, environmentally friendly, proactively administered and socially acceptable manner (Sovacool, et al., 2011). A real-world application of mitigating Supply Chain Vulnerabilities (SCVs) through SCCs enhances not only the financial performance of the oil industry (Fan, et al., 2017) but also the overall performance of the established supply chains (Thun & Hoenig, 2011).

There are numerous SCCs and it is usually difficult and costly for supply chains to adopt all SCCs. There is a need for a mechanism that can be employed to determine which SCCs are most pertinent and relevant for respective supply chains. Thus, supply chains would be able to identify the important SCCs and incorporate a limited number of these SCCs or focus on these SCCs in order of their impact. This study proposes that SCCs can be viewed as a tool to combat vulnerabilities. Therefore, SCVs can be used to prioritise SCCs and thus supply chains can focus on these prioritised CCs according to their importance.

This research study aims to identify and prioritize the supply chain vulnerabilities with regard to Pakistan's oil industry. Furthermore, these prioritized vulnerabilities have then been employed to design a resilience framework, comprising supply chain capabilities. These capabilities are also prioritized on the basis of their effectiveness against vulnerabilities. Thus, the study's primary hypothesis is to determine the rank of SCCs for oil supply chains of developing countries. For this purpose, a hybrid combination of two MCDM techniques has been used. Full Consistency Method (FUCOM), a rather recent technique, has been used to assign relative importance weights to supply chain vulnerabilities. Furthermore, Fuzzy Quality Function Deployment (QFD), has been used to prioritize supply chain capabilities as per their ability to combat the previously prioritized vulnerabilities and reinforce other capabilities.

The full consistency method has been employed because it is an improved method for the relative comparison of criteria. It embodies the advantages of qualitative decision making and non-linear programming, thus assigning a reasonably fair value for relative comparison of attributes. In this study, initially, SCVs have been compared relative to each other and assigned with numerical values with the aid of the FUCOM method. Moreover, the Fuzzy Quality Function Deployment tool was primarily developed to incorporate customer preferences into product design. It prioritises product design features that can ensure adherence to customer preferences. Lately, its scope has been diversified and has been widely adopted in research studies. In this study, it has been used to incorporate resilience against SCVs through SCCs.

The rest of this research study is structured as follows. The Introduction is followed by Literature Review, where research studies relevant to the topic and methodology have been discussed. Data Collection and Methodology elaborates the data collection process and the analysis. Subsequently, the Result and Discussions describe the results and policy recommendations. Finally, the Conclusion section concludes the study.

2. Literature Review

Crude oil is considered one of the key sources of energy. It plays a significant role in the day-to-day functioning of the world's economy. The Oil Supply Companies (OSCs) have multifarious structures with regards to the choice of products, consumer markets, and operations (Ahmad, de Brito M, Rezaei, & Tavasszy, 2017; Saad, Elsaghier, & Ezaga, 2018). Due to the complexity prevailing in the upstream, midstream, and downstream functions, the oil supply chains are quite vulnerable to disruptions. A research study emphasized and assessed safety risks and the overall vulnerability in the oil industry by establishing a risk matrix. The study analyzed the consequences of the indicators such as accidents' proportions, economic loss, reputation loss, and environmental pollution (Tian, et al., 2018). The most dangerous risk associated with OSCs is the financial risk. High price fluctuation within the global energy market is one of the key threats to the financial stability of the oil industry (Chikunov, et al., 2019). The recent shock due to the COVID-19 pandemic has also severely destabilized the energy sector, global economic growth, and geopolitics (McNally, 2020; Đukić et al. 2021).

Similarly, a study addressed vulnerabilities within remote operations of the oil industry including technical information and communications-based risks, organizational risks, and risks associated with human factors (Johnsen, et al., 2007). From the perspective of developing countries, the Nigerian oil industry was assessed with political risks (Frynas & Mellahi, 2003). The researchers concluded that it has varying effects on transnational firms. In some cases, firms underperform while in other cases, firms can get benefits under certain circumstances. In addition, (Bimha, et al., 2020) analyzed the Zimbabwean petroleum industry with respect to the uninterrupted flow of quality products at reasonable prices. The top fifteen oil-importing South Asian countries were assessed on the indicators like geopolitical risk, transportation risk, oil price unpredictability, and US dollar instability (Iqbal, et al., 2020). These risks result in poor performance and competitiveness at both micro and macro levels.

