Optimizing resilience strategies to reduce vulnerabilities in the supply chain based on the QFD approach: The case of the clothing company ZEN

Fersi Ghada[#1], Ghorbel Ahmed[*2], Charfi Momtez[#3]

Université de Sfax Tunisie

Fsegs sfax- Tunisie

ghadafersi@yahoo.fr

ahmed.ghorbel@fsegs.usf.tn

momtezcharfi3@gmail.com

Abstract:With the growth of frequent disruptive events, organizations have become more vulnerable to the consequences undergone by them. As a result, the need for a more resilient supply chain (SC) to mitigate vulnerabilities has become intrinsic.

Our central objective in this research work is to examine the degree of vulnerability and resilience of the supply chain in Tunisian companies and to identify the optimal portfolio of effective resilience strategies to mitigate these vulnerabilities.

Firstly, we will apply the QFD and then investigate the efficiency of the different strategies proposed for the resolution of the problems linked to the supply chain and for the minimization of the risks to which it is exposed.

Our methodology relies on applying the adjusted QFD to identify different resiliencies and vulnerabilities as well developing a multi-objective nonlinear binary program to determine the optimal portfolio of resilience strategies.

Keywords: SCRM, Vulnerability, Resilience, QFD, Multi-objective nonlinear binary model

I. Introduction

Tunisia's current socio-political situation has created enormous management and development difficulties for most Tunisian companies, preventing their managers from improving their supply chain risk management concepts.

Indeed, every organization seeks to be resilient, and to achieve this facet of resilience, the organization must manage its vulnerabilities well. To this end, a number of researchers have studied vulnerability factors and the different resilience capabilities for adopting and overcoming supply chain disruptions in various industrial sectors, based on different supply chain risk management practices and tools.

According to [1] supply chain resilience is "The adaptive capacity of a supply chain to reduce the probability to protect itself against unforeseen disruptions and counter to their spread while keeping track of functions and structures, defend itself through instantaneous and effective reactive plans in order to overcome the disruption and restore the supply chain's robustness."

ISSN: 2961-6638

In the next several sectionswe have developed effective resilience capabilities for the ZEN supply chain in SFAX to mitigate vulnerabilities. We assign weights to the different vulnerabilities by applying the AHP method. We then develop a multi-objective program to determine the portfolio of effective resilience strategies to mitigate vulnerabilities.We will use a modified version of the Quality Function Deployment (QFD) tool to find vulnerabilities and their resilience strategies. This tool enabled us to assess the effectiveness of each resilience strategy in reducing individual risks, to formulate the problem as a non-linear binary program and determine the optimal strategies for maximizing the degree of resilience.

II. Deployment of the quality function (QFD)

Quality function deployment (QFD) stands for a planning tool used to meet customer expectations. It was created in 1972 in Japan as a product quality improvement methodology implemented in organizations such as Mitsubishi, Toyota and their suppliers. Indeed, it proves to be an effective tool to help product developers systematically integrate customer requirements into product and process development [2].

Quality function deployment (QFD) corresponds to a technique for translating customer needs into practical action. This approach allows companies to become proactive in terms of addressing quality issues rather than reactive at the level of responding to customer complaints.

In addition, QFD refers to a holistic concept that translates customer requirements into appropriate technical ones for each stage of product development and production (i.e. marketing strategies, planning, product design and engineering, process development).

This method displays multiple advantages such as high customer satisfaction, potential for breakthrough innovation, low production costs, shorter turnaround times, better communication through teamwork and preservation of knowledge [3].

A. *The Graphic Tool: THE HOUSE OF QUALITY*

Fig. 1exhibits the basic graphical tool of the QFD, often called the "house of quality”.

The house of quality translates the customer's expectations (the WHAT), written in rows, into product specifications (the HOW), written in columns. The basic principle of the passage from one to the other is the answer to the WHAT/HOW question while ensuring that the essential WHY and HOW questions are answered.

ISSN: 2961-6638

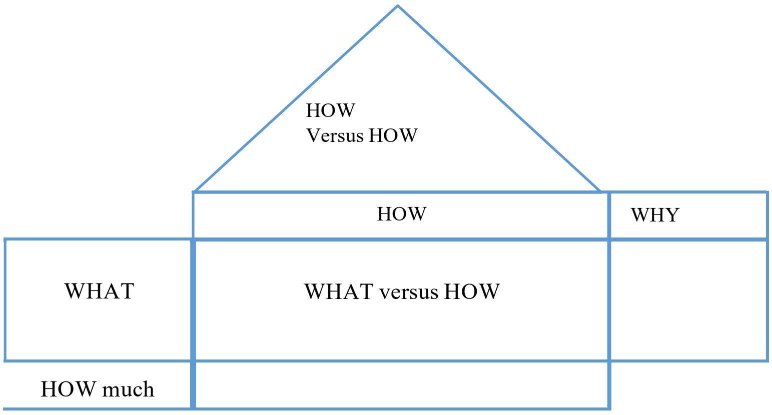


Fig 1 : La maison de la qualité [4]

However, participants in quality house building sessions tend to provide information about their individual judgments in several formats such as numerically or linguistically depending on their different knowledge, experiences, cultures, and circumstances.

Several authorsemphasized that the basic format of the House of Quality (HOQ) comprises six sections: (1) Obtaining customer attributes and their relative importance; (2) Developing design requirements tailored to customer attributes; (3) Planning matrix; (4) Relationships between customer requirements and design requirements; (5) Correlation of design requirements; (6) Action plan.

II. The different uses of QFD in the literature

Quality function deployment (QFD) is considered as an effective tool for systematic planning of new product development. It incorporates customer requirements into every aspect of product design through highlighting customer needs and translating them into technical requirements so that the final product meets customers' expectations (Liu and Wang, 2010).

