The TQM J

Unveiling the relation between the challenges and benefits of Operational Excellence and Industry 4.0: A Hybrid Fuzzy Decision-Making Approach

Journal:	*The TQM Journal*
Manuscript ID	TQM-07-2022-0237.R1
Manuscript Type:	Research Paper
Keywords:	Decision Making, Excellence, Fuzzy logic, Industry 4.0, Quantitative methods

Unveiling the relation between the challenges and benefits of Operational Excellence and Industry 4.0: A Hybrid Fuzzy Decision-Making Approach

Abstract

Purpose. Operational excellence (OpEx) is a direction toward learning and developing an excellent culture in all aspects of an organization. To reach this culture, revolutionizing activities using industry 4.0 (i4.0) technologies might be a significant empowering tool. This study aims to identify the challenges and benefits of both concepts and investigate their interrelationship to be considered in applying industry 4.0 technologies toward operational excellence.

Design. The challenges and benefits of OpEx and i4.0 are identified and finalized by reviewing the literature. The causal relations between the considered factors are extracted using the fuzzy DEMATEL (Decision Making Trial and Evaluation Laboratory) method. Then, the analytical network process (ANP) is applied to determine the importance and weight of the factors (challenges and benefits of OpEx and i4.0) according to the constructed network.

Findings. The findings illustrated a strong network structure between the factors. First, the causal factors included OpEx and i4.0 challenges, while the OpEx challenges also affected the i4.0 challenges. Both group challenges had a significant effect on OpEx and i4.0 benefits. This means that challenges are the causal factors to be considered in the alignment of i4.0 toward OpEx. Among the OpEx challenges, lack of strategic planning and proper infrastructure were the main influential factors. In contrast, lack of government support and undeveloped business models were identified as the main challenges of i4.0.

Originality. OpEx and i4.0 concepts are reviewed, and their pros and cons are studied. Previous studies determined an interaction among these concepts. However, from a practical viewpoint, the relation between the challenges and benefits of i4.0 and OpEx was studied for the first time for their alignment.

Keywords. Operational excellence, industry 4.0, decision-making trial and Evaluation Laboratory, analytical network process.

1. Introduction

Digitalization has caused a technological revolution by innovations and technologies which necessitate novel advantages for businesses in the digital environment. In the recent decade, digital goods and services have been widely consumed by people worldwide. Statistics revealed that in 2015, digital technologies were spread worldwide, such as (i) 3.174 billion internet users, (ii) 179.6 billion applications of IP traffic per month, (iii) 72500 petabytes of IP traffic per month, (iv) 4.2 billion broadband subscribers, and (v) 4.7 billion smartphone service subscribers (Source, International Telecommunications Union (ITU), ICT Indicators Database, 2016; GSMA, The Mobile Economy 2015, Statista 205, The Statistical Portal, 2016). Furthermore, the global report "eLAC" suggested that it is thought that nearly 1.92 billion people bought and sold goods and services online in 2019. Electronic transactions have worth approximately more than US$ 3.5 trillion (Cepal, 2022), and now it is estimated to be around 2.14 billion people (Coppola, 2022). It is now more popular after the covid-19 global crisis, which led many businesses to electronic platforms. The global report Statista illustrates retail e-commerce sales as an inseparable and inevitable part of digitalization transformation (Figure 1).

According to Figure 1, a growing trend in online sales among people has been observed. It also emphasizes the effect of digital transactions on the global economy, where the current economy is transforming into a digital economy (Bárcena et al., 2018). Therefore, more creative and compatible tools to deal well with contemporary economic issues are required. Thus, managerial challenges in the digital age imply that more innovative activities are highly critical for cost reduction, process acceleration, error-proof operations, and enhanced business elements to face this situation successfully. These challenges are recently supported by some paradigms, such as industry 4.0 (i4.0). This paradigm relies on solid and advanced tools and technologies like the Internet of Things (IoT), cloud computing, additive manufacturing, blockchain (Upadhyay, 2020), 5G, etc. that complies with the new generation of changes and improvements (Sun et al., 2012). Industry 4.0 provides a higher level of operational excellence and improvements for corporations through its technological capabilities (Mangla et al., 2020).

Insert Figure 1

Despite the many benefits and advantages of Industry 4.0, it is recognized as a challenging change process for the future economy and advanced environment. McKinsey reports that about 61% of digitalization projects fail (McKinsey, 2018). This fact emphasizes the companies behavior in dealing with this concept, its implication, and its aspects. Many content and information are published on barriers of i4.0 (Sony et al., 2022; Baier et al., 2022; Raj et al., 2020). In comparison, little research corporates to identify the impact of these barriers and challenges on each other and how to manage them by knowing these relationships.

On the other hand, the role of i4.0 barriers alongside quality improvement and operational excellence is rarely considered by experts (Psarommatis et al., 2020). At the same time, this paper aims to identify and examine the impact of these factors and barriers. For this purpose, the importance of these challenges is calculated using the weight of elements by the proposed methodology.

According to the literature, “Operational Excellence” (OpEx) returns to the quality concept. Hammer (2004) believed that this term discusses high-performance achievements through current tools and operating methods, ensuring reduced costs and errors. Regarding the effects and importance of operational excellence and the penetration rate of industry 4.0, this study aims to identify the benefits and challenges of these two concepts and investigate their effects and interaction. In other words, considering industry 4.0 as a technological evolution that can be supposed to support the evolution and involvement of OpEx, one of the main challenges is to understand the pros and cons of these two streams to gain a philosophical viewpoint regarding the multiple points in aligning these two concepts. Therefore, the results are expected to provide a suitable approach for organizations willing to benefit from this integration.

The remainder of this paper is organized as follows. The next section describes a review of the concepts and their definitions. Then, by reviewing the literature, the challenges and benefits of i4.0 and OpEx are identified. The proposed methodology is then described in the third section. The relations between the challenges and benefits of industry 4.0 and OpEx are then evaluated in the fourth section. The obtained result is then discussed in the fifth section. Finally, the paper is concluded in section 6.

2. Literature review

The Institute for Operational Excellence has defined the OpEx as “a situation where employees see and feel the value flows and can prevent and repair its failure” (institute for operational excellence, 2012), while another institute entitled Shingo (Shingo Model Handbook, 2013) believes that OpEx is achieved by applying the practices throughout the whole organization from 4 points of view of “culture, Continuous Process Improvement, Enterprise Alignment and Results” (Found et al., 2018). Based on the literature, through OpEx, companies can implement strategic plans regarding quality, availability, cost, services, and more options compared with rivals (Treacy and Wiersema, 1995). In another definition, operational excellence includes “excellent Ps,” such as excellent people who fund and work for the business; ideal partners who cooperate with the company to supply, market, sell, etc., and excellent processes which are critical elements for business and management, and finally excellent products that stimulate the customers to continuous purchase (Dahlgaard and Dahlgaard-Park, 1999). The importance of OpEx for any type and size of enterprise has been approved due to its capabilities, such as the search for quality, efficiency, and effectiveness in corporations (Aguilera and Ruíz, 2019). Integrating factors adapted from technology, culture, and organization can dynamically identify the difference between the valuable processes of a company's value chain in the direction of continuous improvement and optimal business changes (Gleich and Sauter, 2008). Increasing productivity and cost reduction are known as the main benefits of OpEx (Ojha, 2015; Moktadir et al., 2020). Relevant research indicates that the OpEx concept consists of several elements, as illustrated in Table 1 (Aguilera and Ruíz, 2019).