In past decades, supply chains have been challenged by vulnerabilities in the shape of disasters and have thus left an impact on society and ecosystems (Sodhi, et al., 2012). Resilient supply chains are required in order to tackle the frequently occurring and severe vulnerabilities. Numerous research studies have been conducted on resilient supply chains which focus on capabilities that help to confront such vulnerabilities. The pseudo-resilient supply chain concept was introduced in a study where the supply chain performs much better with the inclusion of risk management capabilities (Rajesh, 2018). A Decision Support System (DSS) was developed keeping in view the Indian petroleum supply chain. Managers can select a suitable risk management strategy and accelerate the execution of risk management enablers (Tarei, et al., 2020). SCCs sum up all such resilient measures to cope up with the vulnerabilities prevailing in any business. A study identified the problem of low visibility and integration in the supply chain and proposed three top resilient measures which include contingency plan, monitoring and maintenance, and the supply chain relationship management (Lam & Bai, 2016).

The complexity of oil supply chains requires effective supplier selection and close relationships to overcome the uncertainty. Researchers developed an integrated approach for supplier selection within Iran's oil industry to ensure a continuous supply stream (Kaviani, et al., 2019). The logistics network of OSCs is also exposed to vulnerabilities. A study discussed the uniform commercial code related to OSCs management issues and developed several strategies to improve the supply chain (Chima, 2007). Another research focused on European Union's oil supply chains and observed that there is a robust resiliencmechanismsm in place, however, it needs to be synchronized (Urciuoli, et al., 2014). (Hossain, et al., 2019) employed a Bayesianetwork-based approach to explore resilience in oil and gas supply chains. In addition, (Alfaqiri, et al., 2019) focused on Africa as a case study and investigated the existence and applicability of the complex system governance in the context of risks in oil supply chains. However, the demand side of oil supply chains, especially in the context of developing countries, has not been adequately addressed from the perspective of oil supply chains.

The adoption of blockchain in supply chains is a modern trend and has gained widespread popularity. Blockchain can enhance OSCs performance with unique features like real-time information sharing, cybersecurity, transparency, reliability, traceability, and visibility (Aslam, et al., 2021). The important and essential technologies of blockchain implementation in OSC has been discussed in a study with four features including trading, management and decision-making, supervision, and cybersecurity (Lu, et al., 2019). Traceability was ranked as the highest core innovation technology to exploit existing SCCs and resources (Hald & Kinra, 2019). Blockchain features including information transparency, information immutability, and effective contracts have a positive impact on partnership growth (Kim & Shin, 2019). A research study identified the disrupted vulnerabilities like piracy in OSCs by providing a holistic complex system of governance (Alfaqiri & Pinto, 2019). Furthermore, issues related to poor governance including weak regulatory system, poor policy regarding oil industry operations, logistics and communication challenges weaken the existing SCCs and industry competitiveness (Bimha, et al., 2020).

FUCOM is a Multi-Criteria Decision-Making (MCDM) technique, and it was developed by (Pamučar, et al., 2018). It has found several applications in determining the weight coefficients of the relative importance of attributes in consideration. (Pamucar & Ecer, 2020) presented the Fuzzy FUCOM approach and applied it to the evaluation of green suppliers. The authors compared the results of Fuzzy FUCOM with Fuzzy Analytical Hierarchy Process and Fuzzy Best Worst Method and thus confirmed its vitality. A research study combined FUCOM approach with D numbers and the Fuzzy RAFSI method for the development of a hybrid decision-making model (Božanić, et al., 2021). Similarly, (Durmić, et al., 2020) used FUCOM in addition with Rough SAW approach. Another research used FUCOM with the MABAC model in a decision making research scenario (Bozanic, et al., 2020). Thus, there is evidence from the literature that FUCOM has been used in addition with other decision-making techniques.