TABLE I:The different uses of QFD in literature

Authors	The different uses of QFD in literature
[5]	They applied the FQFD for risk prioritization and the cause-and-effect diagram to define actions directed towards risk mitigation or elimination in a pharmaceutical company in Colombia.
[6]	They developed a new collaborative quality design framework for complex products using a FQFD approach.
[7]	They identified and prioritized optimal strategies for supply chain

ISSN: 2961-6638

	sustainability in a dynamic environment using FQFD.
[8]	They presented the different applications of the QFD method in the fields of energy and environment.
[9]	They established the selection of suppliers and the impact of internal dependency between them using a fuzzy multi-criteria group decision approach based on the quality function deployment (QFD) methodology.
[10]	They set forward the AHP-QFD methodology to help decision makers make informed decisions about energy efficiency solutions.
[11]	They applied ANFIS (Adaptive Neuro-fuzzy Inference Systems) and FQFD to enact a relationship between strategic planning and operational budgeting
[12]	They proposed a hybrid model implementing AHP and QFDF methods to provide an intelligent solution for vendor evaluation
[13]	They created a combined QFD and AHP approach to measure the performance of alternative suppliers.

III. Assessing the impact of resilience strategies on vulnerabilities

The Case of ZEN (Before Coronavirus)

1. Introduction to ZEN

Zen corresponds to a family business created by the Zouari family, which has been working in the textile sector since 1978. This small company, founded in Sfax in 2003, has proved to be a huge success. The reputation of Zen then exceeded the borders of its city, to give birth to several stores spread in several cities of Tunisia. In the textile and clothing sector, Zen has won the bet to maintain a Tunisian production of quality and to defend a unique know-how. It is a 100% Tunisian brand dedicated to the whole family (men, women, teenagers and children) and leader in the ready-to-wear market. Customer loyalty is one of the major concerns of the company ZEN.

ZEN knows an exponential expansion thanks to its new idea and its quality products and services. It enjoys a good brand image and is increasing its presence thanks to its quality/price ratio as well as the availability and variety of products.

2. Methodology

In this chapter, we adapted the QFD methodology to identify vulnerabilities and resilience strategies. Subsequently, we elaborated a multi-objective methodology to find the portfolio of effective resilience strategies to mitigate the vulnerabilities.

ISSN: 2961-6638

We applied our methodology in a garment company. Our study rests upon three steps: identification of vulnerabilities and resilience strategies, integration with the analytical hierarchy process (AHP), and finally determining effective resilience capabilities (a binary nonlinear mathematical program with program).

Our basic objective is to select the set of strategies that maximize the supply chain resilience indicators while respecting the available financial and budgetary constraints. To achieve such an objective, we invested the responses of the company's managers in order to establish in a first step a modified QFD allowing to analyze the effectiveness of different actions that can be taken to enhance resilience and mitigate resilience and reduce vulnerability the different stages of the supply chain.

ISSN: 2961-6638

Vol.3 Iss.1 pp. 132-151 Journal of Economy & International Finance (EIF)