Insert Table 1

On the other hand, industry 4.0 has become more prevalent in academic and industrial environments (Buer et al., 2018). This term is based on the smart factory concept. In smart factories, the products are always traceable, timely, and locationally (Crnjac et al., 2017). I4.0 can be a production model with more digitalized processes, value chains, and marked outcomes (Rabelo et al., 2019; Camarinha-Matos et al., 2017). In Industry 4.0 (i4.0), we are moving towards intelligent manufacturing using new methods such as the IoT, cloud services, big data, and analytics. Like the OpEx, i4.0 aims for faster production processes, more flexibility, productivity, cost reduction, etc., making it more desirable for industry managers and academic researchers (Dev et al., 2020). Many industries achieve higher boarders of quality by I4.0 implementation (Mangla, et al., 2019). OpEx is realized as a tool that decreases the cost of I4.0 implementation for sustainable purposes (Dev et al., 2020). The concept of i4.0 is based on a well-prepared database, which leads to continuous improvement processes and optimization in production (Crnjac et al., 2017). Merz and Siepmann (2016) claim that i4.0 implementation will occur at three strategic, tactical, and operation levels (Merz & Siepmann, 2016). In this regard, Crnjac et al. (2017) proposed a model at operational model to achieve Operational Excellence in 7 steps looking at i4.0. The use of new methods has constantly been challenged throughout history. According to Frank et al. (2019), given that big data and its analysis are poorly implemented, companies experienced difficulty implementing i4.0 technologies. Dalmarco et al. (2019) illustrated that data analysis, the use of new technologies by existing equipment and workforce, and computational constraints were the main challenges for companies. Luthra and Mangla (2018) believed that organizational challenges have the most significant impact, followed by technological, strategic, legal, and ethical issues. As confirmed by Kiel et al. (2020), the most critical challenge was combining and integrating technology. The organization should update its internal and external infrastructure and synchronize production facilities and machinery. Subsequently, organizational transformation, data security, competition, and collaboration had the most recurrence among the challenges. Similarly, Schneider (2018) examined the management challenges posed by i4.0. He divided these challenges into the following six categories (i) analysis and strategy, (ii) planning and implementation, (iii) collaboration and networking, (iv) business models, (v) human resources, and (vi) change and leadership. Zhou et al. (2015) expressed that developing intelligent devices, building a network environment, including connecting different networks, modeling CPS, integrating, validating, and testing it, and analyzing and processing big data and digital products are the challenges of achieving i4.0.

Some research and studies only investigated the relationship between i4.0 and some quality techniques such as lean six sigma (Yadav et al., 2020; 2021; Chiarini & Kumar, 2021), lean production (Tripathi et al., 2022), TQM (Chiarini, 2020) or focused on i4.0 and operational excellence elements such as productivity, flexibility, (Fragapane et al., 2020; Long et al., 2018; Demartini & Tonelli, 2018) and human resource (Virmani & Salve, 2021). This study investigates the challenging factors and barriers toward i4.0 implementation regarding Opex. According to Chen et al. (2017), Equipment and facilities intelligence, network integration, and knowledge-based production are among the issues and challenges facing organizations. Furthermore, the lack of automation system virtualization, process design, unstable connections between companies, job disruptions, and uncertain economic benefits have concluded the challenges of i4.0 in the circular economy (Abdul-Hamid et al., 2020). Also, i4.0 has created a gap between the ability of employees and the need to quickly advance their roles (Whysall et al., 2019). Moreover, change resistance, uncertain benefits, and implementation costs are significant challenges in using i4.0 in construction projects (Demirkesen & Tezel, 2021). In another study, management commitment, the need for advanced technology such as sensors, high monetary investment, and lack of government support are identified as the main challenges of using i4.0 in India (Aggarwal et al., 2019). On this account, Data management, integration, and retraining are also considered the main challenges of implementing i4.0 (Tay et al., 2021). Besides, Raj et al. (2020) concluded that the lack of a digital strategy, along with a lack of resources, are the main obstacles to the implementation of Industry 4.0. More recently, Calabrese et al. (2021) identified low financial resources, lack of expertise, and lack of knowledge as the main issues in implementing i4.0 in companies. It can be concluded that the challenges consist of (1) organizational, (2) technical, (3) human resources, (4) financial, (5) social, and (6) quality factors in different industries.

On the other hand, regarding the benefits of i4.0, many scholars have attained exciting results. For instance, Masood and Sonntag (2020) concluded that flexibility, cost, efficiency, quality, and competitive advantage were the main benefits of using i4.0 by small and medium-sized (SME) organizations. Before that, according to Waibel et al., 2017, the use of i4.0 aims for production to adapt quickly and react to changes faster, employees to have more flexible tasks, waste and overproduction to be reduced, and the use of renewable energies can be more effective and provides the possibility of monitoring the conditions remotely. Also, Olsen and Tomlin (2020) illustrated that i4.0 increases the speed of production start-up and makes remote monitoring, control, and optimization possible. Similarly, Ghobakhloo (2020) determined energy sustainability, reducing harmful emissions, and improving social welfare as the benefits of using i4.0. Besides, Pereira et al. (2020) proposed that i4.0 makes real-time production planning and dynamic optimization possible. They also concluded that the use of i4.0 increases productivity due to the creation of happiness and satisfaction. Recently, Enrique et al. (2021) illustrated that the use of i4.0 increases flexibility, which reduces the occurrence of errors and the duration of work, and ultimately causes a competitive advantage.

Alongside i4.0, Operational excellence involves the cooperation of each organization member around a new business tool and principles to achieve an important goal (Roth et al., 2020). To achieve this, there are challenges and obstacles facing organizations. Although research rarely concentrates on Operational excellence, some of them are reviewed as guides to obtain more information. According to Chakraborty et al. (2020), implementing information technology (one of the OpEx approaches) faces obstacles such as lack of expertise, security risk, lack of proper infrastructure, and so on. They believed that a lack of financial resources hinders the growth of IT infrastructure to achieve operational excellence.

Conversely, the effort and planning to achieve OpEx results in more benefits. More recently, Tariq et al. (2021) concluded that cultural constraints, fear of the unknown, lack of skilled manpower, and lack of strategic planning are issues to achieving operational excellence through artificial intelligence. Summarizing the reviewed studies, the main challenges and benefits of the two constructs of the current study are represented in Figure 2.

Insert Figure 2

Miandar et al. (2020) reviewed the literature and studies to specify the relation between OpEx and i4.0. They unveiled a supportive relation and interaction between these two concepts. Also, Chiarini and Kumar (2021) investigated a similar connection between i4.0 and leaned six sigma as a new pattern to develop OpEx. They concluded that the implementation of new tools and their integration requires companies to engage in preparatory activities. Luz Tortorella et al. (2022) recently studied the OpEx regarding i4.0, considering four critical aspects: people, participants, processes, and products. However, the relation between the challenges and benefits of i4.0 and OpEx has not been studied in previous studies, which is the main objective of the current manuscript.

3. Methodology

This paper aims to realize the interactions and causal effects among the identified factors to control and propose practical directions for corrective guidelines and actions. Considering the network structure between the criteria (i.e., challenges and benefits of i4.0 and OpEx), one of the most appropriate solutions is DEMATEL to determine the causal network of these challenges and advantages (Decision Making Trial and Evaluation Laboratory) (Kiani Mavi and Standing, 2018). This method makes it possible to visualize the intensity of relationships and their importance by using the theories of graphs and matrix calculations (Ullah et al., 2021). Furthermore, Analytical Network Process (ANP) is a suitable method to link with the DEMATEL method to calculate the importance of criteria and prioritize them (Salehi et al., 2021). Although ANP is a popular method to recognize the influence of factors according to their interactions, it is often difficult for public decision-makers to understand and extract these interrelationships. Here, the DEMATEL method with cause and effect analytical nature enables the experts to perceive the interactions and identify the effects throughout the network of factors (Ortíz et al., 2015).

It seems reasonable that experts use linguistic variables to state their opinion and judge the alternatives and factors during the decision-making process (Chen & Chiu, 2021). More often, uncertainty occurs when the weight of criteria, the importance of experts opinions, and the value of variables are stated with linguistic variables (Peng, Zhou, & Peng, 2017). Uncertainty is undeniably affecting the decision-making process and its results. On this account, cognitive concepts are assumed and supposed as an approach to deal with this issue. (Mushtaq, Bland, & Schaefer, 2011). For decades, fuzzy sets have been proposed as a suitable solution for dealing with uncertainty (Tong & Bonissone, 1980). Since 1965 fuzzy sets have been effectively employed in operational research problems to solve ambiguity and negative effects. It is recognized as a practical tool for both qualitative and quantitative analyses and proposes a suitable way for researchers to solve problems with verbal and conceptual studies (Li, 2013). All of the mentioned methods, such as ANP, can use fuzzy numbers according to the uncertainty of the environment and experts hesitation and intuition (Karuppiah et al., 2020).

In this research, the authors have employed the fuzzy DANP method, which combines the fuzzy DEMATEL technique with the ANP (Yang et al., 2008). To achieve the results, the authors have gone through the following steps. Remark that there are *m* dimensions, each measure has *n* dimensions, and the opinions of *P* experts are gathered (Dinçer et al., 2019; Mahmoudi et al., 2019).