The Quality Function Deployment (QFD) technique was developed in the 1970s by Akao in Japan. QFD, being a comprehensive and extensively recognized quality management tool, was developed to translate customer requirements into characteristics of process or product (Akao & Mazur, 2003). This is achieved by building a House of Quality (HOQ). The needs can be identified through the help of past literature and questionnaire survey from managers and employees. QFD has proven to be a systematic process to resolve the key issues involved in any process. Lately, QFD has been widely used for the selection of strategies, risks, supplier selection while using the weight derived from decision-making tools (Lima-Junior & Carpinetti, 2016; Chen, Ko, & Yeh, 2017). Fuzzy set theory was developed for the mitigation of uncertainty in qualitative judgments (Zadeh, 1965). Fuzzy QFD has been used in a variety of studies. (Wang, et al., 2020) used Fuzzy QFD for developing a system collaborative framework for designing quality products. (Deveci, et al., 2019) employed Fuzzy QFD and developed a framework for quantitative assessment with regards to customer satisfaction in public transportation. Similarly, a study designed a safety methodology with the aid of Fuzzy QFD (Fargnoli, et al., 2018).

This research study contributes to the literature and addresses the research gap from two perspectives. Firstly, it focuses on mitigating vulnerabilities in oil supply chains in the context of developing countries. Oil supply chains in developing countries lie on the demand side in the supply chain spectrum have not been given adequate attention in the literature. Thus, the results of this study would be of considerable significance to developing countries and aid them in enhancing the resilience of oil supply chains. Secondly, this study has used a novel combination of research techniques for addressing supply chain vulnerabilities with supply chain capabilities. The proposed combination of research tools i.e., FUCOM in association with Fuzzy QFD has rarely been used to address the vulnerabilities and design a resilience framework. Thus, the results of this study would not only add a unique perspective to the existing literature regarding risks in oil supply chains but also propose a research framework that can be adopted for enhancing resilience in other sectors.

3. Data Collection & Methodology

This research study is focused on the evaluation of adequate supply chain resilience capabilities against the most important and common vulnerabilities, in the context of Pakistan's oil industry. The study utilizes a unique combination of FUCOM and Fuzzy QFD methods to conduct the analysis. The finalized vulnerabilities and capabilities are presented in Table 1 and 2, respectively.

Table 1. Supply Chain Vulnerabilities

Categories	Vulnerabilities	References
Demand and Supply Vulnerabilities	Resource Unavailability	(Sovacool, et al., 2011); (Feygin & Satkin, 2004)
	Oil Dependence Risks	(Zhang, et al., 2013); (Yang, et al., 2014); (Li, et al., 2014)
	Supplier Disruptions	(Sun, et al., 2017); (Alfaqiri, et al., 2019)
Financial Vulnerabilities	Crude Prices Instability	(Kaufmann, 2016); (Alfaqiri, et al., 2019)
	Economic Recession	(Hanabusa, 2010); (Blos, et al., 2009)
	Refined Fuel Prices Shocks	(Blos, et al., 2009)
Social and Political Vulnerabilities	Geopolitical Risks	(Blos, et al., 2009); (Iqbal, et al., 2020)
	Transportation Risks	(Sun, et al., 2014); (Wu, et al., 2009)
	Pandemic/Epidemics	(Mhalla, 2020)
	Natural Hazards	(Badida, et al., 2019)
	Political Instability	(Blos, et al., 2009); (Block, et al., 2015)
Operational Vulnerabilities	Demand Fluctuations	(Davis, 2018); (Zhu, et al., 2020); (Berget, 2020)
	Information & Communication Disruptions	(Giri & Sarker, 2017); (Aslam, et al., 2021); (Kshetri, 2018)
	Lack of Research & Development	(Kraal, 2019)
	Inadequate Government Policies	(Imbun, 2019); (Aung, 2017); (Akrofi & Antwi, 2020)

The proposed combination is novel as it integrates the two techniques, by utilizing the relative importance weights deducted from the FUCOM analysis in the Fuzzy QFD analysis. In the first step, an extensive literature review was conducted to identify supply chain vulnerabilities and capabilities. It resulted in the identification of several factors, and for maintaining relevancy and reduction of redundancy, a total of fifteen capabilities and vulnerabilities were shortlisted. In addition, a panel of experts was also consulted for shortlisting these factors.

