*14th Annual International Conference on Industrial Engineering and Operations Management*
*Dubai, United Arab Emirates (UAE), February 12-14, 2024*
Publisher: IEOM Society International, USA DOI: 10.46254/AN14.20240256
Published: February 12, 2024

# Industry 4.0 Implementation Barriers for SMEs: A Proposed Decision-Support Model of the Most Appropriate Adoption Route

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## Abstract

Industry 4.0 (I4.0) promises to transform business processes through digital interconnectivity to increase operational efficiency. However, 13 years since its inception, the uptake of I4.0 technologies by companies is still rather low. Our Systematic Literature Review (SLR) shows the different barriers that companies are facing to adopt Industry 4.0 in business production and supply chain operations. These barriers are amplified when it comes to the small and medium enterprises (SMEs). Our Literature review also demonstrates that there is still limited empirical research on how SMEs can be supported to decide the best route to adopt Industry 4.0 given the different barriers. Thus, this research aims to extend the literature review analysis by developing a Multi-Criteria Decision Analysis (MCDA) model that can act as decision-support tool to help SMEs to determine the most ideal route to adoption of new Industry 4.0 technologies given the different barriers. In order to develop our MCDA model, we identified and interviewed representatives from different groups of stakeholders including: (1) business executives, comprising of persons in SME companies responsible for decision-making on operational strategies to be designed and implemented; (2) digital solutions providers, who develop and supply the new I4.0 solutions across the market; and (3) an Industry expert/consultant, who provides customers with the knowledge and guidance on the most appropriate solution for their business. Using the developed MCDA, we show some trade-offs that SMEs are facing in adopting I4.0.

## Keywords
Industry 4.0, Barriers, SMEs, Multi-Criteria Decision Analysis

## 1. Introduction
The fourth industrial revolution, commonly referred to as Industry 4.0 (I.4 0) was first introduced in 2011 during the launch of Germany's High-Tech Strategy 2020 Plan during the Hanover Fair (Xu, Xu and Li, 2018). The plan was aimed at revolutionizing manufacturing processes through use of advanced technology. This influenced other countries to do the same, hence creating a buzz. Consequently, since the concept of I4.0 is inherently digitally driven, multiple technologies began to emerge such as, big data, Internet of Things (IoT), virtual reality, augmented reality, 3D printing, artificial intelligence (AI), machine learning, smart sensors, cloud computing, radio-frequency identification (RFID), robotics, and other cyber-physical systems (CPS), among others (Fernando *et al.*, 2023; Sony *et al.*, 2021; James *et al.*, 2022). Despite the buzz around I4.0, especially AI, there is still a low adoption in businesses more than 12 years later, especially by the small and medium enterprises (SMEs), who make up a majority of the companies in most countries (Goel et al., 2022). This research therefore seeks to investigate the barriers impeding the implementation of I4.0 into SMEs' production and supply chain activities. It considers the managerial perspective of the barriers as they are the key decision-makers on whether the enterprise will adopt I4.0. Additionally, lack of management support for I4.0 has been found to be one of the most significant barriers to its implementation (Machado et al., 2021; Herceg et al., 2020; Chauhan, Singh and Luthra, 2021). This research goes into the mind of a business executive, seeking to understand the factors that prevent them from making the decision to adopt I4.0 for their

business.

### 1.1 Objectives

In this paper, we aim to:

1. To identify the managerial barriers that affect the adoption of I4.0 by SMEs; and
2. To develop a decision support model that can act as decision-support tool to help SMEs to determine the needed level of adoption given the different barriers.

## 2. Literature Review

In order to obtain the literature review for this paper, we used a systematic approach to make sure that the recent trends in the literature had been captured and enable an in-depth analysis for the literature. We classified the obtained literature into three themes. The Industry 4.0 Technologies, Industry 4.0 Implementation Barriers – the TOE Framework and Industry 4.0 Challenges for SMEs.

### 2. 1 I4.0 Technologies

Historically, every industrial revolution was powered by a form of technology. The first one, industry 1.0, had water and steam-powered machines, electric-powered machines for industry 2.0, and advanced electronics and computers for industry 3.0 (Klingenberg, Borges and Antunes, 2022). Thus, to be able to understand the barriers to I4.0, it is important to first understand the underlying technologies driving the fourth industrial revolution. Out of the 46 accepted articles, 27 authors (59%) listed the different I4.0 technologies, while the remaining 41% simply referred to "industry 4.0 technologies". The list of technologies determined are illustrated in Figure 1 below.