1. First, it is required to form the fuzzy DEMATEL direct communication matrix using the linguistic scale represented in Table 2. At first, the authors developed the raw matrix, and then the linguistic terms were converted into their equivalent fuzzy numbers and merged as follows. Note that the value of $\tilde{E}_{ij}^{k} = \left(l_{ij}^{k}, m_{ij}^{k}, u_{ij}^{k}\right)$ represents the fuzzy estimation of expert *k* for the influence of the *i*th element (dimension/ factor) on the *j*th element.

$$\tilde{x}_{ij} = \frac{\sum_{k=1}^{P}\tilde{E}_{ij}^{k}}{P} = \left(\frac{\sum_{k=1}^{P} l_{ij}^{k}}{P}, \frac{\sum_{k=1}^{P} m_{ij}^{k}}{P}, \frac{\sum_{k=1}^{P} u_{ij}^{k}}{P}\right) \quad (1)$$

Insert Table 2

----

2. The obtained matrix is then normalized using the following formulas.

$$\tilde{X} = K.\tilde{Y} \quad (2)$$

$$K = \frac{1}{\max\limits_{1\le i\le n}\sum_{j=1}^{n} u_{ij}} i,j = 1,2,\ldots \quad (3)$$

3. Then, the total relations matrix (TRM) was constructed according to equation 4.

$$\tilde{T} = \lim_{s \to \infty} (\tilde{Y} + \tilde{Y}^2 + \ldots + \tilde{Y}^s) \quad (4)$$

4. Using Opricovic and Tzeng, (2003), the $\tilde{T}$ matrix was defuzzified. To this aim, the triangular fuzzy number $\tilde{t}_{ij} = \left(l_{ij}^k, m_{ij}^k, u_{ij}^k\right)$ was normalized as follows.

$$\tilde{z}_{ij} = \frac{\tilde{t}_{ij} - \min_i l_{ij}^t}{\max_i u_{ij}^t - \min_i l_{ij}^t} \quad (5)$$

Then the left and the right normalized bound matrix was obtained as follows ($LR = \left[\left(l_{ij}^a, r_{ij}^a\right)\right]_{n \times n}$).

$$l_{ij}^a = \frac{m_{ij}^z}{1 + m_{ij}^z - l_{ij}^z} \quad (6)$$

$$r_{ij}^a = \frac{u_{ij}^z}{1 + u_{ij}^z - m_{ij}^z} \quad (7)$$

Accordingly, the crisp normalized matrix ($V = \left[v_{ij}\right]_{n \times n}$) was obtained as follows.

$$v_{ij} = \frac{l_{ij}^a(1 - l_{ij}^a) + r_{ij}^a \times r_{ij}^a}{1 - l_{ij}^a + r_{ij}^a} \quad (8)$$

Eventually, the final crisp matrix was formed as follows ($F = \left[f_{ij}\right]_{n \times n}$).

$$f_{ij} = \min_i l_{ij}^t + v_{ij} \times \left(\max_i u_{ij}^t - \min_i l_{ij}^t\right) \quad (9)$$

5. To draw the cause-effect diagram, the sum of rows vector $\tilde{D}$, and the sum of columns vector $\tilde{R}$ were calculated as follows.

$$\tilde{D} = [\textstyle\sum_{i=1}^{n} \tilde{f}_{ij}] \quad (10)$$

$$\tilde{R} = [\textstyle\sum_{j=1}^{n} \tilde{f}_{ij}] \quad (11)$$

$\tilde{R}$+$\tilde{D}$ and $\tilde{R}$-$\tilde{D}$ values indicate the degree of significance and degree of causality, respectively. Notably, the above steps were performed for the dimensions, i.e., OpEx and i4.0 challenges and benefits, and their corresponding factors, respectively ($F^g = \left[f_{ij}^g\right]_{m \times m}; i,j = 1,\ldots,m$, $F^h = \left[f_{kl}^h\right]_{n \times n}; k,l = 1,\ldots,n$).

6. Then, the weightless supermatrix (W) was formed. First, the F^hmatrix was normalized. For this purpose, the column elements were divided by the sum of the corresponding column elements.

$$N^h = \begin{bmatrix} f_{11}^h/h_1 & \cdots & f_{1l}^h/h_1 & \cdots & f_{1n}^h/h_1 \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ f_{k1}^h/h_i & \cdots & f_{kl}^h/h_i & \cdots & f_{kn}^h/h_i \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ f_{n1}^h/h_n & \cdots & f_{nl}^h/h_n & \cdots & f_{nn}^h/h_n \end{bmatrix}; \quad (12)$$

$$h_k = \sum_{l=1}^{n} f_{kl}^h$$

Afterwards, the matrix was transposed, and the weightless supermatrix (W^f) was obtained.

7. The final crisp matrix of criteria $\left(F^g = \left[f_{ij}^g\right]_{m \times m}\right)$ consists of $n \times n$ sub-matrices for n dimensions. Each sub-matrix was normalized as in the previous step to obtain the unweighted criteria matrix. After normalizing all the sub-matrices ($N^g = \left[n_{ij}^g\right]_{m \times m}$), as in the previous step, they were transposed; finally, the weightless supermatrix of the criteria (W^g) eventuated. The weighted supermatrix ($W = \left[w_{ij}\right]_{m \times m}$) was obtained through $w_{ij} = w_{ij}^g \times w_{kl}^h$.
8. Ultimately, the obtained matrix was multiplied by itself several times ($\lim_{u \to \infty} W^u$) until it converges to a constant value, which is the weight of each criterion.

Insert Figure 3

----

4. Results

The hybrid FDANP has been implemented, and the results are described in the following section. The results are based on the experience and intuition of twelve experts. At first, a framework consisting of potential experts is identified. To select a group of appropriate experts, the following criteria were considered (i) at least a master degree in related topics, e.g., industrial engineering, technology management, operations management, logistic, supply chain management, etc., (ii) at least five years of experience in one of the fields of i4.0, OpEx, or preferably both, (iii) reputation in at least one of the considered concepts. Considering the mentioned qualifications and via a snowball sampling method (Bernard, 2000), a list of 17 experts was identified, and 12 experts agreed to participate in the research. Table 3 illustrates the experts qualifications.

Insert Table 3

Using linguistic variable and their corresponding triangular fuzzy numbers (TFNs) in Table 2, the fuzzy initial direct relation matrix of individual experts is extracted and then aggregated. In the following steps, the normalized initial direct-relation matrix and the total-relation matrix were calculated, as shown in Table 4. Step 5 uses the CFCS method to get the defuzzified total relation matrix (see Table 5). The authors set a threshold value (0.59) to filter out negligible relationships. The threshold was measured based on the arithmetic mean of the total relationship matrix values. The essential relationships are shown in italic and underlined values. Using the dataset (R+C) and (R-C) given in Table 5, the causal diagram of the dimensions was plotted as presented in Figure 4. As shown in Figure 4, OpEx benefits (D_2) were the most critical dimension having the highest (R+C) value. The rest of the dimensions were ranked as Industry 4 benefits (D_4), Industry 4 challenges (D_3), and OpEx challenges (D_1). Moreover, the dimensions were divided into two clusters, namely the cause cluster and the effect cluster, based on (R-C) values. Positive values of R-C were considered causes, and negative values of R-C were assumed as effects. The cause cluster included D_1 and D_3 with positive (R-C) values, while the effect cluster was composed of D_2 and D_4 with negative (R-C) values.

Insert Table 4

Insert Table 5

Insert Figure 4

A similar procedure (steps 1–6) was also applied for the criteria level. After measuring the defuzzified total relation matrix for criteria, the datasets of (R+C) and (R-C) were extracted as given in Table 6. The essential criteria in each dimension can be determined based on (R+C) values. Consequently, (i) lack of financial resources was the most important among the OpEx challenges, followed by (ii) lack of expertise and (iii) lack of proper infrastructure. In the OpEx benefits, the criteria were ranked as (i) increasing productivity, (ii) increasing production, (iii) cost reduction, and (iv) increasing customer satisfaction. On the other hand, (i) digital production was the most critical criteria in the industry 4.0 challenges, followed by (ii) high monetary investment and (iii) integration of technology. Eventually, (i) competitive advantage was the most important amongst the industry 4.0 benefits, followed by (ii) efficiency and (iii) use of renewable energy. Moreover, based on (R-C) values, the cause-and-effect clusters are determined in the last column of Table 6.