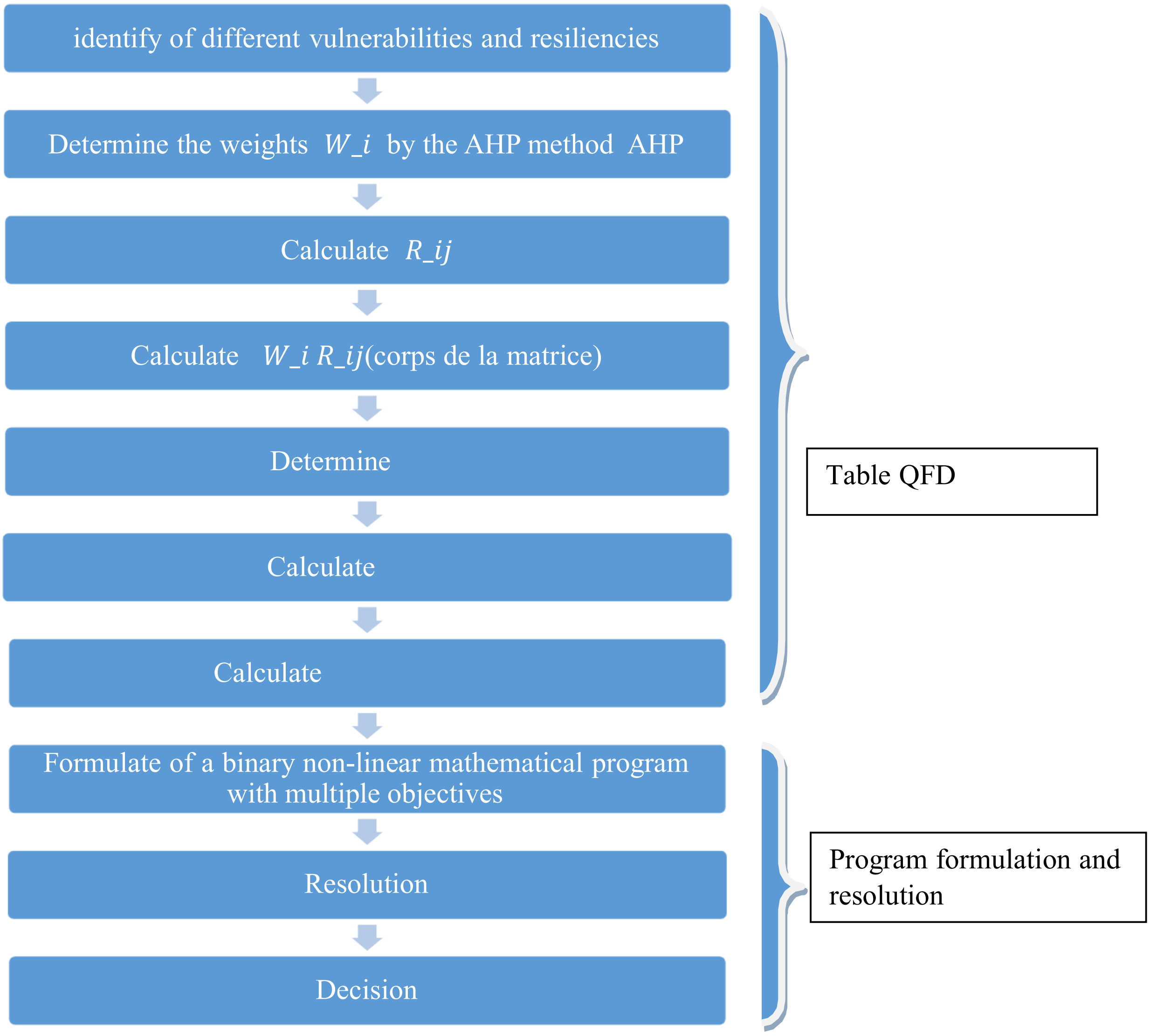


Fig 2: Methodology for selecting an optimal portfolio of resilience strategies.

Step 1: Identification of vulnerabilities and resilience strategies

Grounded on literature reviews and interviews, we managed to identify the different vulnerabilities and resiliencies of the textile sector to start filling in the QFD table.

. There are 33 vulnerabilities. Among them, 22 vulnerabilities were selected and 13 resilience strategies were chosen to mitigate the vulnerabilities.

In Step 1, we defined the items in the**CRi** (what) row that represent the vulnerabilities ZEN's supply chain currently faces and the items in the **DRj** (how) that represent resilience strategies or capabilities to mitigate vulnerabilities (Fig 3).

ISSN: 2961-6638

The vulnerabilities and resiliencies were collected from the literature review and interviews with officials.

To find **Rij** responses, we asked respondents to indicate "the extent of vulnerability reduction i as a result of implementing resilience j" applying the widely used scale of 9 (strong mitigation), 3 (moderate mitigation), 1 (weak mitigation), and 0 (no mitigation). [14];[15];[16].

Step 2: Integration with the hierarchical analysis process (AHP).

In step 2, we applied Saaty's AHP method to estimate the values of **wi** (importance of each vulnerability).

The hierarchical analysis process is a structured technique for organizing and analyzing of complex decisions, based on mathematics and psychology. It was developed by Thomas L. Saaty in the 1980's. It aims to refine the decision process throng examining the by examining the consistency and logic of the decision maker's preferences.

The overall weight of each vulnerability reflects to a great extent its importance of vulnerability.

To apply the AHP method we used the Super Decisions software.

Fig 3 illustrates the**wiRij** values (in the main body of the matrix) and the AIj values for different resilience strategies.

The **AIj** are the absolute importance of the resilience strategies

Example: the magnitude of DV3 vulnerability reduction by the ST2 resilience strategy is equal to 3, so**wiRij** =3*0.009=0.027

The magnitude of DV4 vulnerability reduction by the ST3 resilience strategy is equal to 9, so **wiRij** =9*0.026=0.234

Note that in our case, **AIj** is interpreted as "full resilience" of the resilience strategy to mitigate vulnerabilities.

$$\mathbf{AI_j = \sum_{i=1}^{m} w_i R_{ij} \quad \forall \ jj = 1, \dots\dots, n} \qquad \mathbf{(1)}$$

For example, for the ST1 strategy: ST1 : $\mathbf{AI_1}$= $W_1R_{11} + W_2R_{21} + W_3R_{31} + W_4R_{41} + \dots\dots\dots =$ $0 + 0 + 0 + 0.081 + 0.246 + \cdots \dots.. + 0 + 0.144 = 2.379$

The relative importance (resilience) of resilience strategy j is determined by:

$$\mathbf{RI_j = \frac{AI_j}{\sum_{j=1}^{n} AI_j}} \qquad \mathbf{(2)}$$

For example : $\mathbf{RI_1} = \frac{\mathbf{AI1}}{\sum_{j=1}^{n} \mathbf{AI_j}}$ =2.379/33.174=0.071

Economy: Actions and steps are common to both strategies so that the application of one strategy can reduce the effort and cost to apply the other. Someactions and steps or tools are already implemented.

In step 2, we collected the quantitative data ($\mathbf{w_i R_{ij}}$) to find the $\mathbf{AI_j}$and $\mathbf{RI_j}$values (see equations (1) and (2)). We also collected data on the costs $\mathbf{C_j}$ of implementing resilience strategies to find the

ISSN: 2961-6638

resilience efficiency $\mathbf{RE_j}$ and cost savings when two resilience strategies i and j are implemented simultaneously.

According to[17] the resilience efficiency **REj** is calculated as follows:

$REj = AIj/cj$

where **REij**= measures the effectiveness of strategy j in addressing the problem related to vulnerability i, and

Cj indicates the cost of implementing the resilience strategy.

As an example, $RE1 = 2.379/10 = 0.2379$

It is noteworthy that resilience strategies ST6 (Skills and efficiency development through training and consulting), ST7 (Product and process improvement for efficiency and waste reduction), ST5 (Quality control and reduction of defective products), ST4 (Backup capacity), and ST2(Multiple sources of supply) display the highest IAs (3.822, 3.643,3.63,3.117, and 3.027 respectively)

It remains to be noted that resilience strategy ST6 (Skills and Efficiency Development through Training and Consulting) exhibits the highest ER value of 1.911 followed by resilience strategy ST11 (Social and Environmental Compliance) with 0.826 and strategy ST2 (Multiple Sourcing) of 0.756.

