Improving manufacturing Efficiency in the industry 4.0 era: empirical evidence from the manufacturing companies

Raghda Abdellatif Abdelkhalik *

Lecturer, Department of Accounting, Faculty of commerce for girls, Al-Azhar University,Cairo, Egypt.

ABSTRACT:

Purpose – This study aims to examine the effect of virtual manufacturing (VM) on improving manufacturing efficiency to achieve sustainable business practices through focusing on cost reduction, the prediction of needed resources in the implementation processes, and mitigating Environmental, Health, and Safety (EHS) risks in the industry 4.0 environment.

Design/methodology/approach – This study uses the technique for order preference by similarity to ideal solution (TOPSIS) to examine the effect of VM on improving manufacturing efficiency to achieve sustainable business practices. The study relied on a sample of 25 automotive industry companies. There are several criteria used to assess the effect of VM on managing the costs of production and reducing EHS risks in industry 4.0.

* Corresponding author, **Raghda Abdellatif Abdelkhalik**-
d.raghda02@ymail.com
raghdaabdellatif@azher.edu.eg
https://orcid.org/0000-0002-7676-4563

Findings – The results of this study indicate that there is a positive effect of VM to achieve sustainable business practices. The empirical evidence of this study shows that the full application of VM technology in manufacturing processes leads to a performance improvement of approximately 98.9%.

Research implications- The results of this study inform firms as well as the academic literature and practitioners who are concerned with sustainable business and environmental conservation about the effect of VM on manufacturing efficiency to meet changing customer requirements and achieve sustainable development.

Practical implications- VM solutions provide a digital manufacturing process environment to optimize the manufacturing processes before moving to physical implementation to keep pace with the era of the Fourth Industrial Revolution.

Originality/value- This study can be considered as a contribution to the flow of management accounting research about the effect of VM on improving manufacturing efficiency to achieve sustainable business practices. The study is among the first to assess the effects of VM on managing the costs of production and reducing EHS risks in industry 4.0. The study evidence appears to be robust there is no endogeneity problem.

Key Words: Virtual Manufacturing, cost management, cost reduction, Factories of the Future, industry 4.0.

المستخلص:

الهدف - تهدف هذه الدراسة إلى فحص تأثير التصنيع الافتراضي (VM) على تحسين كفاءة التصنيع لتحقيق ممارسات الأعمال المستدامة من خلال التركيز على خفض التكلفة ، والتنبؤ بالموارد اللازمة في عمليات التنفيذ، وإدارة تكاليف الإنتاج وتقليل مخاطر البيئة والصحة والسلامة(EHS Risks) في عصر الصناعة الرابعة.

التصميم / المنهجية / المدخل : تستخدم هذه الدراسة أسلوب ترتيب الأفضلية عن طرق التشابه مع الحل المثالي (TOPSIS) لفحص تأثير VM على تحسين كفاءة التصنيع لتحقيق ممارسات الأعمال المستدامة. وقد اعتمدت الدراسة على عينة من ٢٥ شركة لصناعة السيارات. تم استخدام العديد من المعايير المستخدمة لتقييم تأثير VM على إدارة تكاليف الإنتاج وتقليل مخاطر البيئة والصحة والسلامة في عصر الصناعة الرابعة.

النتائج - تشير نتائج هذه الدراسة إلى وجود تأثير إيجابي لتطبيق VMلتحقيق ممارسات الأعمال المستدامة. يُظهر الدليل التجريبي لهذه الدراسة أن التطبيق الكامل للتصنيع الافتراضي في عمليات التصنيع يؤدي إلى تحسين الأداء بنسبة ٩٨,٩٪ تقريبًا.

آثار البحث : تُطلع نتائج هذه الدراسة الشركات وكذلك المؤلفات الأكاديمية والممارسين المهتمين بالأعمال المستدامة والحفاظ على البيئة حول تأثير VM على كفاءة التصنيع لتلبية متطلبات العملاء المتغيرة وتحقيق التنمية المستدامة.

الآثار العملية - توفر حلول VM بيئة عملية تصنيع رقمية لتحسين عمليات التصنيع قبل الانتقال إلى التنفيذ المادي لمواكبة عصر الثورة الصناعية الرابعة.

الأصالة / القيمة: يمكن اعتبار هذه الدراسة كمساهمة في تدفق أبحاث المحاسبة الإدارية حول تأثير VM على تحسين كفاءة التصنيع لتحقيق ممارسات الأعمال المستدامة. هذه الدراسة هي من بين أولى الدراسات التي تقيم آثار VM على إدارة

تكاليف الإنتاج وتقليل مخاطر البيئة والصحة والسلامة في عصر الصناعة الرابعة. إن أدلة الدراسة قوية ولا توجد مشكلة في التجانس.