Table 2. Supply Chain Vulnerabilities

S. No.	SC Capabilities	References
1.	Minimization of Shutdown Period	(Machado, et al., 2020)
2.	Compliance with Regulatory Developments	(Myasnikova, et al., 2019); (Sanchez, et al., 2019)
3.	Improved Reliability	(Aslam, et al., 2021); (Hasan, et al., 2020)
4.	Real-time Information Sharing System	(Aslam, et al., 2021); (Hald & Kinra, 2019); (Queiroz, et al., 2019)
5.	Transparency	(Aslam, et al., 2021); (Cole, et al., 2019); (Kim & Shin, 2019)
6.	Traceability	(Aslam, et al., 2021); (Hasan, et al., 2020); (Kshetri, 2018); (Song, et al., 2019)
7.	Visibility	(Aslam, et al., 2021); (Kim & Shin, 2019); (Kshetri, 2018) ; (Rogerson & Parry, 2020)
8.	E-Procurement	(Aslam, et al., 2021); (Tie & Cheng, 2015)
9.	Risk Management Culture	(Ahmad, et al., 2016); (Pagell & Wu, 2009)
10.	Improved Forecast Reliability	(Chima, 2007); (Vonderembse, et al., 2006)
11.	Timely and Effective Delivery	(Ako, 2012); (Ablo, 2015); (Chang, et al., 2011)
12.	Continuous Supply Stream of Products	(Neiro & Pinto, 2003)
13.	Product Quality in Compliance with Specifications	(Wei, et al., 2019)
14.	Unbundling/Decentralization of Authority in Petroleum Industry	(Agrell & Bogetoft, 2017)
15.	Managing Bullwhip	(Rajesh, 2018); (Mackelprang & Malhotra, 2015)

The techniques used in this study are reliant on expert opinion for assigning importance and adequacy weights to attributes. Therefore, a questionnaire was developed which comprised of three major parts. In the first part, the experts were asked to gauge the relative importance of each attribute, and in the second part, the experts were asked to rate the effectiveness of each capability against vulnerabilities. The third part focused on the nature of bolstering or undermining the relationship between capabilities. The experts' panel was comprised of reputable managers in the oil industry. These experts, as shown in figure 1, were serving in refineries, exploratory firms, OMCs, and the Ministry of Petroleum. A total of eleven responses were gathered which are sufficient, considering the detailed nature of the questionnaire and the usual sample size used in MCDM techniques. The questionnaires were filled after a detailed briefing to experts and their queries regarding various aspects of questionnaires were addressed.

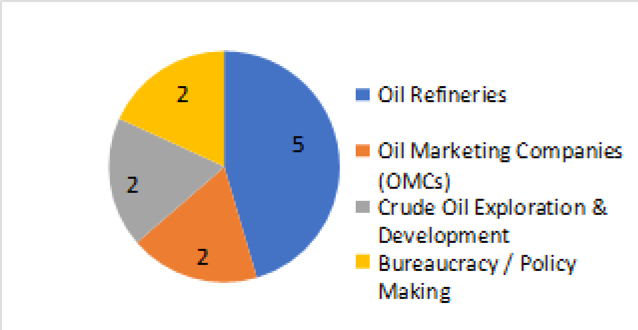

Figure 1. Experts' Panel

3.1. Fully Consistency Method (FUCOM)

Fully Consistency Method (FUCOM) is a Multi-Criteria Decision Making (MCDM) technique, developed by (Pamučar, et al., 2018). FUCOM has been employed to gauge the relative effectiveness of supply chain vulnerabilities, as each vulnerability has a different level of importance owing to its probability, severity, costs, and other aspects. The various steps involved in the FUCOM method are explained below.

Step 1: The set of factors, whose relative importance is to be gauged, is identified. A questionnaire is formed, and the experts are asked to respond on a Likert scale, determining the importance of each factor.