The cost **Cj**of implementing the resilience strategies is found in a more elaborated manner. Each respondent is asked to provide his most likely, optimistic, and pessimistic estimates of **Cj**.

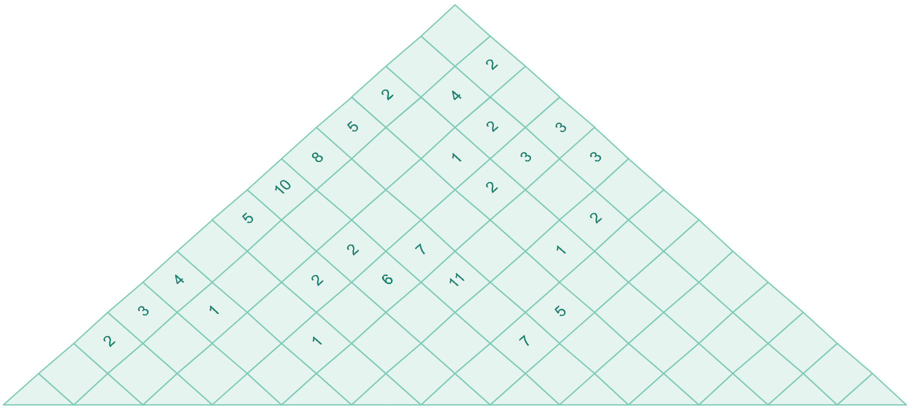
To find the savings, respondents were asked to indicate whether there are savings from implementing two strategies simultaneously and with what amounts to be implemented simultaneously and what the estimated savings might be.

The triangle in Fig 3 reveals these savings data. For example, resilience strategies 1 and 3 can be implemented simultaneously.

The triangle at the top of the house represents the savings **Sij** from the simultaneous application of strategies **STi**and **STj**or the degree of correlation between both of them. An empty square indicates zero correlation between the two strategies i.e., there are no savings and the total cost of implementing the both of them is the sum of **Ci** + **Cj**.

On the other side, a non-zero correlation indicates that implementing both strategies will result in a saving cost of an amount **Sij** such that the cost of implementing simultaneous implementation of both strategies is equal to **Ci** + **Cj-Sij**.

ISSN: 2961-6638



	ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8	ST9	ST10	ST11	ST12	ST13	weights
DV2	0	0	0	0	0	0.129	0	0	0	0	0.387	0	0	0.129
DV3	0	0.027	0.027	0	0.081	0.081	0.027	0	0	0	0	0.027	0	0.009
DV4	0	0.234	0.234	0	0.234	0.234	0.078	0.078	0.078	0	0.078	0.078	0.078	0.026
SV1	0.081	0.081	0.027	0.027	0.081	0.081	0.081	0.027	0.027	0.081	0.027	0.081	0.081	0.009
SV2	0.246	0	0.246	0.246	0.738	0.738	0.738	0.246	0.246	0.246	0.738	0	0.246	0.082
SV3	0141	0.423	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.423	0.047
SV5	0.243	0	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.243	0.027
FV1	0.099	0.033	0	0.033	0	0	0	0	0	0	0	0	0	0.011
FV2	0.201	0.201	0	0.201	0	0	0	0	0	0	0	0	0	0.067
FV3	0.126	0.126	0	0.126	0.378	0.126	0	0	0.378	0	0.126	0	0	0.042
FV4	0.243	0.027	0	0	0.081	0	0	0	0.081	0.081	0	0	0	0.027
FV5	0.051	0.051	0	0	0.051	0.051	0	0	0.051	0.051	0	0	0.017	0.017
OV1	0.111	0	0.111	0	0.111	0.333	0.111	0	0	0	0.037	0	0	0.037
OV2	0.063	0	0.063	0.063	0.063	0.189	0.063	0	0	0	0.021	0	0	0.021
OV3	0.324	0.972	0.324	0.972	0.972	0.972	0.972	0.324	0.324	0	0	0.972	0	0.108
IV1	0	0.375	0	0.375	0	0	0.375	0.375	0.375	0	0	0.125	0.375	0.125
IV2	0	0.123	0	0	0.123	0	0.123	0.123	0.123	0	0	0.041	0.123	0.041
DO1	0.195	0.195	0.195	0.585	0.195	0.585	0.585	0.195	0.195	0.195	0	0.195	0.585	0.065
DO2	0.078	0.078	0.078	0.234	0.078	0	0.078	0.078	0.078	0.078	0	0.234	0.078	0.026
DO3	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0	0.033	0.033	0.011
DO6	0	0	0	0	0.141	0	0.141	0.141	0.141	0.141	0	0.047	0.141	0.047
DO7	0.144	0.048	0.048	0	0.048	0.048	0.016	0.144	0.048	0.144	0.016	0.016	0.144	0.016
AI	2.379	3.027	1.608	3.117	3.63	3.822	3.643	1.986	2.4	1.272	1.652	2.071	2.567	
Coût	10	4	3	8	8	2	25	20	9	5	2	15	5	
RE	0.2379	0.7567	0.536	0.3896	0.4537	1.911	0.1457	0.0993	0.267	0.2544	0.826	0.1380	0.513	

Fig 3: Supply chain resilience model before COVID -19: AI=absolute importance; 〖ST〗_j=Resilience strategy j; DV, SV, FV, OV, IV, DO =various vulnerabilities; RE=Resilience effectiveness.

Using the QFD stepwise procedure, we identified vulnerabilities and corresponding resilience strategies.