الكلمات المفتاحية: التصنيع الافتراضي ، إدارة التكلفة ، تخفيض التكلفة ، مصانع المستقبل ، عصرالصناعة الرابعة.

1. Introduction:

In the 21st century, product design and development has become complex to meet changing customer requirements (Ahmed et al., 2022). Since the advent of the Internet and the emergence of electronic and information technology at the dawn of the third millennium, societies have changed rapidly and drastically, as the increasing importance of knowledge along with globalization and the implications of technological development in the era of the Fourth Industrial Revolution created a completely different world (Wen et al., 2022). As the business environment moves to produce diversified and profitable products. Therefore, firms are exposed to many rapid and continuous changes, including the information and communication revolution and the trend towards digital transformation (Del Giudice et al., 2021b). Which resulted in a surge Competition between firms, and the increasing challenges they face. Therefore, companies need to improve their innovation activities to design and optimize production systems as well as to select products that best match customer needs (Demartini et al., 2017). Accordingly, agile and reconfigurable production systems are needed to handle various products (He and Bai, 2021). This is because this fourth industrial revolution, which differs from previous revolutions in its intensity, complexity and breadth, where basis on a new technological phenomenon called digital transformation. As a result, attention to improving manufacturing processes has become indispensable to meet business developments and global competitive conditions (Frank et al., 2019, Hanaysha and Alzoubi, 2022). In order to face these rapid and continuous challenges in the modern business environment, the use of digital transformation on the part of firms has become an urgent necessity to develop their operational performance so that they can support their competitive capabilities. Where the digitalization of manufacturing greatly encourages companies to implement differentiated competitive strategies(Wen et al., 2022).

The fourth industrial revolution supports the creation of the "smart factory" or, equivalently "Factory of the Future" (FoF). Sustainable smart manufacturing plays an indispensable role. Where physical and digital systems are integrated with the aim of reaching mass personalization and faster product development(Demartini et al., 2017, He and Bai, 2021).

In addition, in recent years, a variety of factors and events have led to a significant change in the global economy, which led to increasingly fierce competition in the markets and prompted many firms to review their operations to become more efficient and seek opportunities to improve their performance(Dalenogare et al., 2018).In order to maintain financial results and acceptable shareholder and customer satisfaction. Therefore, improving processes have taken over thinking researchers significantly in order to arrive at more accurate systems and methodologies that contribute to effectively reducing the costs of organizations in a manner that does not affect the level of quality required. These challenges require new methodologies for adapting with FoF (Frank et al., 2019).One of the most significant tools that can be used to keep up with the development of the business environment and FoF is virtual reality (VR) technologies(Peruzzini et al., 2021).

Although there is a large repository of literature available on the VM, some questions remain unanswered. Although prior studies (e.g., (Jha, 2016, de Sousa Jabbour et al., 2018, Bougaa et al., 2015, Demartini et al., 2017, Wen et al., 2022) have examined the impact of VM in many fields, they did not examine the impact of VM on the cost reduction of production activities and mitigate the EHS risks of these activities which supports sustainable business in industry 4.0. Therefore, to address this research gap in the management accounting literature, this study aims to examine the role of VM in improving processes in industrial companies.

The purpose of this study is to contribute to this stream of research, providing further empirical evidence about the effect exerted by VM on the manufacturing sector to achieve sustainable business in FoF. To achieve the aims of the study, an empirical study was carried out on the Egyptian automotive industry which depends on a large group of feeding industries such as engineering, chemical, and electrical industries.

The findings of this study find that VM solutions provide a digital manufacturing process environment to optimize the manufacturing processes before moving to physical implementation. Where virtual representations of the tangible product early at the concept stage allow for a better understanding of the problem. In addition, the full application of VM technology in manufacturing processes leads to a performance improvement of approximately 98.9%.

The study makes several contributions to the extant literature on management accounting. First, focus on the contribution of VM in the manufacturing sector to achieve sustainable business. Second, our study contributes to the scarcity of work on this topic by demonstrating the contribution of virtual manufacturing tools to improve manufacturing efficiency by reducing costs, providing a high level of agility, predictive insights about needed resources, and mitigating EHS risks. Third, providing further empirical evidence about how VM contributes to improving manufacturing efficiency and sustainable business practices in the industry 4.0 environment.

This study is organized as follows. In the next section, a brief overview of the literature on VM technology in manufacturing is presented. Section 3 describes the theoretical framework and hypotheses development. Section 4 describes the research methodology. Section 5 shows the results of the study. Finally, Section 6 presents the conclusion with a discussion of the study's contributions, implications, limitations, and future research opportunities.