Step 2: The average importance weight for each factor is determined and the factors are ranked in the decreasing order of their weights.

$$SCV_{j(1)} > SCV_{j(2)} > SCV_{j(3)} > \ldots\ldots > SCV_{j(k)} \quad (1)$$

Where SCV represents the supply chain vulnerabilities, and j represents the ranks of criteria when arranged in an order.

Step 3: Comparative priorities of criteria, which represent the advantage of criteria over other criteria, are determined with the aid of equations 2 and 3.

$$\alpha_{j/_{j+1}} = \frac{SCV_j}{SCV_{j+1}} \quad (2)$$

$$\Phi = \alpha_{1/2}, \alpha_{2/3}, \ldots, \alpha_{k/k+1} \quad (3)$$

Step 4: A non-linear programming model is constructed, which essentially comprises of two conditions.

The ratio of final weight coefficients of criteria equals the respective comparative priority.

$$\frac{w_j}{w_{j+2}} = \frac{\alpha_j}{\alpha_{j+1}} \quad (4)$$

The condition of mathematical transitivity is fulfilled by the weight coefficients.

$$\frac{w_j}{w_{j+1}} = \frac{\alpha_j}{\alpha_{j+1}} * \frac{\alpha_{j+1}}{\alpha_{j+2}} \qquad (5)$$

Step 5: The final weight coefficients are determined by forming and solving a nonlinear programming model. The standard format of the model is given below.

These weight coefficients are later used in the Fuzzy QFD analysis, explained in the next section.

$$\min \chi$$

s.t.

$$\left| \frac{W_j}{W_{j+1}} - \phi_{j/_{j+1}} \right| \leq \chi, \forall j$$

$$\left| \frac{W_j}{W_{j+2}} - \phi_{j/_{j+1}} * \phi_{j+!/_{j+2}} \right| \leq \chi, \forall j$$

$$\sum_{j=1}^{n} w_j = 1,$$

$$w_j \geq 0, \forall j \qquad (6)$$

3.2. Fuzzy Quality Function Deployment (QFD)

Quality Function Deployment alternatively knows as, House of Quality is a tool developed by Akao, a Japanese researcher (Akao, 1990). Originally, it was designed to translate customer requirements into product design. However, its scope has lately been diversified and it's widely used in scenarios where there are sets of clearly defined challenges and solution strategies. The challenges and strategies are referred to as WHATs and HOWs respectively. In this study, the supply chain vulnerabilities and capabilities constitute WHATs and HOWs.

QFD analysis is also dependent upon the experts' response, which inherently contains vagueness or uncertainty up to a certain degree. In order to mitigate this uncertainty, Fuzzy Set Theory developed by (Zadeh, 1965) has been incorporated in the QFD. The Fuzzy set theory considers the relative importance of attributes instead of absolute judgments. The various steps involved in Fuzzy QFD analysis are explained below.

Step 1: The WHATs and HOWs for the QFD model are identified and expert opinion is gathered. Experts' panel is asked to respond on a Likert scale, regarding the effectiveness of each strategy against a challenge, and the supporting or diminishing role with respect to other strategies.

Step 2: The final weights derived from the FUCOM analysis for SCVs are used as the importance weights of strategies or WHATs in the QFD model. This step embodies the methodolgoial contribution of the study as it incorporates the relative importance weights derived from the FUCOM analysis, instead of absolute weightages given by experts. Thus, the relative importance weights increase the authencity of the weights and improve the overall analysis.

Step 3: The Relationship matrix is constructed, between WHATs and HOWs. The (i,j) entry in the matrix shows the strength of jth HOW in achieving ith WHAT. In this case, it represents the ability of jth capability to mitigate ith vulnerability. The matrix is developed, based on the average value of expert responses. The experts are asked to rate the effectiveness of each strategy against each challenge on the Likert scale given in Table 3.