ISSN: 2961-6638

In terms of the importance of these vulnerabilities, four principles of vulnerabilities were identified: failure in production planning and stock management (OV3), delay in customs clearance (IV1), non-compliance with social and environmental standards (SV2) and political instability (DV2).

Step 3: Proposed methodology for determining effective resilience capabilities in QFD

The concept of effectiveness and generating effective solutions prevails in a multi-objective decision domain [18]. A general multi-objective decision problem is expressed as follows:

$$\left.\begin{array}{l} Max(min) f_i(X) = C^i(X)\, i = 1, \ldots, p \\ g_j(X) \leq b_j\; j = 1 \ldots \ldots \ldots, q \end{array}\right\} \quad (3$$

where $X = (x_1, \ldots\ldots\ldots, x_n)$ denote n-dimensional decision variables ;

$f_i()$ indicates P contradictory and linear objective functions p i=1,2,..., p

$g_j()$ refers to the constraint j, j=1,2,.., q.

A feasible solution X^* to problem (3) is said to be efficient (for a maximisation problem) if there is no other feasible solution X such that for all i=1,...,p , $f_i(X) \geq f_i(X^*)$ et $f_i(X) > f_i(X^*)$ for at least one i.

In other words, X^* is not dominated by any other solution in terms of fulfilling the objective function.

According to [19]the following formulation can be used to maximise supply chain resilience.

$$\left.\begin{array}{l} Max f_1(X) = \sum_{j\in n}^{n} RE_j x_j \\ Max f_2(X) = \sum_{k\in n, k\neq j} RE_k x_k \\ \ldots\ldots \\ Max f_p(X) = \sum_{i\in n, i\neq k\neq j} RE_i x_i \\ \\ \text{constrained : } \sum_{j=1}^{n} c_j x_j - \sum_{i=1}^{n} \sum_{j>i}^{n} S_{ij} x_i x_j \leq B \\ x \in X \\ x_i \in \{0,1\}, \end{array}\right\} \quad (4)$$

where n is the number of resilience strategies.

$\boldsymbol{RE_j}$: is the effectiveness of resilience strategy j ;

$\boldsymbol{x_j}$ is equal to one or zero, depending on whether the corresponding resilience strategy j is selected or not ;(decision variable)

$\boldsymbol{C_j}$ is the cost of implementing resilience strategy j ;

$\boldsymbol{S_{ij}}$ is the savings made if resilience strategies i and j are implemented simultaneously;

B is the budget available to manage supply chain risk.

ISSN: 2961-6638

It is worth noting that there are different conflicting objectives that need to be optimised simultaneously. It is therefore necessary to find an effective and satisfactory solution to problem (4) through interacting with the decision-maker.

Note that any solution to problem (4) will offer a portfolio of resilience strategies so as to mitigate vulnerabilities.

To find the optimal portfolio of strategies, we need to reformulate problem (4) as follows:

$$\left.\begin{array}{l} Max \sum_{i=1}^{p} \lambda_i f_i(X) \\ souscontrainte: \sum_{j=1}^{n} C_j x_j - \sum_{i=1}^{n} \sum_{j>i}^{n} S_{ij} x_i x_j \leq B \\ x \in X \end{array}\right\} \quad (5)$$

p is the number of objective functions in the program

where λ_i($i = 1, \dots, p$) are positive values representing the weights (importance) given by the decision maker to the different objective functions Multi-objective optimisation domain theorems indicate that any solution to problem (5) stated above is an efficient (non-dominated) solution to problem (4) [20].

Note that the large weights $\lambda_i$are only needed to find the first efficient solution to problem (4)

We therefore set forward an interactive procedure that finds a satisfactory portfolio, to explore other effective solutions through modifying the decision-makers' weights.

We shall now introduce an interactive procedure to identify a satisfactory portfolio of effective resilience strategies in order to mitigate vulnerabilities.

Step 1: Optimise each objective function in problem (4).

p optimal solutions are obtained. Decision-makers will act according to the maximum value of each individual objective. An efficient solution may be a compromise of the solutions.

Step 2: Formulate problem (5) where each $\lambda_i = \mathbf{1}$ ($i = 1, \dots, p$).Solve problem (5). The solution will be efficient (non-dominated) for problem (4). Offer it to the decision maker.

Step 3: If the decision-maker is satisfied with this solution (after comparing it with the solutions found in step 1), it will be retained. This solution offersthe satisfactory portfolio of resilience strategies to mitigate vulnerabilities. If the decision-maker is not satisfied, go on to step 4.

Step 4: Discuss with the decision maker to adjust the values of λ_i and find new values representing their preferences for the objective functions.

Step 5: Formulate and solve problem (5) with the new values of λ_i . Proceed to step 3.

ISSN: 2961-6638

In Step 3, we developed a multi-objective binary program and applied the stepwise procedure to find the satisfactory portfolio of effective resilience strategies. We defined three objectives to maximise:

- Maximise the resilience of "Supply" processes by applying at least one of the strategies ST2, ST4, ST9 and ST13.
- Maximise the resilience of "Processing" processes by applying at least one of the strategies ST5, ST6, ST7, ST11 and ST12.
- Maximise the resilience of "Distribution" processes by applying at least one of the strategies ST1, ST3, ST8 and ST10.

The existence of a budget constraint makes it impossible to apply all the strategies at once and achieve a maximum level of resilience for the 3 processes at the same time. According to the manager, the B budget can be set at 80 million dinars.