2. Literature Review

Previous studies have discussed the role of VR and VM in the manufacturing environment. They differed in the field of application, techniques, and goals. For example, de Sousa Jabbour et al. (2018) discussed the role of simulation lab in implementing virtual manufacturing. They presented the VM environment and highlighted potential application areas.

In addition, prior studies (e.g. (Wang et al., 2016, Dalenogare et al., 2018, Demartini et al., 2017) have focused on proposing appropriate tools to cope with the fourth industrial revolution which supports FoF by using digital technologies. Ale Ebrahim et al. (2008) addressed virtual teams and their characteristics, dealing with innovation in virtual environments and the relationship to research and development activities.

While (Grajewski et al., 2013)examined the possibilities of immersive VR application during the complex design process and virtual models of a manufacturing ergonomics characterized by a high level of quality to illustrate the role of virtual reality in industry 4.0. While Bougaa et al. (2015)discussed the possibilities of applying virtual reality technologies to manufacturing engineering and assessing its role in industry 4.0. They reviewed recommendations made by four main European reports on the defies that must be met to the requirements of industry 4.0. In another study, Darmoul et al. (2015) pointed out that the developed semi-immersive environment gives users a sense of being in the digital environment. They also indicated how it enabled them to work with digital objects as they would in the real world.

While Tang (2014) addressed the effect of the virtual forum and virtual team on the creativity of manufacturing personnel. Jha (2016) explained the importance of virtual manufacturing in product life cycle management (PLM) as a business approach to accommodating people, processes, business, and information systems for managing the entire product life cycle across organizations. While Talekar et al. (2017)dealt with critical reviews and applications of VR and provided information about its applications. While Demartini et al. (2017)conducted a qualitative review of the literature to investigate the possibility of adopting augmented and virtual reality for workforce training by developing a set of factors that can be used by virtual team managers to create an effective relationship between members. Frank et al. (2019)examined adoption patterns of Industry 4.0 technologies in manufacturing firms. They suggested a conceptual framework for Industry 4.0 technologies.

While Peruzzini et al. (2021) examined the application of virtual reality to manufacturing to support the design of human-centered workstations, considering both process efficiency and plant ergonomics. The results of this study showed that the new VM-based methodology is more robust to predict critical process matters thanks to direct user feedback that simulates specific tasks and allows for more accurate ergonomic analysis. He and Bai (2021) proposed a framework for smart, sustainable digital manufacturing. they showed that sustainable smart manufacturing platforms can be linked together to integrate the value chain between companies and form a new industrial form.

Wen et al. (2022) examined the relationship between manufacturing digitization and investment in institutional innovation based on data from publicly listed Chinese manufacturing companies. they shoed through their empirical evidence that manufacturing enterprises have significantly increased their investment in innovation activities in the process of digital transformation. in addition, digital transformation has an indirect impact on the market competition strategy of manufacturing enterprises. As Wen et al. (2022) outlined that highly viable manufacturing organizations are more adaptable to digital transformation and tend to implement differentiated competitive strategies. Hence, the effect of innovation incentives is greater for high-viability enterprises, regardless of operating size, ownership, or productivity.

From the discussion of previous studies, it can be said that it did not address the effect of VM on improving manufacturing efficiency to achieve sustainable business practices in the industry 4.0 environment. Therefore, the current study works to bridge this gap. The present study contributes to the stream of prior studies of managerial accounting research, providing further empirical evidence about how VM contributes to improving Manufacturing Efficiency in the industry 4.0 era.

3. The theoretical framework and hypothesis development

3.1 Theoretical framework

Under the highly competitive environment and the many changes surrounding firms, the firms seek to obtain a greater share in the market by focusing on improving manufacturing efficiency to reduce costs and increase quality, which leads to its sustainability in the business environment and achieving progress and progress at the local and global levels Wen et al. (2022). The ability to innovate and develop is associated with keeping pace with technological changes in the business environment (He and

Bai, 2021). The emergence of "knowledge" industries such as software and biotechnology as well as the importance of innovation in the "old economy" industries have fueled this growth, the goal of which is to increase company-wide innovation and ultimately company value(Pandit et al., 2011). Development may be beneficial to the company's ultimate profit, but it is an expense. After all, companies spend large sums on research and trying to develop new products and services. Consequently, companies seek to achieve visions of future factories that include concepts such as one site, one worker, one tablet, complete recycling, and zero waste production (Arens, 2019). In the last few years, one of the most trending topics in both professional and academic fields is the term the fourth industrial revolution also called “Factory of the Future” has drawn much attention from governments and companies. These terms describe the vision of a transformation of industry based on new technologies and innovative concepts and resulting in more efficient production methods (Hanaysha and Alzoubi, 2022). Industry 4.0 was coined in 2011 by a German initiative of the federal government with universities and private companies. It was a strategic program to develop advanced production systems with the aim of increasing the productivity and efficiency of the national industry(Kagermann et al., 2013).