Table 3. Linguistic Scale for Relationship Matrix

Degree of Relationship			
Degree of Relationship	Fuzzy Number		
Strong	0.7	1	1
Medium	0.3	0.5	0.7
Weak	0	0	0.3

Step 4: The Correlation matrix is constructed between HOWs. It represents the nature of the relationship between various HOWS. The (i,j) entry in the matrix shows the relationship of ith HOW and jth HOW. In this case, it represents the relationship between supply chain capabilities. The matrix is developed, based on the average value of expert responses. The positive values show supporting relationships while negative values show a damaging relationship between strategies. The experts are asked to rate the effectiveness of each strategy against each challenge on the Likert scale given in Table 4.

Table 4. Linguistic Scale for Relationship Matrix

Degree of Correlation			
Degree of Relationship	Fuzzy Number		
Strong Positive	0.3	0.5	0.7
Positive	0	0.3	0.5
Negative	-0.5	-0.3	0
Strong Negative	-0.7	-0.5	-0.3

Step 5: The relative importance weights of each HOW are calculated from the relationship matrix, with the aid of equation 7.

$$RI_j = \sum_{i=1}^{n} W_i * R_{ij} \qquad (7)$$

where j = 1,2,..,m and $\left(R_j = R_{jU}, R_{jM}, R_{jU}\right)$

Here W_i refers to the weight coefficients calculated from FUCOM analysis, while R_{ij} represents the entries of the relationship matrix.

Step 6: The priority weights are calculated with equation 8.

$$RI_j^* = RI_j + \sum_{k=j} T_{kj} * RI_k \qquad (8)$$

where j = 1,2,.., m and $\left(RI_j^* = RI_{jL}^*, RI_{jM}^*, RI_{jU}^*\right)$

Here, T refer to the entries of the correlation matrix.

Step 7: The priority weights are normalized by the division of each value by the maximum value of priority wights. Subsequently, the priority weights are de-fuzzified via geometric mean. The HOWs are then ranked in the descending order of the de-fuzzified weights.

4. Results and Discussion

The results and discussion section is divided into two parts. The first part focuses on the results of the FUCOM analysis while the second part elaborates on the results of the Fuzzy QFD analysis.

4.1. FUCOM Analysis – Supply Chain Vulnerabilities

The non-linear programming model of FUCOM analysis resulted in final weight coefficients given in Table 5.

Table 5. Rankings of SCVs derived from FUCOM

Rankings	Supply Chain Vulnerabilities		Weight
1	SCV 4	Crude Prices Instability	0.096
2	SCV 6	Refined Fuel Prices Shocks	0.093
3	SCV 12	Demand Fluctuations	0.083
4	SCV 13	Information & Communication Disruptions	0.083
5	SCV 15	Inadequate Government Policies	0.080
6	SCV 3	Supplier Disruptions	0.069
7	SCV 1	Resource Unavailability	0.067
8	SCV 2	Oil Dependence Risks	0.065
9	SCV 9	Pandemic/Epidemics	0.065
10	SCV 14	Lack of Research & Development	0.065
11	SCV 5	Economic Recession	0.056
12	SCV 8	Transportation Risks	0.049
13	SCV 11	Political Instability	0.048
14	SCV 7	Geopolitical Risks	0.046
15	SCV 10	Natural Hazards	0.035

The weights coloumn of the anlysis indicate the final relative weights assigned to SCVs. Each of the SCVs have been assigned with a weight between 0 and 1, and the sum of all these weights equal 1. These weights indicate the priority of each vulnerability with respect to other vulnerabilities, and the higher weights indicate increased priority.

The FUCOM analysis indicates that crude oil price instability is a top-ranked vulnerability, which can jeopardize the steady operations of oil supply chains. Crude oil price instability is directly associated with stock returns of oil companies, production costs, diminished profit margins, inability to meet consumer demand, inventory costs, and policy fluctuations (Apergis & Miller, 2009; Arouri & Nguyen, 2010). However, this vulnerability is inherently extrinsic in nature as crude oil prices are primarily determined by the Organization of Petroleum Exporting Countries (OPEC). Moreover, fuel price shock occupied second place in ranked vulnerabilities. In Pakistan, usually, fuel prices are revised on a fortnightly basis. Thus, there are constant speculations about expected trends or policy decisions, and OMCs respond respectively. In case of lower expected prices, these companies try to delay procurement and in case of higher prices, the ignominious practise of hoarding takes place.