The total cost of implementing the strategies is equal to the sum of the costs of the different strategies to be implemented minus the savings made as a result of the simultaneous application of both interrelated strategies. This cost must not exceed the budget B allocated by the company to improve the resilience of the supply chain.

$$Maxf_1(X) = RE_2x_2 + RE_4x_4 + RE_9x_9 + RE_{13}x_{13}$$

$$Maxf_2(X) = RE_5x_5 + RE_6x_6 + RE_7x_7 + RE_{11}x_{11} + RE_{12}x_{12}$$

$$Maxf_3(X) = RE_1x_1 + RE_3x_3 + RE_8x_8 + RE_{10}x_{10}$$

Subject to:

$$\begin{aligned} c_1x_1 + c_2x_2 + c_3x_3 + c_4x_4 + c_5x_5 + c_6x_6 + c_7x_7 + c_8x_8 + c_9x_9 + c_{10}x_{10} + c_{11}x_{11} + c_{12}x_{12} + c_{13}x_{13} \\ - S_{1.3}x_1x_3 - S_{1.4}x_1x_4 - S_{1.3}x_1x_3 - S_{1.5}x_1x_5 - S_{1.7}x_1x_7 - S_{1.8}x_1x_8 - S_{1.9}x_1x_9 \\ - S_{1.10}x_1x_{10} - S_{1.11}x_1x_{11} - S_{2.5}x_2x_5 - S_{2.12}x_2x_{12} - S_{2.13}x_2x_{13} - S_{3.7}x_3x_7 \\ - S_{3.8}x_3x_8 - S_{3.11}x_3x_{11} - S_{3.12}x_3x_{12} - S_{4.6}x_4x_6 - S_{4.8}x_4x_8 - S_{4.9}x_4x_9 \\ - S_{4.11}x_4x_{11} - S_{4.12}x_4x_{12} - S_{4.13}x_4x_{13} - S_{5.9}x_5x_9 - S_{5.13}x_5x_{13} - S_{6.11}x_6x_{11} \\ - S_{6.12}x_6x_{12} - S_{7.9}x_7x_9 - S_{7.10}x_7x_{10} \le B \qquad \forall J = 1 \text{ ou } 0 \end{aligned}$$

$$Max\ f_1(X) = 0.756x_2 + 0.389x_4 + 0.267x_9 + 0.513x_{13}$$

$$Max\ f_2(X) = 0.453x_5 + 1.911x_6 + 0.145x_7 + 0.826x_{11} + 0.138x_{12}$$

$$Max\ f_3(X) = 0.237x_1 + 0.536x_3 + 0.099x_8 + 0.254x_{10}$$

Subject to:

$10x_1$+$4x_2$+$3x_3$+$8x_4$+$8x_5$+$2x_6$+$25x_7$+$20x_8$+$9x_9$+$5x_{10}$+$2x_{11}$+$15x_{12}$+$5x_{13}$
-$0.2x_1x_3$-$0.3x_1x_4$-$0.4x_1x_5$-$0.5x_1x_7$-$1x_1x_8$-$0.8x_1x_9$-$0.5x_1x_{10}$-$0.2x_1x_{11}$-$0.1x_2x_5$-$0.4x_2x_{12}$-
$0.2x_2x_{13}$-$0.2x_3x_7$-$0.2x_3x_8$-$0.1x_3x_{11}$-$0.2x_3x_{12}$-$0.1x_4x_6$-$0.6x_4x_8$-$0.7x_4x_9$-$0.2x_4x_{11}$-
$0.3x_4x_{12}$-
$0.3x_4x_{13}$-1,1x_5x_9-$0.3x_5x_{13}$-$0.1x_6x_{11}$-$0.2x_6x_{12}$-$0.7x_7x_9$-$0.5x_7x_{10}$<=80

ISSN: 2961-6638

We followed a step-by-step procedure to find a satisfactory portfolio of effective resilience strategies. We used LINGO as the optimization software. The optimal solutions yielding the optimal portfolio of resilience strategies are outlined in Table 4

To solve the program, we used LINGO program writing:

TABLE 4 : OPTIMAL PORTFOLIO OF RESILIENCE STRATEGIES (BEFORE COVID-19)

Programme ($\lambda_1, \lambda_2, \lambda_3$)	**X1**	**X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**	**X9**	**X10**	**X11**	**X12**	**X13**	Z_1	Z_2	Z_3	Z_4	Z_5
P1 (1, 0,0)	1	1	1	1	1	1	0	1	1	0	1	1	1	**1.925**				
P2 (0, 1,0)	1	1	0	1	1	1	1	0	0	1	1	1	1		**3.473**			
P3 (0, 0,1)	1	0	1	1	1	1	0	1	1	1	1	1	1			**1.126**		
P4 (1/3,1/3,1/3)	1	1	1	1	1	1	1	0	1	1	1	0	1				**2.095**	
P5 (0.35, 0.55, 0.1)	0	1	1	1	1	1	1	0	1	0	1	1	1					**2.637**

If the company's objective is to maximise the degree of resilience of the procurement process independently of the resilience of other processes, it should opt to implement all the strategies except ST7 and ST10. This would result in an optimal level of resilience Z_1=1.925. In this case, the resilience indicators for the processing and distribution processes are equal to 3.328 and 0.872 respectively.

On the other side, if the company's objective is to maximise the degree of resilience of the treatment process independently of the resilience of the other processes, it should opt to implement all the strategies except ST3, ST8 and ST9. This achieves an optimal level of resilience Z_2=3.473. In this case, the resilience indicators for the supply and distribution processes are equal to 1.658 and 0.491, respectively.

This provides an optimum overall resilience level of 2.095 (i.e. a resilience level of 1.925 for the supply process, 3.335 for the treatment process and 1.027 for the distribution process).