Insert Table 6

Based on the crucial relationships using a threshold value (0.53) for the defuzzified total relation matrix, the impact relation map can be illustrated in Figure 5, which indicates the cause-and-effect relationship among the leading and sub-criteria, including the benefits and challenges of OpEx and i4.0.

Insert Figure 5

Following steps 7 and 8 (ANP), the unweighted super-matrix of dimensions and the unweighted super-matrix of criteria were constructed. Step 9 calculated the weighted matrix by multiplying the matrices for the requirements and dimensions. Finally, the weighted super-matrix was limited to get a long-term stable super-matrix. The global influential weights of criteria are given in Table 7. It turns out that (i) Increasing productivity with the weight (0.083), (ii) Increasing customer satisfaction (0.075), (iii) Cost reduction (0.073), and (iv) Increasing production (0.072), all from the OpEx benefits dimension were the most important ones.

Insert Table 7

----

5. Discussion and Implications

Operational excellence as a qualitative concept is widely required by enterprises and businesses. It necessitates more innovative approaches (Pellissier, 2009) and technologies (Miandar et al., 2020). Industry 4.0 revolution and its tools and principles provide a combination of IT and ICT innovations (Barreto et al., 2017). Today industries need to get along with this revolution and benefit from its advantages; however, they should also deal with relevant problems and challenges. To this aim, many studies were reviewed to identify the benefits and challenges of OpEx and i4.0. The previous research and studies were significantly around the benefits and challenges of these two concepts separately. At the same time, few studies tried to investigate their effects on each other to determine how to integrate them for organizational improvements. According to these studies, the most common issue happens while implementing and integrating new technologies, as the companies should prepare and update the present physical infrastructures to match new technologies (Kiel et al., 2020). Then the industries face so-called "soft issues" such as strategy, planning, human resource, collaboration, etc.

Furthermore, the employees should be personally and professionally prepared and qualified to develop ambitious goals through the tools of i4.0 (Whysall et al., 2019). The present study concentrated on the challenges and benefits of OpEx and i4.0 and their behavior regarding each other. The challenges and benefits were extracted through the literature and finalized by expert opinions for this aim. Afterwards, the interrelationship between these elements was extracted, and their weights were determined using FDANP. These weights probably help senior managers prioritize the improvement actions regarding their limited resources by looking at these weights and determining their importance.

Based on the obtained results (Table 6), the weight of the "lack of financial resources" was the highest weight among OpEx challenges suggesting the significant effect of monetary support (Oesterreich and Teuteberg, 2016; Erol et al., 2016; Calabrese et al., 2021) as a challenge for enterprises while implementing i4.0 tools and principles. As previously mentioned, the literature claimed that the first challenge for technology integration relates to infrastructures, which depend on financial support. Therefore, corporates, especially startups in different funding stages, should precisely consider the present budget and required financial supports and investments when claiming how to work and responding to the business's future changes. Required infrastructures are expensive and should be seen in the company's road map. "Lack of expertise" is ranked the second OpEx effective challenge, as was previously mentioned as the soft tissue and challenge of corporations toward technology integration (Chakraborty et al., 2020; Calabrese et al., 2021). In the primary steps, skilled personnel and educated employees will matter while staffing and selecting the critical partners for startups. In return, "increasing productivity" was determined as the most important benefit of OpEx (Pereira et al., 2020).

On the other hand, the challenges of industry 4.0 were examined, and "investment" was recognized as the most effective element (Bosman et al., 2019). Considering the uncertainty in a competitive economy and scarce resources, investing in the correct part of this technology integration is crucial to start with preferable activities and prevent financial waste. Industry 4.0, with its achievement and effects, brings "advantages" for companies; relevant tools and methods lead to savings, cost reduction, and more productivity (Pinon et al., 2018). Due to the high financial requirement to equip the organizations infrastructure, savings are desirable for companies. In addition to examining the weight and importance of benefits and challenges separately, the interrelationships of these elements were investigated in this study. According to results (Figure 5), OpEx challenges affect both challenges and benefits of industry 4.0. As operational excellence encompasses extended and total concepts of quality, it may cause effects industry 4.0 dimensions. It also supports industry 4.0 (Miandar et al., 2020).

The lack of proper infrastructure interestingly affects the benefits and challenges of industry 4.0. It requires "intelligent equipment" and consequently requires "high monetary investment" (i4.0 challenges). On the other hand, this impacts quality, flexibility, efficiency, and competitive advantages (Hou, 2020). Lack of financial resources may lead to changes in high monetary investment, quality, and competitive advantages and require companies to substitute renewable energies (Guan, et al., 2021). According to Figure 5, cost reduction and increased production impact competitive advantage (Payaro et al., 2018). Furthermore, the "increase in customer satisfaction" leads to changes in "social welfare" (Fraser and Wu, 2016). Moreover, the i4.0

challenges influences were investigated. These challenges significantly affected the OpEx benefits, such as “increasing productivity” (Setiawan et al., 2022). Regarding these challenges, the absence of a “clear Business model” and lack of “process design” as managerial concepts may cause changes in productivity (Osiyevskyy et al., 2020). Besides, the impact of i4.0 challenges was examined on OpEx challenges as “digital production” influenced two dimensions so-called “lack of expertise” and “lack of financial resources” (Luz Tortorella et al., 2022). These two items of OpEx challenges were also influenced by the i4.0 benefits such as “efficiency” (Abdalmenem et al., 2019).

6. Conclusion and Future Recommendation

Although some studies investigated the challenges and benefits of OpEx and i4.0, their relationships, effective elements, synchronous analysis, prioritizing their interaction precedence, and weights were neglected in the previous research. After extracting the aspects through the literature review, they were finalized according to experts opinions. Then, the pairwise matrix of these elements was established and completed by the same experts. The result illustrated the strength and significant interrelationship among the OpEx and i4.0 challenges and benefits. The identified network of relations proposed that while OpEx challenges affected both challenges and benefits of i4.0, these two concepts have a significant effect on i4.0 benefits. The findings suggested that operational excellence behaves supportively and requires the companies to implement i4.0 to compensate for the shortages and lack of resources by efficient results of its new tools. While it was supposed that i4.0 affects the OpEx, this study reveals their synchronous implementation as complementary to each other. Therefore, it can be said that this concept has not been applied as widely as expected due to a lack of sufficient recognition and existing challenges. *Theoretically,* the main contribution of the current study can be considered as aggregating two distinctly matured fields of OpEx and i4.0 that are studied deeply and jointly. Still, previous studies do not consider the mutual relations among the challenges and benefits of these fields.

Beyond the above findings, the current study deals with some limitations that can be divided into theoretical and methodological boundaries. The theoretical limitation refers to the lack of studies on the OpEx challenges and benefits that can be extended in future research. Also, there is no consensus on the OpEx definition (Liu, Jazayeri, Dadi, Maloney, & Cravey, 2015)and its current definitions are very broad, while it seems essential to concentrate on some aspects (Found, Lahy, Williams, Hu, & Mason, 2018). Furthermore, the current framework is extracted generally, while future studies can propose industry-specific frameworks. From the point of view of methodological perspective, The vital role of experts is undeniable for OpEx models (Liu, Jazayeri, Dadi, Maloney, & Cravey, 2015). However, the input of the FDANP analysis in this research was gathered from the experts of the emerging economy of Iran with limited experience in OpEx and i4.0. Hence, the results might not be generalizable for developed and developing countries. Also, the reviews suggest that OpEx applications are minimal worldwide (Antony, et al., 2022). As mentioned before, there is a vast difference between the conceptual and operational definitions of the OpEx concept. A systematic literature review, or any other study, to reach a more refined and consensed definition of OpEx might be an essential clue for further research.

Moreover, a system dynamic-based approach can be proposed to analyze and evaluate the dynamicity of relations among the concepts. The generalization of the findings using other types of uncertainty and cognitive mapping methods can be another clue for future studies. Using the Delphi approach and the opinions of experts from global firms with successful experience in implementing i4.0 and OpEx provides a valuable source of benchmarking and policy making.

References

Abdalmenem, S. A., Abu-Naser, S. S., Al Shobaki, M. J., and Abu Amuna, Y. M. (2019), *Relationship between e-Learning Strategies and Educational Performance Efficiency in Universities from Senior Management Point of View.*

Abdul-Hamid, A. Q., Ali, M. H., Tseng, M. L., Lan, S., and Kumar, M. (2020), Impeding challenges on industry 4.0 in circular economy: Palm oil industry in Malaysia. *Computers and Operations Research*, *123*, 105052.