The concept of the Factory of the Future represents a new industrial stage of the manufacturing systems by integrating a set of emerging and convergent technologies that add value to the whole product lifecycle(Dalenogare et al., 2018, Wang et al., 2016). FoF is rooted in advanced manufacturing, i.e. an adaptable system where flexible lines automatically adjust production processes for multiple types of products and changing conditions(Wang et al., 2016, Frank et al., 2019). This allows to increase equality, productivity and flexibility and can help to achieve customized products at a large scale and in a sustainable manner with better resource consumption (Dalenogare et al., 2018, de Sousa Jabbour et al., 2018)..FoF also considers the exchange of information and integration of the supply chain, synchronizing production with suppliers to reduce delivery times and information distortions that produce bullwhip effects(Frank et al., 2019).

There is considerable interest by developed countries in the transition to FoF for example, The European Factories of the Future Research Association (EFFRA) launched The Factories of the Future research program in 2009 as one of three Public-Private Partnerships (PPP). It served to address the challenges and opportunities for manufacturing future products and economic, social, and environmental sustainability. This program has identified FoF in Sustainable manufacturing which focuses on industrial and knowledge-based technologies, ICT-enabled intelligent manufacturing, and increased reusability of production systems towards global interoperable factories. In addition to high productivity manufacturing, high-precision manufacturing, new materials in manufacturing, value-added services, and zero-defect manufacturing(Rai et al., 2021, Ridgway et al., 2013)

The European Commission has launched a strategic roadmap that fixed a list of manufacturing challenges to be considered for transforming to FoF of manufacturing systems with higher capabilities to face competitive conditions as follows(Ad-hoc, 2010, Bougaa et al., 2015)

a) Achieving cost efficiency with the wide adoption of standards, enhancing safety and reinforcing ergonomics conditions, and adopting new manufacturing technologies to new product features.

b) Relying on sustainable energy and resources system through optimal resource consumption with the use of renewable, environmentally friendly resources and increasing the re-usability of production systems towards global interoperable factories.

c) Producing high-value-added products with a focus on each component of the product taking into consideration the short time-to-market (from the concept to the final product).

d) Achieving adaptability/reconfigurability of infrastructure through a modular approach in production systems, introducing higher and more stable product quality through increased process robustness and accuracy.

The UK Government Science Office has identified a model for FoF based on six elements(Bougaa et al., 2015, Ridgway et al., 2013):

A. Goals and Metrics: FoF has sets of goals and metrics that focus on achieving customer needs and an eco-friendly environment.
B. Culture: FoF works within the supply chain and has partnership agreements with local universities and schools.
C. Technology: social media and big data are routinely used to support the first component. Which is integrated through design, manufacturing, service, and strategic standardization supporting the reformation of business models.
D. People: within the possible and responsible teams, people are involved in knowledge and problem-solving.
E. Processes and practices: They are agile through simple systems to communicate and understand in addition to green innovation and societal development.
F. Infrastructure: All this is supported by automobiles, shipbuilding, semiconductors, steel, machinery, and textiles/materials; including establishing regional cluster networks, regional institutions, and public and private sector funding.

In Japan, as part of a cohesive “innovation program and FoF” strategic roadmap and linked manufacturing competitiveness strategy include(Ridgway et al., 2013):

- Sustainable growth and social issues targeted through an emphasis on green innovation, particularly green ICT e.g., smart grid, cloud computing., in particular, 'whole systems approach' addressing sustainable manufacturing, energy conservation, and eco-friendly, low carbon, resource-efficient, smart manufacturing technologies.
- Emphasis on actions to improve profitability via the prevention of technology leakage and strategic standardization supporting reformation of business models.
- Other priority areas include rare metal substitution, visualization technologies and integration of IT systems with production technologies, nanotechnology ('Green Nanotechnology', 'Nano-Bio', 'Nanoelectronics'), biotechnology, medical technologies, advanced measurement and analytics technology.

When discussing and analyzing the above initiatives of some countries relating to FoF it is clear that the European Factories of the Future Research Association (EFFRA) aims at enhancing production efficiency, high added value components/goods, and eco-friendly factories, in terms of cost and time efficiency, product quality, etc. The UK government's recommendations emphasize the role of the human being in the FoF, by considering culture, gender equality, worker skills, customer involvement in the product design, etc. Finally, the Japanese recommendations focus on technologies that achieve profitability via the prevention of technology leakage and Sustainable growth like visualization technologies, nanotechnology, and biotechnology.