Similarly, if the objective is to simultaneously maximise the resilience of the three processes with the same budgetary constraints and with different emphases on each process (0.35 for the supply process, 0.55

ISSN: 2961-6638

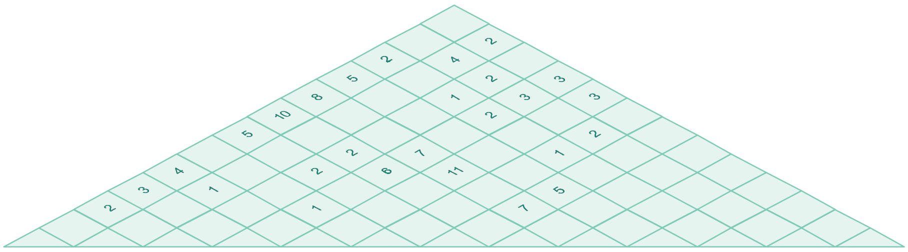
for the treatment process, 0.1 for the distribution process), the optimal solution is to implement all the strategies except ST1, ST8 and ST10. This achieves an optimal overall resilience level of 2.637 (i.e. a resilience level of 1.925 for the supply process, 3.473 for the treatment process, 0.536 for the distribution process).

eventually, we can infer that the optimal portfolio of strategies depends largely on the process for which we are aiming to maximise the degree of resilience and basically on the importance ascribed to each process in terms of maximising its level of resilience.

Assessing the impact of resilience strategies on vulnerability: the case of ZEN (Durant COVID-19)

We adapted the same QFD methodology (vulnerabilities and resiliencies are similar to study 1). Next, we elaborated the same multi-objective methodology approach to find the portfolio of effective resilience strategies during covid-19.

ISSN: 2961-6638



	ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8	ST9	ST10	ST11	ST12	ST13	weights
DV2	0	0	0	0	0	0	0	0	0	0	0.129	0	0	0.129
DV3	0	0.009	0.009	0	0.027	0.009	0.027	0	0	0	0	0.027	0	0.009
DV4	0	0.026	0.026	0	0.026	0.026	0.078	0.078	0.026	0	0.026	0.078	0.078	0.026
SV1	0.081	0.081	0.027	0	0.009	0.009	0.027	0.027	0	0.009	0.009	0.081	0.009	0.009
SV2	0.082	0	0.082	0.082	0.246	0	0.246	0.246	0.082	0.082	0.246	0	0.082	0.082
SV3	0.047	0.141	0.141	0.047	0.047	0.047	0.141	0.141	0.047	0.047	0.141	0.047	0.047	0.047
SV5	0.027	0	0.027	0.027	0.027	0.027	0.027	0.081	0.027	0.027	0.027	0.027	0.027	0.027
FV1	0.033	0.011	0	0.011	0	0	0	0	0	0	0	0	0	0.011
FV2	0.134	0.067	0	0.067	0	0	0	0	0	0	0	0	0	0.067
FV3	0.042	0.042	0	0.042	0.126	0.126	0	0	0.126	0	0.042	0	0	0.042
FV4	0.081	0.027	0	0	0.027	0	0	0	0.027	0.027	0	0	0	0.027
FV5	0.017	0.017	0	0	0.017	0.017	0	0	0.017	0.017	0	0	0.017	0.017
OV1	0.037	0	0.037	0	0.037	0.111	0.037	0	0	0	0.037	0	0	0.037
OV2	0.021	0	0.021	0.021	0.021	0.021	0.021	0	0	0	0.021	0	0	0.021
OV3	0.108	0.324	0.108	0.324	0.324	0.324	0.324	0.324	0.108	0	0	0.972	0	0.108
IV1	0	0.125	0	0.125	0	0	0.125	0.375	0.125	0	0	0.125	0.125	0.125
IV2	0	0.041	0	0	0.041	0	0.041	0.123	0.041	0	0	0.041	0.041	0.041
DO1	0.065	0.065	0.065	0.195	0.065	0.195	0.195	0.195	0.065	0.065	0	0.195	0.195	0.065
DO2	0.026	0.026	0.026	0.078	0.026	0	0.026	0.078	0.026	0.026	0	0.234	0.026	0.026
DO3	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.033	0.011	0.011	0	0.033	0.011	0.011
DO6	0	0	0	0	0.047	0	0.047	0.141	0.047	0.047	0	0.047	0.047	0.047
DO7	0.016	0.016	0.016	0	0.016	0.016	0.016	0.144	0.016	0.048	0.016	0.016	0.048	0.016
AI	0.828	1.029	0.596	1.03	1.14	0.939	1.389	1.986	0.791	0.406	0.694	1.923	0.753	
Coût	10	4	3	8	8	2	25	20	9	5	2	15	5	
RE	0.0828	0.2572	0.1987	0.1287	0.1425	0.4695	0.0555	0.099	0.08789	0.0812	0.347	0.1282	0.1506	

Fig 5: Supply chain resilience model (Durant covid-19): AI=absolute importance; 〖ST〗_j=resilience strategy j; DV, SV, FV, OV, IV, DO =various vulnerabilities; RE=resilience effectiveness.

ISSN: 2961-6638

TABLE 5: EFFECTIVE PORTFOLIO OF RESILIENCE STRATEGIES (DURING COVID-19)

Programme($\lambda_1, \lambda_2, \lambda_3$)	**X1**	**X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**	**X9**	**X10**	**X11**	**X12**	**X13**	**Z1**	**Z2**	**Z3**	**Z4**	**Z5**
P1 (1, 0,0)	1	1	1	1	1	1	0	1	1	0	1	1	1	**0.622**	1.086	0.329		
P2 (0, 1,0)	1	1	0	1	1	1	1	0	0	1	1	1	1	0.535	**1.141**	0.163		
P3 (0, 0,1)	1	1	1	0	1	1	0	1	1	1	1	1	1	0.494	1.086	**0.460**		
P4 (1/3,1/3,1/3)	1	1	1	1	1	1	0	1	1	0	1	1	1	0.622	1.086	0.379	**0.695**	
P5 (0.35, 0.55, 0.1)	0	1	1	1	1	1	1	0	1	0	1	1	1	0.622	1.141	0.198		**0.865**

We followed the stepwise procedure to find the satisfactory portfolio of effective resilience strategies during Covid-19. We used LINGO as the optimization software. The optimal solutions and the portfolio of resilience strategies are depicted in Table 5.