Aggarwal, A., Gupta, S., and Ojha, M. K. (2019), Evaluation of key challenges to industry 4.0 in Indian context: a DEMATEL approach. In *Advances in Industrial and Production Engineering* (pp. 387-396), Springer, Singapore.

Aguilera, J. T., and Ruíz, N. (2019), Operational Excellence: Concept Review and Meaning Restructuration. *International Conference on Industrial Engineering and Operations Management* (pp. 678-688), Bangkok,: IEOM Society International.

Bárcena, A., Prado, A., Cimoli, M., and Pérez, R. (2018), *The new digital revoltion; From the customer internet to the industrial internet.* Economic Commission for Latin America and the Caribbean (ECLAC),

Barreto, L., Amaral, A., and Pereira, T. (2017), Industry 4.0 implications in logistics: an overview. *Procedia manufacturing, 13*, 1245-1252.

Bernard, H. (2000), *Social research methods: qualitative and quantitative approahces.* New Delhi: Sage Publications Inc.

Bosman, L., Hartman, N., and Sutherland, J. (2019), How manufacturing firm characteristics can influence decision making for investing in Industry 4.0 technologies. *Journal of Manufacturing Technology Management.*

Calabrese, A., Levialdi Ghiron, N., and Tiburzi, L. (2021), 'Evolutions' and 'revolutions' in manufacturers' implementation of industry 4.0: a literature review, a multiple case study, and a conceptual framework. *Production Planning and Control*, *32*(3), 213-227.

Chakraborty, S., Sharma, A., and Vaidya, O. S. (2020), Achieving sustainable operational excellence through IT implementation in Indian logistics sector: an analysis of barriers. *Resources, Conservation and Recycling*, *152*, 104506.

Chen, B., Wan, J., Shu, L., Li, P., Mukherjee, M., and Yin, B. (2017), Smart factory of industry 4.0: Key technologies, application case, and challenges. *Ieee Access*, *6*, 6505-6519.

Chevalier, S. (2022, 7 1), *https://www.statista.com/statistics/379046/worldwide-retail-e-commerce-sales/#statisticContainer*. Retrieved from Statista: https://www.statista.com/statistics/379046/worldwide-retail-e-commerce-sales/#statisticContainer

Chiarini, A., and Kumar, M. (2021), Lean Six Sigma and Industry 4.0 integration for Operational Excellence: evidence from Italian manufacturing companies. *Production planning and control, 32*(13), 1084-1101.

Coppola, D. (2022, 7 1), *Number of digital buyers worldwide from 2014 to 2021*. Retrieved from Statista: https://www.statista.com/statistics/251666/number-of-digital-buyers-worldwide/

Dahlgaard, J., and Dahlgaard-Park, S. (1999), Integrating business excellence and innovation management: developing a culture for innovation, creativity and learning,. *Total quality management, 10*(4-5), S465-S471.

Dalmarco, G., Ramalho, F. R., Barros, A. C., and Soares, A. L. (2019), Providing industry 4.0 technologies: The case of a production technology cluster. *The journal of high technology management research*, *30*(2), 100355.

Demirkesen, S., and Tezel, A. (2021), Investigating major challenges for industry 4.0 adoption among construction companies. *Engineering, Construction and Architectural Management*.

Dinçer, H., Yüksel, S., and Martínez, L. (2019), Interval type 2-based hybrid fuzzy evaluation of financial services in E7 economies with DEMATEL-ANP and MOORA methods. *Applied Soft Computing Journal*, *79*, 186–202. https://doi.org/10.1016/j.asoc.2019.03.018

Enrique, D. V., Druczkoski, J. C. M., Lima, T. M., and Charrua-Santos, F. (2021), Advantages and difficulties of implementing Industry 4.0 technologies for labor flexibility. *Procedia Computer Science*, *181*, 347-352.

Erol, S., Jäger, A., Hold, P., Ott, K., and Sihn, W. (2016), Tangible Industry 4.0: a scenario-based approach to

learning for the future of production. *Procedia CiRp*, *54*, 13-18.
Cepal, N.U. (2022), *Digital technologies for a new future.* Latin America and the Caribbean (ECLAC),
Frank, A. G., Dalenogare, L. S., and Ayala, N. F. (2019), Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics*, *210*, 15-26.
Fraser, M. W., and Wu, S. (2016), Measures of consumer satisfaction in social welfare and behavioral health: A systematic review. *Research on Social Work Practice, 26*(7), 762-776.
Ghobakhloo, M. (2020), Industry 4.0, digitization, and opportunities for sustainability. *Journal of cleaner production*, *252*, 119869.
Gleich, R., and Sauter, R. (2008), *Operational Excellence: Innovative Approaches and Best Practices in the Production.* Haufe-Lexware: Verlag GmbH and Co. KG.
Guan, D., Comite, U., Sial, M. S., Salman, A., Zhang, B., Gunnlaugsson, S. B., and Mentel, G. (2021), The impact of renewable energy sources on financial development, and economic growth: The empirical evidence from an emerging economy. *Energies, 14*(23),
Hammer, M. (2004), Deep Change: How Operational Innovation Can Transform Your Company. *Harvard Business Review, 82*(4), 84-93.
Hou, C. K. (2020), The effects of IT infrastructure integration and flexibility on supply chain capabilities and organizational performance: An empirical study of the electronics industry in Taiwan. *Information Development, 36*(4), 576-602.
Karuppiah, K., Sankaranarayanan, B., Ali, S. M., Chowdhury, P., and Paul, S. K. (2020), An integrated approach to modeling the barriers in implementing green manufacturing practices in SMEs. *Journal of Cleaner Production*, *265*, 121737. https://doi.org/10.1016/j.jclepro.2020.121737
Kiel, D., Müller, J. M., Arnold, C., and Voigt, K. I. (2020), Sustainable industrial value creation: Benefits and challenges of industry 4.0. In *Digital Disruptive Innovation* (pp. 231-270),
Kiani Mavi, R., and Standing, C. (2018), Critical success factors of sustainable project management in construction: A fuzzy DEMATEL-ANP approach. *Journal of Cleaner Production*, *194*, 751–765. https://doi.org/10.1016/j.jclepro.2018.05.120.
Luthra, S., and Mangla, S. K. (2018), Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies. *Process Safety and Environmental Protection*, *117*, 168-179.
Luz Tortorella, G., Cauchick-Miguel, P. A., Li, W., Staines, J., and McFarlane, D. (2022), What does operational excellence mean in the Fourth Industrial Revolution era? *International Journal of Production Research, 60*(9), 2901-2917.
Mahmoudi, S., Jalali, A., Ahmadi, M., Abasi, P., and Salari, N. (2019), Identifying critical success factors in Heart Failure Self-Care using fuzzy DEMATEL method. *Applied Soft Computing Journal*, *84*, 105729. https://doi.org/10.1016/j.asoc.2019.105729
Mangla, S. K., Kusi-Sarpong, S., Luthra, S., Bai, C., Jakhar, S. K., and Khan, S. A. (2020), Operational excellence for improving sustainable supply chain performance. *Resources, Conservation, and Recycling, 162*.
Masood, T., and Sonntag, P. (2020), Industry 4.0: Adoption challenges and benefits for SMEs. *Computers in Industry*, *121*, 103261.
Miandar, T., Galeazzo, A., and Furlan, A. (2020), Coordinating knowledge creation: a systematic literature review on the interplay between operational excellence and Industry 4.0 technologies. *Knowledge Management and Industry 4.0*, 137-162.
Moktadir, M. A., Dwivedi, A., Rahman, A., Chiappetta Jabbour, C. J., Paul, S. K., Sultana, R., and Madaan, J. (2020), An investigation of key performance indicators for operational excellence towards sustainability in the leather products industry. *Business Strategy and the Environment*, *29*(8), 3331-3351.
Ojha, S. K. (2015), Operational excellence for sustainability of Nepalese industries. *Procedia-Social and Behavioral Sciences*, *189*, 458-464.
Olsen, T. L., and Tomlin, B. (2020), Industry 4.0: Opportunities and challenges for operations management. *Manufacturing and Service Operations Management*, *22*(1), 113-122.
Oesterreich, T. D., and Teuteberg, F. (2016), Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in industry*, *83*, 121-139.