Hence, it can be said that the technologies required to transform to FoF are largely already available and exploiting these technologies to enable new products is what brings a competitive advantage. The FoF will make adaptive control tend towards self-learning and there will be an emphasis on the transition from manual manufacture of prototypes, through semi-automation to fully automated systems.

3.2 Hypotheses development

Prior research (e.g., (Jha, 2016, Frank et al., 2019, Peruzzini et al., 2021, Wen et al., 2022) showed that VM can be defined as an integrated industrial environment that is practiced to improve all levels of decision and control. This technology can provide a better integration among designers and customers' requirements, allowing the interaction and immersion of the user in the virtual world based on graphical 3D images created in real-time by the computer(Peruzzini et al., 2021). Therefore, it may be used in industry for the training, design, assembly, and disassembly of products, manufacturing, and virtual prototyping(Lawson et al., 2016), as well as improvements in ergonomics of the workplace(Grajewski et al., 2013). Thus, VM can be used in Product design, planning, and control strategies.

All these Strategies can be simulated in the virtual environment and thus helps in optimizing the outcomes before practical applications(Talekar et al., 2017).

With all the above said, VM technology breaks down barriers between humans and computers by immersing viewers in a computer-generated stereoscopic environment (Talekar et al., 2017, Darmoul et al., 2015). In previous literature, Virtual Manufacturing has been dealt with in many studies, but it belongs to the field of artificial intelligence as modern technology and has not been subjected to its impact on improving manufacturing efficiency through managerial accounting literature. Therefore, in line with what was mentioned above from previous studies, the effect of VM on improving manufacturing efficiency is studied through a set of factors, which include cost reduction, agility, the prediction of needed resources in the implementation processes, and mitigating EHS risks.

3.2.1 VM and cost reduction

There is a growing stream of literature that empirically examines cost reduction of a company's processes (e.g.,(Müller et al., 2022, He and Bai, 2021) pointed out that the cost reduction Process is a key trend in manufacturing companies and a logical step in the evolution for increasing manufacturing process efficiency and lower cost of goods (COGs). Previous research (e.g., (Ammar et al., 2021, He and Bai, 2021) provided results stating the importance of industry 4.0 technologies in reducing costs, improving material quality, and solving complex manufacturing problems in the transition to FoF. As Peruzzini et al. (2021) pointed out that VR allows companies to maintain product quality and reduce time and wastage in production. So, it is expected that VM provides a high level of Improving Manufacturing Efficiency through cost reduction.

Hypothesis 1: *VM has a positive effect on cost reduction.*

3.2.2 VM and agility

Over the last few decades, the level of competition has increased significantly. Customers care about product quality, delivery time, and price(Mohanty et al., 2022). As a result, organizations must implement an agility system to achieve continuous progress and raise quality and productivity. Given the increasing complexity of the manufacturing environment, it is important to enhance the agility of facilities to reduce the cascading effects of intense competition. Thus, agility is one of the requirements and enabling factors of FoF(Hsu et al., 2022). The most urgent requirements to enhance the agility of enterprises are the adoption of investment in digital transformation to improve economic efficiency. When these procedures are improved, corporate agility can be improved, resulting in long-term collaboration with partners and visualization to respond quickly to customer needs. Therefore, improved levels of customer service and satisfaction. Thus, agility must be available in manufacturing processes to increase their efficiency(Mohanty et al., 2022, Del Giudice et al., 2021a). As Ahmed (2022)noted the importance of agility in creating an improved organizational speed for small and medium-sized manufacturing companies through the ability of the digital platform within the boundary conditions of environmental dynamism, which increases the efficiency of manufacturing processes. Thus, it is expected that VM provides a high level of agility in Improving Manufacturing Efficiency.

Hypothesis 2: *VM has a positive effect on an agility*.

3.2.3 VM and the prediction of needed

Industry 4.0 technologies offer tremendous opportunities to make better decisions. As Industry 4.0 transforms manufacturing environments into physical electronic ones, AI will be indispensable for data analysis and subsequent decision-making(Rai et al., 2021, Hanaysha and Alzoubi, 2022). FoF encourages the use of smart sensors, devices, and machines to enable intelligent factories that constantly collect production-related data. Industry 4.0 technologies enable the generation of actionable intelligence by processing aggregated data to increase manufacturing efficiency without significantly changing the resources required(Rai et al., 2021). Additionally, the ability of

Industry 4.0 technologies to provide predictive insights has enabled complex manufacturing patterns to be discerned and provides a pathway for an intelligent decision support system in a variety of manufacturing tasks such as intelligent and continuous inspection, quality improvement, predictive maintenance, supply chain management, process improvement, and scheduling task(Hanaysha and Alzoubi, 2022). Thus, it is expected that VM contributes provide predictive insights about needed resources in the implementation processes to improve manufacturing efficiency.