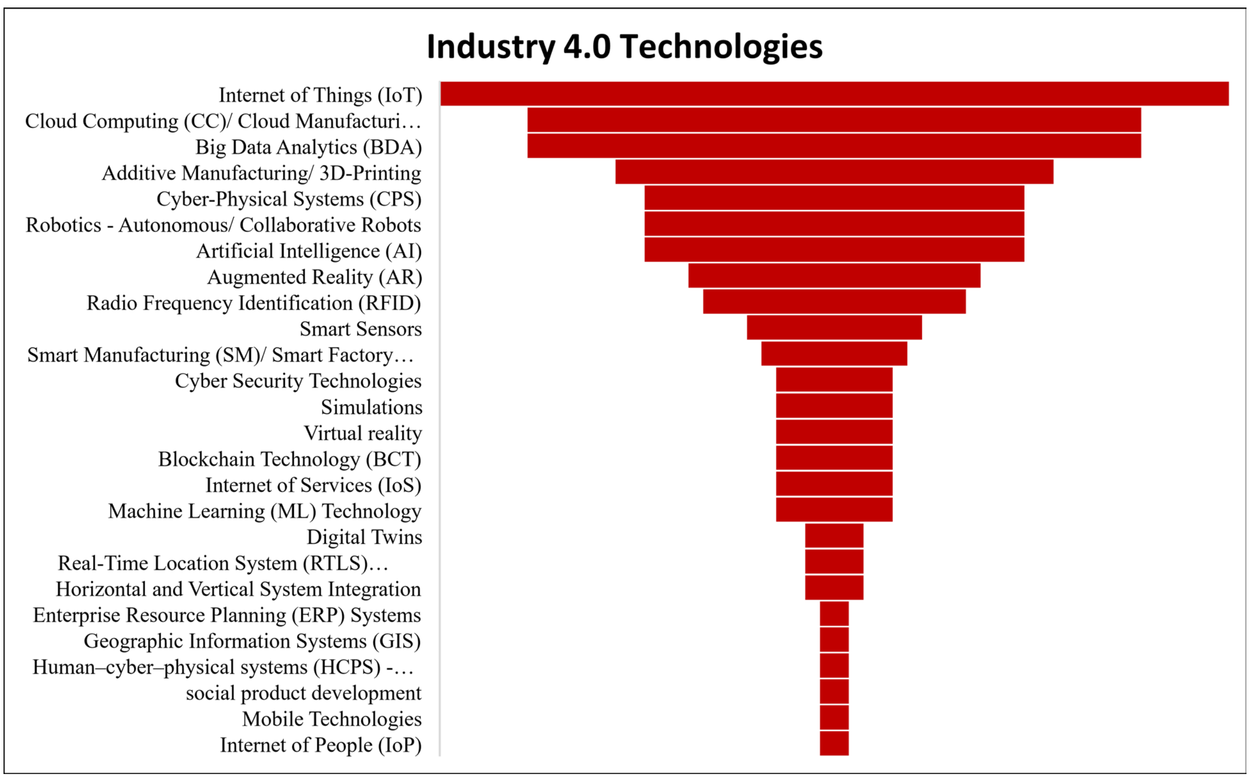


Figure 1. Industry 4.0 Technologies

From the above results, the 5 most common I4.0 technologies include Internet of Things (IoT), cloud computing/cloud manufacturing, big data analytics, additive manufacturing, commonly referred to as 3D printing, and cyber-physical systems (CPS). It was however noted that there were significant variations in the terminologies used to describe the different technologies. For example, articles such as (Fernando et al., 2023; Machado et al., 2021; Lahane, Paliwal and Kant, 2023) referred to CPS as a group word for smart sensors, cloud computing, microprocessors, etc., while

(Raj et al., 2020) listed CPS as a stand-alone technology, together with sensors and cloud computing. Thus, technologies like AI and machine learning may appear to have fewer mentions as independent terms, but they may already have been captured under group terms such as 'CPS, 'IoT' and 'cloud computing. Other uncommon technologies which have revolutionized manufacturing processes are augmented, virtual reality and simulations, which enable the enactment of expected outcomes before actual production is done (Yaqub and Alsabban, 2023).

## 2.2 I. 4.0 Implementation Barriers – the TOE Framework

To evaluate the managerial I4.0 implementation barriers identified from the articles, the TOE framework as adopted in Ghobakhloo et al. (2022) was used. Inferring from the name, the TOE framework involves analysis of factors from three perspectives, namely, the technological, organizational, and environmental contexts. The TOE framework is a robust evaluation method for determining factors in a company's contextual environment that influence its ability to invest in new technology (Rahman et al., 2022).