Unpredictable demand proved to be yet another vital risk in the petroleum sector. The recent COVID-19 pandemic exhibited a strong and unpreceded fluctuation in consumer demands. OPEC asked its petroleum sector to cut oil production by a record of 10 million barrels per day in May 2020, which was still not sufficient to minimize the gap between demand and supply (IEA, 2020). Since the lockdowns are expected to happen routinely in a near future due to the ravaging nature of the pandemic, and other reasons, consumer demand would remain unpredictable and would thus adversely affect oil supply chains. Information and communication disruptions are also prevalent in the petroleum industry of Pakistan. These disruptions have severe disastrous impacts on the functioning and operations of oil supply chains. These disruptions cause supply-demand imbalance, financial mismanagement, and increased operational costs. Thus, the ranking derived from FUCOM analysis is justifiable and there is a need to design preemptive strategies which should help in overcoming these vulnerabilities.

4.2. Fuzzy QFD Analysis – Supply Chain Capabilities

The results of the Fuzzy QFD analysis are presented in the Table 6. The RI coloumn lists the relative importance weights of SCCs. These weights indicate the strength of each SCC with respect to combating SCVs as per their importance, and the capacity of each SCC to withhold/support other SCCs.

Table 6. Rankings of SCCs derived from QFD

Rankings		Supply Chain Capabilities	RI
1	SCC4	Real-time Information Sharing System	0.38
2	SCC7	Visibility	0.37
3	SCC8	E-Procurement	0.37
4	SCC6	Traceability	0.36
5	SCC5	Transparency	0.36
6	SCC15	Managing Bullwhip	0.33
7	SCC9	Risk Management Culture	0.30
8	SCC3	Improved Reliability	0.29
9	SCC11	Timely and Effective Delivery	0.28
10	SCC12	Continuous Supply Stream of Products	0.28
11	SCC10	Improved Forecast Reliability	0.27
12	SCC1	Minimization of Shutdown Period	0.24
13	SCC13	Product Quality in Compliance with Specifications	0.08
14	SCC 2	Compliance with Regulatory Developments	-0.06
15	SCC14	Unbundling/Decentralization of Authority in Petroleum Industry	-0.12

The results of the Fuzzy QFD analysis are presented in the table 6. The RI column lists the relative importance weights of SCCs. These weights indicate the strength of each SCC with respect to combating SCVs as per their importance, and the capacity of each SCC to withhold/support other SCCs.

The results of the Fuzzy QFD analysis present strong evidence for the need for the incorporation of blockchain features in Pakistan's petroleum supply chains. The top five capabilities, prioritized as a result of Fuzzy QFD analysis are associated with blockchain features and practices. The top-ranked strategy that would mitigate most vulnerabilities and play a supporting role with regards to other capabilities, is the real-time information sharing system. Its incorporation would lead to the smooth functioning of the business activities and effective communication within and between business entities (Wanga, et al., 2020). It would also aid in improved forecasts as the varying trend of demand and supply can be instantaneously accommodated in the forecasting mechanisms (Zhoua & Benton, 2007). The information system would provide accurate information regarding the status of availability of crude, demand at the downstream end, and the transportation associated with OSCs. Thus, its incorporation would lead to mitigation of vulnerabilities as respective authorities would be better able to track down instabilities and interruptions, conduct effective planning, design preemptive strategies.

Similarly, the adoption of visibility as a vulnerabilities mitigation mechanism would serve in a variety of ways. It would enhance focus, monitoring, and control of the entire operations of oil supply chains (Bartlett, et al., 2007). There are several products involved in the OSCs and each product has a distinct route, source, and destination. In addition, there are supporting roles for ensuring the smooth delivery of products. Visibility would maintain coordination between all these segments of operations.