Opricovic, S., and Tzeng, G. H. (2003), Defuzzification within a multicriteria decision model. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, *11*(05), 635-652.

Osiyevskyy, O., Bao, Y., and DaSilva, C. M. (2020), Using AI to improve economic productivity: a business model perspective. *Handbook of artificial intelligence and robotic process Automation: policy and government applications*, 57.

Payaro, A., Naik, A. A., Guedez, R., and Laumert, B. (2018), Identification of required cost reductions for CSP to retain its competitive advantage as most economically viable solar-dispatchable technology. *In AIP Conference Proceedings.*

Pellissier, R. (2009), Innovation in operational excellence in a complex environment. *PICMET'09-2009 Portland International Conference on Management of Engineering and Technology* (pp. 811-825), Portland : IEEE.

Pereira, A. G., Lima, T. M., and Santos, F. C. (2020), Industry 4.0 and Society 5.0: opportunities and threats. *International Journal of Recent Technology and Engineering*, *8*(5), 3305-3308.

Pinon, M., Nascimento, M. H., de AB Junior, J., Tavares, T., and de Souza Silva, V. L. (2018), Applications and Advantages of the Internet of Things (IoT) at Industry . *Journal of Engineering and Technology for Industrial Applications, ITEGAM-JETIA, 4*(15), 189-194.

Raj, A., Dwivedi, G., Sharma, A., de Sousa Jabbour, A. B. L., and Rajak, S. (2020), Barriers to the adoption of industry 4.0 technologies in the manufacturing sector: An inter-country comparative perspective. *International Journal of Production Economics*, *224*, 107546.

Roth, N., Deuse, J., and Biedermann, H. (2020), A framework for System Excellence assessment of production systems, based on lean thinking, business excellence, and factory physics. *International Journal of Production Research*, *58*(4), 1074-1091.

Shamim, S., Cang, S., Yu, H., and Li, Y. (2016, July), Management approaches for Industry 4.0: A human resource management perspective. In *2016 IEEE congress on evolutionary computation (CEC)* (pp. 5309-5316), IEEE.

Sung, T. K. (2018), Industry 4.0: a Korea perspective. *Technological forecasting and social change*, *132*, 40-45.

Salehi, R., Asaadi, M. A., Haji Rahimi, M., and Mehrabi, A. (2021), The information technology barriers in supply chain of sugarcane in Khuzestan province, Iran: A combined ANP-DEMATEL approach. *Information Processing in Agriculture*, *8(3)*, 458-468.

Schneider, P. (2018), Managerial challenges of Industry 4.0: an empirically backed research agenda for a nascent field. *Review of Managerial Science*, *12*(3), 803-848.

Setiawan, I., Buana, U. M., and Buana, U. M. (2022), Integration of Total Productive Maintenance and Industry 4. 0 to increase the productivity of NC Bore machines in the Musical Instrument Industry. *In Proceedings of the 11th Annual International Conference on Industrial Engineering and Operations Management*, *11*, pp. 4701-4711. Singapore.

Sun, Y., Yan, H., Lu, C., Bie, R., and Thomas, P. (2012), A holistic approach to visualizing business models for the internet of things. *Communications in Mobile Computing, 1*(1), 1-7.

Tay, S. I., Alipal, J., and Lee, T. C. (2021), Industry 4.0: Current practice and challenges in Malaysian manufacturing firms. *Technology in Society*, *67*, 101749.

Tariq, M. U., Poulin, M., and Abonamah, A. A. (2021), Achieving Operational Excellence Through Artificial Intelligence: Driving Forces and Barriers. *Frontiers in Psychology*, *12*.

Treacy, M., and Wiersema, F. (1995), *The discipline of market leaders: Choose your customers, narrow your focus, dominate your market.* New York: Perseus Books.

Ullah, F., Sepasgozar, S. M. E., Jamaluddin Thaheem, M., Cynthia Wang, C., and Imran, M. (2021), It’s all about perceptions: A DEMATEL approach to exploring user perceptions of real estate online platforms. *Ain Shams Engineering Journal*, *12*(4), 4297–4317. https://doi.org/10.1016/j.asej.2021.04.023

Upadhyay, N. (2020), Demystifying blockchain: A critical analysis of challenges, applications and opportunities. *International Journal of Information Management, 54*.

Waibel, M. W., Steenkamp, L. P., Moloko, N., and Oosthuizen, G. A. (2017), Investigating the effects of smart production systems on sustainability elements. *Procedia manufacturing*, *8*, 731-737.

Whysall, Z., Owtram, M., and Brittain, S. (2019), The new talent management challenges of Industry 4.0. *Journal of Management Development*.

Wu, W. W. (2012), Segmenting critical factors for successful knowledge management implementation using the fuzzy DEMATEL method. *Applied Soft Computing Journal*, *12*(1), 527–535.

https://doi.org/10.1016/j.asoc.2011.08.008
Yang, Y., Shieh, H., Leu, J., and Tzeng, G.-H. (2008), A novel hybrid MCDM model combined with DEMATEL and ANP with applications. *International Journal of Operations Research*, *5*(3), 160–168.
Zhou, K., Liu, T., and Zhou, L. (2015, August), Industry 4.0: Towards future industrial opportunities and challenges. In *2015 12th International conference on fuzzy systems and knowledge discovery (FSKD)* (pp. 2147-2152), IEEE.

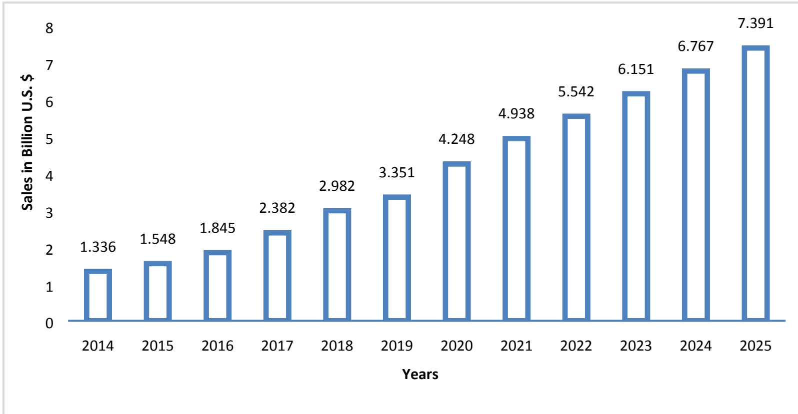

Figure 1. Retail e-commerce sales worldwide from 2014 to 2025 (Source: Chevalier, 2022)