Conclusion

In this research work, we developed effective resilience capabilities of the ZEN supply chain in SFAX in order to mitigate vulnerabilities.

It is noteworthy that the most prominent vulnerabilities can be summarized as follows: problem in production planning and inventory management (OV3), delay in customs clearance (IV1), non-compliance with social standards and environmental factors (SV2) and political instability (DV2).

We can conclude that during covid-19, the company needed to opt for the same portfolios to optimize the resilience of the supply and production processes separately. In this respect,maximizing the total resilience of the three processes simultaneously with the same emphasis on the processes will grant us new solutions.

The results reveal that resilience levels deteriorated during covid-19 compared to the covid-19 period.

ISSN: 2961-6638

References

[1] Kamalahmadi, Masoud.,& Parast,Mahour Mellat.,2016 . A review of the literature on the principles of enterprise and supply chain resilience: Major findings and directions for future research. *The International Journal of Production Economics,* 171, 116–133.

[2] Akao, Y., 1990. Quality Function Deployment: Integrating Customer Requirements into Product Design. Productivity Press, Cambridge, MA.

[3]Bossert, JL., 1991. Quality Function Deployment: A Practitioner's Approach. ASQC Quality Press, NY

[4]Duret, Daniel., & Pillet, Maurice., 2005.Qualité en production : De l'ISO 9000 à Six Sigma. Edition d'Organisation, 406.

[5] Osorio Gómez, J. C., & España, K. T., 2020. Operational Risk Management in the Pharmaceutical Supply Chain Using Ontologies and Fuzzy QFD. *Procedia Manufacturing*, 51, 1673–1679. doi:10.1016/j.promfg.2020.10.233.

[6] Wang, H., Fang, Z., Wang, D., & Liu, S., 2019. An Integrated Fuzzy QFD and Grey Decision-making Approach for Supply Chain Collaborative Quality Design of Large Complex Products. *Computers & Industrial Engineering*, 106212. doi:10.1016/j.cie.2019.106212

[7]Chowdhury, M. M. H., Agarwal, R., &Quaddus, M., 2018. Dynamic capabilities for meeting stakeholders' sustainability requirements in supply chain. *Journal of Cleaner Production*, doi:10.1016/j.jclepro.2018.12.222

[8]Akbas, H., & Bilgen, B., 2017. An integrated fuzzy QFD and TOPSIS methodology for choosing the ideal gas fuel at WWTPs. *Energy*, 125:484−497.

[9]Karsak, E. E., &Dursun, M., 2015. An integrated fuzzy MCDM approach for supplier evaluation and selection. *Computers & Industrial Engineering*, 82, 82–93

[10]Shao, Y., Geyer, P., & Lang, W., 2014. Integrating requirement analysis and multi-objective optimization for office building energy retrofit strategies. *Energy and Buildings*, 82, 356–368.

ISSN: 2961-6638

[11]Kannan, D., &Jafarian, A., 2013. Competitive performance improvement by operational budget allocation using ANFIS and fuzzy quality function deployment : a case study. *The International Journal of Advanced Manufacturing Technology,* 68, 849–862.

[12]Soroor, J., Tarokh, M. J., Khoshalhan, F., &Sajjadi, S., 2012. Intelligent evaluation of supplier bids using a hybrid technique in distributed supply chains. *Journal of Manufacturing Systems,* 31, 240-252.

[13]Ho, W., Dey, P. K., &Lockström, M., 2011. Strategic sourcing: a combined QFD and AHP approach in manufacturing. Supply Chain Management. *An International Journal,* 16(6), 446-461.

[14] Chan, LK.,& Wu, ML.,2002. Quality function deployment: a literature review. *European Journal of Operational Research*, 143(3):463–97.

[15] Faisal, MN., 2013 .Managing risk in small and medium enterprises (SMEs) supply chains' using quality function deployment approach. *International Journal of Operations Research and Information Systems*, 4(1):64–83.

[16] Pujawan, IN., &Geraldin, LH., 2009.House of risk: a model for proactive supply chain risk management. *Business Process Management Journal,* 15 (6):953–67.

[17] Vugrin, ED., Warren, DE., &Ehlen, MA., 2011. A resilience assessment framework for infrastructure and economic systems: quantitative and qualitative resilience analysis of petrochemical supply chains to a hurricane. *Process Safety Progress*, 30(3):280–290. doi:10.1002/prs.10437

[18] Deb, K., 2014. Multi-objective optimization. In: Burke EK, Kendall G, editors. Search methodologies: introductory tutorials in optimization and decision support techniques. New York: Springer; 403–49.

[19] Chowdhury, Md., Maruf, Hossan., &Quaddus, Mohammed .A.,2015 .A multiple objective optimization based QFD approach for efficient resilient strategies to mitigate supply chain vulnerabilities: The case of garment industry of Bangladesh ,*Omega*, 5–21.

ISSN: 2961-6638

[20] Larbani, M., &Aouni, B., 2011. A new approach for generating efficient solutions within the goal-programming model. *Journal of the Operational Research Society,* 62 (1):175–82.

ISSN: 2961-6638