### 2.2.1 Technological Barriers

The technological perspective focuses on the use of different software and accompanying hardware to support the operations of the company and the interactions between them. The most common barrier identified under this perspective was the lack of required infrastructure to support adoption of new technology solutions (in 33 articles). Kumar et al. (2022) posit that I4.0 technologies are dependent on the firm's underlying hardware and software as they are intended to be integrative in nature. This is a common challenge in SMEs as their managers do not prioritize new technology adoption, but rather focus on the routine fulfillment of customer orders. Raj et al. (2020) suggest collaboration amongst industry players for the joint development of the supporting technological infrastructure. The second most common barrier is that of data insecurity and privacy fears. With system integration, there will be sharing of information across multiple platforms which exposes the company to potential loss of production information internally considered trade secrets (Sony et al., 2021).

Other technological barriers identified include: incompatibility of the new systems with existing technologies as each product has its unique set of code (Machado et al., 2021); unreliable internet connection, especially for most SMEs (Kumar et al., 2022; Raj et al., 2020); lack of awareness of what the different technologies are and what they do (James et al., 2022; Saniuk and Saniuk, 2018); risk of failure of the technology adopted, given its maturity levels which also means a potential lack of an alternative replacement in the market (Horváth and Szabó, 2019; Kumar, Singh and Dwivedi, 2020); and, lastly, concerns about availability of data required by the new technologies (Yurekli and Schulz, 2022), including how it will be securely stored (Machado et al., 2021; Attiany et al., 2023), and measuring data accuracy (Goswami and Daultani, 2022).

### 2.2.2 Organizational Barriers

The organizational perspective focuses on the interplay between the employees, business processes and policies, management, and resources to achieve operational efficiency. For this study, the Organizational category was further broken down into Operational, Socio-Cultural, and Strategic barriers as captured in Lahane, Paliwal and Kant (2023). This enabled a clearer view of the different types of organizational barriers.

The most common operational barrier was identified to be lack of skilled human resources to tackle I4.0 technologies, including insufficient knowledge for training and upskilling purposes (Kumar, Vrat and Shankar, 2021a; Terra, Berssaneti and Quintanilha, 2021). Lack of the required know-how means that the adoption of I4.0 will collapse before it starts since technology is only as good as the users. The second most common operational barrier is the high cost of investing in new technology. Given the nascent state of the technologies, there is low competition in the market, hence higher prices to the customers (Pech and Vaněček, 2022). Businesses, especially SMEs, do not have sufficient working capital for investment in new technologies, as most are still recovering from the financial losses that were caused by the Covid-19 pandemic. A key but uncommon barrier identified is where the business managers believe there is no need to adopt I4.0 since the existing systems are working optimally. This is a valid barrier, in the spirit of not fixing it if it is not broken. However, Cugno, Castagnoli and Büchi (2021) highlight that such an assertion could be due to another barrier; lack of knowledge about the benefits of I4.0 to the business, which was also identified as one of the common operational barriers.

From a socio-cultural perspective, the most common identified barrier to I4.0 adoption was resistance to change. In line with the paradigm of not fixing what is already working discussed under the operational perspective, a lot of employees, especially the senior-aged ones, view new technology adoption as a disruption to what they know how to do, and have been doing well for many years (Caiado et al., 2022; Yurekli and Schulz, 2022). Resistance by employees could also be the result of other barriers such as risk of data privacy breaches (Kumar, Vrat and Shankar, 2021a), fear of job losses, especially for low-skilled workers, who make up a significant proportion in manufacturing and agricultural SMEs (Kumar et al., 2022), and risk of strain to existing personnel (Kumar, Suhaib and Asjad, 2021).

From a strategic perspective, the barrier that came up the most is lack of management buy-in to the I4.0 concept. Managers allocate most of their time to running the day-to-day operations to meet increasing customer demand thus they may not prioritize taking time to understand I4.0 and its benefit and impact to future demand management. Stentoft et al. (2021) refers to this as a lack of ambidexterity by management, as their role should encompass both running the current business affairs and investing in ways to efficiently deal with future demand requirements.

The lack of management buy-in is also attributed by another barrier; lack of a detailed digital strategy, a change-management strategy, and an overall organizational strategy (Rajput and Singh, 2021; Müller, Kiel and Voigt, 2018). This barrier was also identified in the content analysis as shown in Table 1. Lack of a reliable strategy has the negative implication of incoordination between the different business units, which stalls decision-making (Shang, Saeidi and Goh, 2022).

### 2.2.3 Environmental Barriers

The environmental perspective involves the interaction between the company and other industry players such as the government, suppliers, investors, consultants, and competitors, and how they influence I4.0 adoption. The environmental barriers were further broken down into Regulatory and Other External categories.