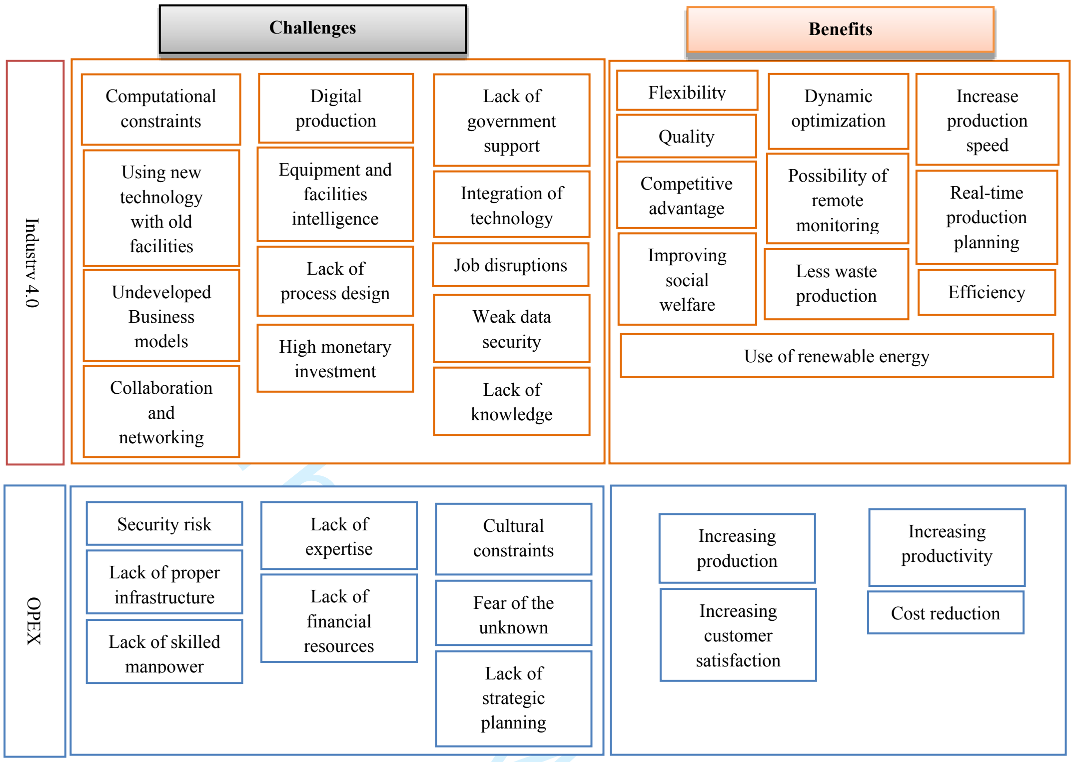

Figure 2. The main challenges and benefits of i4.0 and OpEx

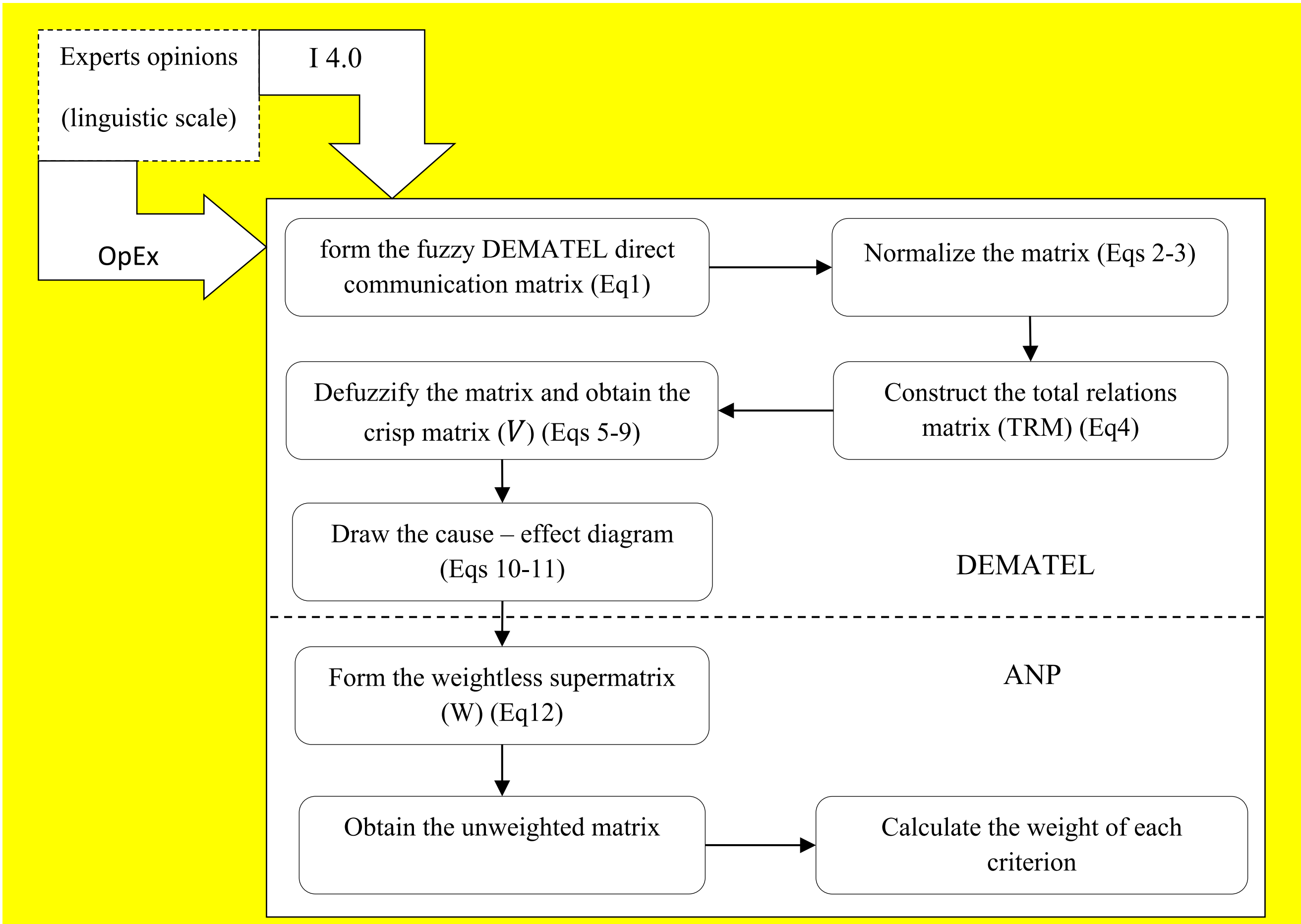

Figure 3. The methodology steps

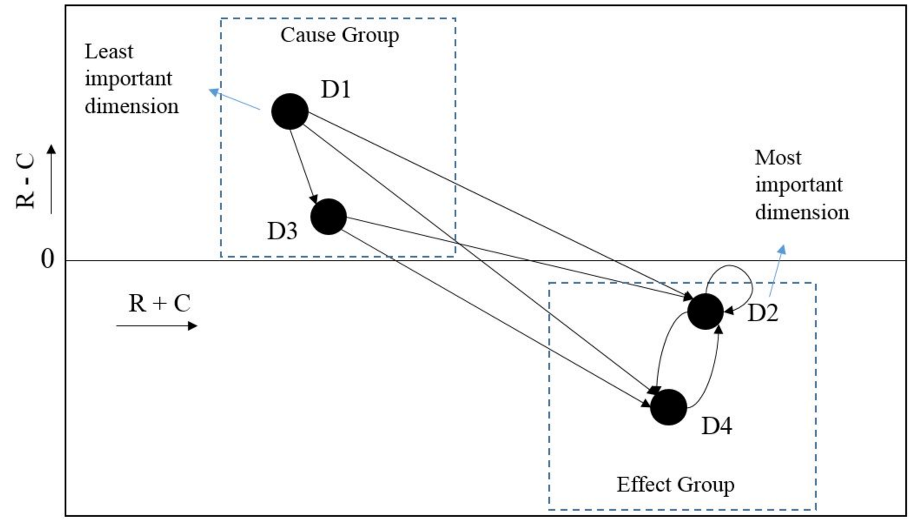

Figure 4. The causal diagram of the dimensions

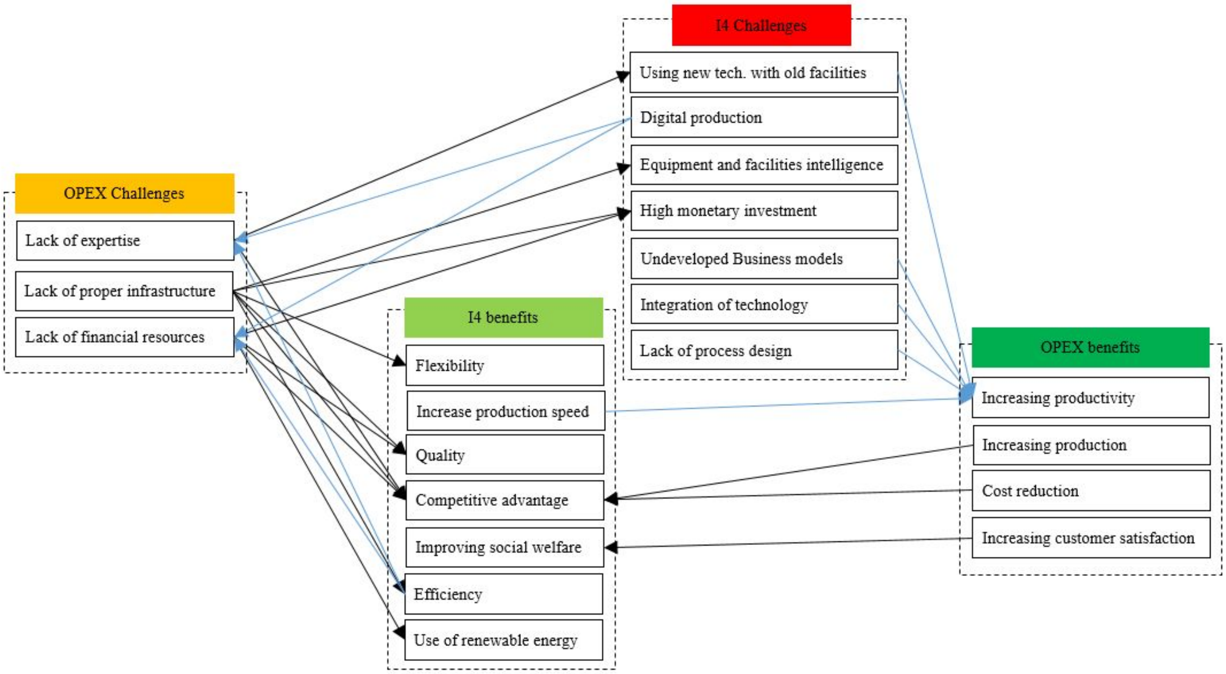

Figure 5. The impact relation map for the main criteria

Table 1. The main concepts of OpEx

Main concept	Details
Improvement process	• business process Optimization • Control of operation • Lean process • Strategic flexibility • Process improvement terms • Fast response • Reliability in products and services
Quality initiatives	• Efficiency • Culture of an organization • Respect • Removing the non-value-added activities • Customer Familiarity • Strategic performance • Benchmarking
Quality measurement	• DEA • Efficiency metric • Measuring operations and new environmental challenges

Table 2. Linguistic variables and their corresponding TFNs

Linguistic variable	Corresponding TFNs
No influence (NL)	(0, 0, 0.25)
Very low influence (VL)	(0, 0.25, 0.5)
Low influence (L)	(0.25, 0.5, 0.75)
High influence (H)	(0.5, 0.75, 1.0)
Very high influence (VH)	(0.75, 1.0, 1.0)

Table 3. Profile of experts

Education	M.A. 7	Ph.D. 5		
Experience	5 – 10 years 4	10 – 15 years 5	More than 15 years 3	
Job position	Supply chain manager 2	Industry 4.0 expert 3	Quality management expert 4	IT expert 3

Table 4. the normalized direct-relation and total relation matrix for the dimensions

	D_1	D_2	D_3	D_4
D_1	(0, 0, 0)	(0, 0, 0)	(0.182, 0.318, 0.455)	(0.273, 0.409, 0.546)
D_2	(0, 0, 0)	(0, 0, 0)	(0.091, 0.227, 0.364)	(0.318, 0.455, 0.546)
D_3	(0.091, 0.227, 0.364)	(0.182, 0.318, 0.455)	(0, 0, 0)	(0, 0, 0)
D_4	(0, 0.136, 0.273)	(0.227, 0.364, 0.5)	(0, 0, 0)	(0, 0, 0)
	D_1	D_2	D_3	D_4
D_1	(0.018, 0.198, 1.243)	(0.106, 0.393, 1.914)	(0.195, 0.471, 1.716)	(0.311, 0.669, 2.268)
D_2	(0.009, 0.179, 1.122)	(0.099, 0.37, 1.738)	(0.102, 0.368, 1.506)	(0.352, 0.696, 2.106)
D_3	(0.094, 0.329, 1.326)	(0.209, 0.525,1.941)	(0.036, 0.224, 1.309)	(0.092, 0.374, 1.782)
D_4	(0.002, 0.228, 1.173)	(0.25, 0.552, 1.891)	(0.023, 0.198, 1.221)	(0.08, 0.344, 1.672)

Table 5. Defuzzified total relation matrix for the dimensions

	D_1	D_2	D_3	D_4	R	R+C	R-C
D_1	0.37	*0.638*	*0.66*	*0.911*	2.58	4.148	1.013
D_2	0.337	*0.596*	0.55	*0.911*	2.394	5.129	-0.341
D_3	0.48	*0.743*	0.41	*0.611*	2.244	4.238	0.250
D_4	0.38	*0.758*	0.374	0.57	2.083	5.086	-0.921
C	1.568	2.735	1.994	3.003			

Table 6. The dataset (R+C) and (R-C) for criteria

Dimension	Criteria	R	C	R+C	R-C	Cause (C) Effect (E)
OpEx challenges	Security risk	0.74	0.99	1.73	-0.25	E
	Lack of proper infrastructure	*1.40*	*1.16*	*2.56*	*0.25*	*C*
	Lack of skilled manpower	*1.25*	*1.09*	*2.34*	*0.16*	*C*
	Lack of expertise	*1.47*	*1.27*	*2.75*	*0.20*	*C*
	Lack of financial resources	*1.48*	*1.33*	*2.81*	*0.14*	*C*