Furthermore, E-procurement is another rapidly growing modern trend that enables purchasing via digital means. It reduces delivery time, provides better bargaining options, increases accountability and transparency, and minimizes communication disruptions (Jelassi & Martínez-López, 2020). E-Procurement can also reduce severity or impact in case of occurrence of disruptions. It also reduces significant costs through reduction of lead time, effective resource planning, and reduction of inventory levels.

Traceability has also proven to be a dominant feature with regard to resilience in supply chains. It helps in mapping down the processes and the complete journey of petroleum products in the oil industry. Petroleum products require adequate and well-designed safety and quality measures, which can be improved with traceability mechanisms as companies are in knowledge of where, when, and how their products are coming (Malik, et al., 2021). It also aids in protective mechanisms against physical thefts in vulnerable areas.

Supply chain transparency is another feature that increases acceptibilty and success of supply chains (Jabbar, et al., 2021). Transparancy refers to the practice of communicating information, functional status, operationa; standards, and impact within supply chains, to upstream and downstream linkages and customers (Gardnera, et al., 2019). Trasnparancy in supply chains assure customers and other associated entities that supply chain's practices align with their ethical, functional, and busuiness values. Thus, it increases confidence in supply chains and associated entities are able to positively engage with the supply chain. Ensuring transaparancy is also a blockchain feature, and with the use of digitial communication, artificial intelligence, and industry 4.0, the information can be gathered, analysed and broadcasted to respective audience (Saberi, et al., 2019).

In addition to the five discussed SCCs, all the other SCCs with positive RI values are viable strategies and should be incorporated in oil supply chains of Pakistan. However, in case of time, cost, or other constraints, priority should be given to the top five ranked strategies. The incorporation of top five SCCs would enable Pakistan's oil supply chains to track demand, disruptions, variations and respond proactively to these challanges. It would also aid in effective monitoring of market and operational status, effective planning, and optimized distribution of resources. These benefits would lead to stability in the overall oil industry and government authorities would be able to design and implement improved policies. Companies operating the in upstream and downstream of OSCs would also be able to gain functional insights. Thus, the supply chain data management support system, if integrated with the products, materials, suppliers, and governmental bodies, would provide numerous benefits.

5. Conclusion

The oil industry is one of the key determinants of the effective functioning of national economies. Its smooth, timely, and efficient supply reinforces other sectors of the economy while interruptions in its services lead to deleterious effects on the overall economy. Therefore, it is pertinent for government authorities and private sectors to design preemptive strategies that could identify and minimize the impact of vulnerabilities. This research study aimed to identify and prioritize various supply chain vulnerabilities that could occur within Pakistan's oil industry. Subsequently, it identified and prioritized supply chain capabilities that can improve the risk mitigation profile of Pakistan's oil industry.

This study employed a combination of FUCOM and Fuzzy QFD, MCDM techniques, for analysis. FUCOM was used to rank the supply chain vulnerabilities while Fuzzy QFD aided in prioritizing supply chain capabilities in order to preemptively deal with the vulnerabilities. A total of ten supply chain vulnerabilities and ten supply chain capabilities were identified from the literature and analyzed. Results indicated that crude price instability, fuel price shocks, unpredictable demand, and information and communication disruptions are amongst the most important vulnerabilities. In order to reduce the impact of these vulnerabilities, oil supply chains should incorporate real-time information sharing systems, visibility, e-procurement, traceability, and transparency practices in every aspect of their operations. These strategies are associated with the blockchain technologies, that are gaining popularity day by day.

Pakistan is a developing country whose oil industry and its intermediaries are lagging in terms of financial performance. The mitigation of vulnerabilities would lead to relative stability, increase the confidence of investors, boost economic activities and thus improve the quality of life of citizens besides bolstering economic activities.

This research study has few limitations as it relied only on qualitative judgements of experts and first hand numerical data was not incorporated. Moreover, the experts panel was limited in geographical context, as all the experts had professional experience in a common country. In future studies the analysis can be improved by feasibility analysis of the recommended features, pilot studies relying on firsthand data, geographical expansion of experts' panel, and the factors considered in this study can be further diversified. In addition, the comparative analysis with the established methodologies and proposed methodology can also be conducted.

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