Hypothesis 3:*VM has a positive effect on the prediction of needed resources in the implementation processes*

3.2.4 VM and mitigating EHS risks

Mourtzis et al. (2022) explained that Fourth Industry techniques can reduce uncertainties and risks that increase production vulnerability and deal with them, thus increasing productivity, efficiency, and profitability. In the second half of the twentieth century, Fourth Industry technologies accelerated manufacturing automation and fulfilled the requirements of the factories of the future.

In this context, Tavana et al. (2022) noted the importance of the fourth industry techniques in achieving improvement and sustainability of facilities by achieving green dimensions and controlling for solving complex engineering problems.

So, it is expected that the use of VM, which is one of the modern technologies, will reduce EHS risks such as accidents, reduce carbon emissions, and thus reduce the sanctions imposed by governments and society.

Hypothesis 4: *VM has a positive effect on mitigating EHS risks.*

4. Research Methodology

4.1 Sample and data selection

The study sample was chosen from the Egyptian automotive industry, which is one of the aggregate industries that depend on a large group of feeding industries that belong to most industrial activities such as engineering, chemical, and electrical industries. The questionnaires were distributed to production managers to assess the impact of VM on manufacturing processes of the FoF by offering three alternatives and making a comparison of these alternatives.

The first alternative (A1) is manufacturing processes are not based on VM, the second alternative (A2) is manufacturing processes use VM with manufacturing processes partially, and the third alternative (A3) is manufacturing processes are based on VM totally. A comparison of these alternatives is made through a set of criteria that have been identified by analyzing the available literature. This comparison is based on previous studies and the opinions of managers of industrial companies. Therefore, the main criteria were defined using extensive library studies and expert opinion.

Finally, four criteria were selected: (a) C1 = cost reduction, (b) C2 = agility, (C) C3 = the prediction of needed resources in the implementation processes, (d) C4 =mitigating EHS risks. All criteria are equally important. Therefore, all parameters are given a weight of 0.25 for normalization. Engineers, employees, and production managers indicate which of the three alternatives is better than the other in terms of contributing to the achievement of the above-mentioned criteria.

4.2 Data Analysis and Model specification

This study employs the technique for order preference by similarity to the ideal solution TOPSIS technique to test the study hypotheses. TOPSIS is one of the major techniques that helps with Multiple Criteria Decision Making (MCDM) problems. It helps the decision-maker to organize problems, analyze behavior, and arrange alternatives. This technique is widely applied because of its logic, rationality, and calculational simplicity(Shih et al., 2007) . A positive ideal solution maximizes the benefit criteria or attributes and minimizes the cost criteria or attributes, whereas a negative ideal solution maximizes the cost criteria or attributes and minimizes the benefit criteria or attributes.

The TOPSIS method is expressed in a succession of six steps as follows:

Step 1: Calculate the normalized decision matrix. The normalized value r_{ij} is calculated as follows:

$$r_{ij} = x_{ij} \sqrt{\sum_{i-1}^{m} x_{ij}^2} \quad i = 1, 2, ..., m \qquad \text{and } j = 1, 2, ..., n.$$

Step 2: Calculate the weighted normalized decision matrix. The weighted normalized value v_{ij} is calculated as follows:

$$v_{ij} = r_{ij} \times w_j \quad i = 1, 2, \ldots, m \qquad \text{and } j = 1, 2, ..., n. \qquad (1)$$

Where w_j is the weight of the j^{th} criterion or attribute and $\sum_{j=1}^{n} w_j = 1$.

Step 3: Determine the ideal (A^*) and negative ideal (A^-) solutions.

$$A^* = \{(\max_i v_{ij} \mid j \in C_b), (\min_i v_{ij} \mid j \in C_c)\} = \{v_j^* \mid j = 1,2,\ldots,m\} \qquad (2)$$

$$A^- = \{(\min_i v_{ij} \mid j \in C_b), (\max_i v_{ij} \mid j \in C_c)\} = \{v_j^- \mid j = 1,2,\ldots,m\} \qquad (3)$$

Step 4: Calculate the separation measures using the m-dimensional Euclidean distance. The separation measures of each alternative from the positive ideal solution and the negative ideal solution, respectively, are as follows:

$$S_i^* = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^*)^2}, \; j = 1,2,\ldots,m \qquad (4)$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^-)^2}, \; j = 1,2,\ldots,m \qquad (5)$$

Step 5: Calculate the relative closeness to the ideal solution. The relative closeness of the alternative A_i with respect to A^* is defined as follows:

$$RC_i^* = \frac{S_i^-}{S_i^* + S_i^-}, i = 1,2,\ldots,m \qquad (6)$$

Step 6: Rank the preference order.