	Cultural constraints	1.08	1.12	2.21	-0.04	E
	Lack of strategic planning	*1.38*	*0.91*	*2.28*	*0.47*	*C*
	Fear of the unknown	0.99	0.99	1.98	0.00	E
OpEx benefits	Increasing production	1.16	1.31	2.47	-0.14	E
	Increasing customer satisfaction	0.69	1.27	1.95	-0.58	E
	Increasing productivity	1.19	1.50	2.69	-0.31	E
	Cost reduction	1.11	1.33	2.45	-0.22	E
Industry 4 challenges	*Computational constraints*	*0.69*	*0.68*	*1.36*	*0.01*	*C*
	Using new technology with old facilities	*0.98*	*0.84*	*1.81*	*0.14*	*C*
	undeveloped Business models	*0.98*	*0.60*	*1.57*	*0.38*	*C*
	Collaboration and networking	*0.81*	*0.69*	*1.50*	*0.13*	*C*
	Digital Production	*1.01*	*0.86*	*1.87*	*0.15*	*C*
	Equipment and facilities intelligence	0.69	0.91	1.60	-0.22	E
	Lack of process design	*0.89*	*0.66*	*1.55*	*0.23*	*C*
	High monetary investment	*0.94*	*0.92*	*1.86*	*0.01*	*C*
	Lack of government support	*0.88*	*0.29*	*1.18*	*0.59*	*C*
	Integration of technology	0.89	0.96	1.84	-0.07	E
	Job disruptions	0.78	0.82	1.60	-0.04	E
	Weak data security	0.50	0.67	1.18	-0.17	E
	Lack of knowledge	0.63	0.69	1.32	-0.06	E
Industry 4 benefits	Flexibility	0.82	0.92	1.74	-0.09	E
	Quality	0.75	1.01	1.75	-0.26	E
	Competitive advantage	0.84	1.09	1.94	-0.25	E
	Improving social welfare	0.39	0.85	1.23	-0.46	E
	Dynamic optimization	0.80	0.80	1.60	0.00	E
	Possibility of remote mo1toring	0.85	0.87	1.72	-0.02	E
	Less waste production	0.66	0.79	1.45	-0.13	E
	Increase production speed	*0.92*	*0.78*	*1.70*	*0.14*	*C*
	Real-time production plan1ng	*0.88*	*0.71*	*1.59*	*0.17*	*C*
	Efficiency	*0.96*	*0.92*	*1.88*	*0.03*	*C*
	Use of renewable energy	*0.98*	*0.87*	*1.85*	*0.11*	*C*

Table 7. The global influential weights of criteria

Dimension	Criteria	Weight
OpEx challenges	Security risk	0.019
	Lack of proper infrastructure	0.022
	Lack of skilled manpower	0.021
	Lack of expertise	0.025
	Lack of financial resources	0.026
	Cultural constraints	0.021
	Lack of strategic planning	0.017
	Fear of the unknown	0.018
OpEx benefits	Increasing production	0.072
	Increasing customer satisfaction	0.075
	Increasing productivity	0.083
	Cost reduction	0.073
Industry 4.0 challenges	Computational constraints	0.013
	Using new technology with old facilities	0.018
	undeveloped Business models	0.012
	Collaboration and networking	0.014
	Digital Production	0.019
	Equipment and facilities intelligence	0.020
	Lack of process design	0.014
	High monetary investment	0.022
	Lack of government support	0.007
	Integration of technology	0.022
	Job disruptions	0.020
	Weak data security	0.014
	Lack of knowledge	0.014
Industry 4.0 benefits	Flexibility	0.029
	Quality	0.035
	Competitive advantage	0.039
	Improving social welfare	0.031
	Dynamic optimization	0.025
	Possibility of remote mo1toring	0.027
	Less waste production	0.027
	Increase production speed	0.025
	Real-time production plan1ng	0.022
	Efficiency	0.030
	Use of renewable energy	0.029