5. Results

Points scale from 1 to 5 is used to determine the importance of each criterion as shown in the Tables (I) and (II).

Tab1e I Points Scale

Low	1
Below average	2
Average	3
Good	4
High	5

Table II. Elements of the decision matrix

Alternatives	**Criteria**			
	C1	C2	C3	C4
A1	3	1	1	1
A2	2	4	3	4
A3	3	5	5	4
Weight	0.25	0.25	0.25	0.25
$\sqrt{\sum x^2_{ij}}$	4.69	6.481	5.916	5.745

Source: Authors' calculations

That the first alternative (A1) which is manufacturing processes not based on VM achieves the criterion of cost reduction (C1) with an average degree, achieves criteria of agility (C2), the prediction of needed resources in the implementation processes (C3) and the mitigating EHS risks (C4) with a Low degree.

Many respondents showed that the second alternative (A2) which is partially used VM with manufacturing processes achieves the criterion of cost reduction (C1) with a below-average degree, achieves the criterion of Agility (C2) with a good degree, achieves the criterion of the prediction of needed resources in the implementation processes (C3) with an average degree and achieves criterion of the mitigating EHS risks (C4) with a good degree.

Most of the respondents (93.5 percent) showed that the third alternative (A3) which is manufacturing processes fully based on VM achieves criterion of cost reduction (C1) with an average degree, achieves criterion agility (C2) with a high degree. In addition, (A3) achieves the criterion of the prediction of needed resources in the implementation processes (C3) with a high degree and achieves criterion of the mitigating EHS risks (C4) with a good degree.

Using the TOPSIS steps, it is possible to choose between A1, A2, and A3 according to the pre-set criteria in order to select the alternative that is best in achieving the requirements of FoF. After taking the decision matrix from the selection criteria, a standardized decision matrix should be made. According to the formula, Rij is written as (step 1) as follows: -

R11= 3/4.69 = 0.6397, R21= 1/6.481= 0.1543, R31 = 1/5.916=0.169, R41 =1/5.745=0.174.

R12=2/4.69= 0.431, R22= 4/6.481=0.617, R32 = 3/5.916= 0.507, R42 =4/5.745= 0.696.

R13 =3/4.69= 0.6397, R23 =5/6.481=0.771, R33 =5/5.916= 0.845, R43 =4/5.745=0.696.

Table III Normalized values of Decision matrix

Alternatives	**Criteria**			
	C1	C2	C3	C4
A1	0.6397	0.1543	0.169	0.174
A2	0.431	0.617	0.507	0.696
A3	0.6397	0.771	0.845	0.696

Source: Authors' calculations

Then it is multiplied with the weight of each criterion with the normalized performance value of each cell. It can be seen that 0.25 is being multiplied by the normalized performance value as follow:

V_{11}= 0.6397*0.25= 0.160, V_{21}= 0.1543*0.25=0.039, V_{31} =0.169*0.25= 0.042, V_{41} =0.174*0.25=0.044.

V_{12}=0.431*0.25=0.108, V_{22}=.0.617*0.25=0.154 V_{32} = 0.507*0.25= 0.127, V_{42} =0.696*0.25=0.0435.

V_{13}=0.6397*.025=0.160, V_{23} =0.771*0.25= 0.019, V_{33} =0.845*0.25= 0.211, V_{43} =0.696*0.25=0.174.

Table IV Weighted Values of Decision Matrix

Alternatives	Criteria			
	C1	C2	C3	C4
A1	0.160	0.039	0.042	0.044
A2	0.108	0.154	0.127	0.0435
A3	0.160	0.019	0.211	0.174

Source: Authors' calculations

The positive ideal (A^*) and negative ideal (A^-) solutions are determined using Step 3 equations (2) and (3). The results are shown in Table V.

Table V Positive and Negative Solutions

Solution	cost reduction (C1)	Agility (C2)	prediction of needed resources in the implementation processes (C3)	mitigating EHS risks (C4)
Positive Ideal A^+	0.160	0.154	0.211	0.174
Negative Ideal A^-	0.108	0.019	0.042	0.0435

Source: Authors' calculations

Next, the value of Euclidean distance of (The separation of each competitive alternative) is calculated by the separation distance of each competitive alternative from the ideal and non-ideal solution. Therefore step 4 (Eq.4 and 5), the results are shown in Tables VI and VII.

Table VI The Separation Measures Using the Euclidean distance

S_{i1}^{*}	0.4755	S_{i2}^{-}	0.0001
S_{i2}^{*}	0.0926	S_{i3}^{-}	0.20318
S_{i3}^{*}	0.0001	S_{i1}^{-}	0.27109

Source: Authors' calculations

The result of the ranking of alternatives (step 6) is derived using step 5 Equation (6) (Table VII). The first alternative is considered as the best maximization of expected benefits for the company to cost reduction, a high level of agility, the prediction of needed resources in the implementation processes, and reduce EHS risks.

Table VII Results of Closeness Coefficient and Rank the preference order

Alternatives	RC_i^{*}	Rank
(A1) manufacturing processes do not base on V M	0.00297	3
(A2) Partially use of VM with manufacturing processes	0.6969	2
(A3) manufacturing processes based on VM	0.989	1

Source: Authors' calculations

According to the results in Table VII, the full application of VM technique in manufacturing processes leads to 98.9% performance improvement, while the partial application of V M technique in manufacturing processes leads to improvement by 69.7%. Subsequently, it can be said that the results of the empirical study support the study hypotheses. Where the results show that there is a positive significant relation between VM application and cost reduction, the prediction of needed resources in the implementation processes, and mitigating EHS risks in the industry 4.0 environment.

6. **Discussion and Conclusion**

This study contributes to the management accounting literature by providing further empirical evidence about how VM contributes to improving manufacturing efficiency, and sustainable business practices through focusing on cost reduction, the prediction of needed resources in the implementation processes and mitigating EHS risks in the industry 4.0 environment. The study employs TOPSIS to examine the impact of VM on improving manufacturing efficiency and sustainable business practices. The study relied on a sample of 25 companies. The study sample was chosen from the automotive industry companies in Egypt. The results of the empirical study support the study hypotheses that VM improves manufacturing efficiency and sustainable business practices by focusing on cost reduction, forecasting the resources needed in implementation processes, and mitigating EHS risks in the industry 4.0 environment.

The results of this study are in line with Müller et al. (2022), He and Bai (2021) , Ammar et al. (2021), and Peruzzini et al. (2021) that VM provides a high level of Improving Manufacturing Efficiency through cost reduction. In addition, VM allows companies to maintain product quality and reduce time and wastage in production. Also, the results of this study support the results from Frank et al. (2019) and Bougaa et al. (2015)that VM technology meets the requirements of the competitive condition in FoF through achieving customers' needs and improving profitability through industry 4.0. Also, the results of this study support findings from Hsu et al. (2022) and Mohanty et al. (2022) that agility is one of the requirements and enabling factors of FoF, which VM provides a high level of agility to Improving Manufacturing Efficiency.

The study results show that VM solutions provide a digital manufacturing process environment to optimize the manufacturing processes before moving to physical implementation. Virtual representations of the tangible product early at the concept stage allow for a better understanding of the problem. So, VM allows for adapting the system view according to the user profile/intentions, and virtual navigation in the virtual production line. Correspondingly, it helps to extract requirements and useful information, and connect knowledge bases to the virtual objects in the virtual environments. The present results, in general, are consistent with the literature (e.g.,(Rai et al., 2021, Hanaysha and Alzoubi, 2022) as Industry 4.0 technologies transform manufacturing environments into physical electronic ones. Where the results of the study show that VM can provide predictive insights about needed resources in the implementation processes to Improve manufacturing efficiency. In addition, VM provides a pathway for an intelligent decision support system in a variety of manufacturing tasks such as quality improvement, predictive maintenance, and scheduling task. Also, VM enables reliable decision-making at an early stage, therefore VM allows for better estimation and perception of depth and virtual objects information. VM provides the users with data in virtual environments and intelligent information processing. Consequently, the customer can participate in the solution definition/customization through VM environments. In addition to a virtual adaptation of the production line which allows for saving time and resources. Thus, it boosts creativity and innovation skills with virtual reality capabilities for multiple experimentation situations. In addition, the high quality and realism offered by VR help define and discuss realistic prototypes/mockups. In virtual environments, the user can choose how to interact with the system to check, which is not the case in real environments. This allows for failure analysis techniques with the virtual objects to validate the behavior of the system before producing it. So, the study results support the results from Mourtzis et al. (2022) and Tavana et al. (2022) that industry 4.0 techniques can reduce uncertainties and risks that increase production vulnerability and deal with them. the present results show that the use of VM, which is one of the industry 4.0 technologies, will reduce EHS risks such as accidents, reduce carbon emissions, and thus reduce the sanctions imposed by governments and society.

Despite the contribution of the study, it has a few limitations that provide promising opportunities for future research. First, the sample represents only a small percentage of a larger population to which it could reasonably apply. Future research may target a larger sample. Second, this study investigated Egyptian companies, which may influence the results. Therefore, future research may target more countries that may influence the results. Finally, only industrial companies were investigated. Therefore, future studies may focus on different sectors. These issues need further study in future research on this subject.

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