From a legal or policy perspective, the most mentioned barrier to I4.0 adoption was the lack of detailed regulations by policy makers, to safeguard against cybercrime and data theft. In the absence of clear regulations, companies have become skeptical about embracing I4.0 as it involves multi-channel data sharing (Saniuk and Saniuk, 2018). Additionally, there are no international standards and protocols that can be relied on in the absence of local regulations, which makes decision-makers shy away from engaging in unsupervised technologies (Caiado et al., 2022; Kumar et al., 2021). To deal with this challenge, Gromova, Koneva and Titova (2022) suggest co-creation of global policies amongst different nations to enable standardization and definitions of I4.0 for contracting purposes.

For the Other External barriers, inadequate stakeholder support was the most common. Support from internal stakeholders would lead to faster decision-making, while that of the external stakeholders would lead to access to funding, business growth opportunities, better understanding of the technologies in the market, and joint development projects (Kumar, Suhaib and Asjad, 2021). Another external barrier identified was the lack of coordination amongst the different value chain players. For the industry players comprising of supply chain providers, there is little push towards collaboration in the development of desired I4.0 technologies (Lahane, Paliwal and Kant, 2023) and for knowledge providers such as universities and research centers, there are minimal partnership opportunities with firms for joint research and knowledge exchange on implementation of I4.0 (Cugno, Castagnoli and Büchi, 2021).

### 2.3. I4.0 Challenges for SMEs

Despite most I4.0 barriers being common to all businesses regardless of their size, the impact of the barriers to small and medium enterprises (SMEs) should not be ignored. For example, the barrier of high cost of implementing I4.0 while faced by every company, it is more severe in SMEs as their access to funding is limited as a result of their perceived riskiness by traditional financial institutions (Kumar et al., 2022). Large corporations have the advantage of having built up their credit score over the years, which makes it easier to access required funding.

Additionally, a majority of businesses in about every country fall under the SME bracket, which means that their contribution to their country's Gross Development Product is significant (Agarwal et al., 2022). Prause (2019) highlights that successful economies lean on the success of the manufacturing industry, but further in, the latter industry would not survive without the input of SMEs. At the moment, adoption of I4.0 by SMEs is however lower than that of large corporations, which puts them at an unfair competitive position (Goel et al., 2022).

## 3. Methods

Out of the available literature on I4.0 barriers, very few of them recommend solutions to eliminating those same barriers. While identification of the barriers helps to create awareness about the roadblocks in I4.0 adoption, offering potential solutions on how to eliminate them will motivate business managers to move towards I4.0 knowing, that whatever challenges they are facing can be overcome. Additionally, Nimawat and Gidwani (2021) noted from their systematic review of I4.0 barriers that most SMEs are still at the point of deciding whether or not to undertake the initial I4.0 investment. Thus, this research proposes a decision-support model, through Multi-Criteria Decision Analysis (MCDA), to help managers make decisions on the most appropriate options for I4.0 adoption, given their constraints. MCDA is a solution seeking operational research (OR) methodology that systematically structures the problem, factors in the decision-maker's preferences and makes recommendations based on the same (Cinelli et al., 2020). This enables the decision-maker to narrow down their options and eventually choose the most preferred alternative.

The MCDA methodology was effected through the Visual Interactive Sensitivity Analysis software, commonly referred to as V.I.S.A$^{TM}$. A key strength of the program is that it models decisions based on a hierarchical weighted value (HWV) approach (Valerie Belton and Visual Thinking International Limited, 2001). This means that the criteria are assigned weights starting with the most to the least important one according to the decisionmaker. The HWV approach is similar to the stepwise weight assessment ratio analysis (SWARA) approach applied in (Kumar, Vrat and Shankar, 2021b), that attributes criteria weights on the basis of 'comparative importance'. Other weighting methods in literature include Simple Additive Weighting (SAW), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and Analytical Hierarchy Process (AHP), among others (Turskis, Keršulienė and Zavadskas, 2010; James et al., 2022; Saraswat et al., 2023).

## 4. Data Collection

Input from industry players was sought to identify their perspectives of I4.0 implementation barriers. The interlinkages were then determined using a cognitive map. The stakeholder groups selected for the empirical study include: (1) business executives, comprising of persons in SME companies responsible for decision-making on operational strategies to be designed and implemented; (2) digital solutions providers, who develop and supply the new I4.0 solutions across the market; and (3) an Industry expert/consultant, who provides customers with the knowledge and guidance on the most appropriate solution for their business, based on their evaluation of the company's needs and circumstances.

## 5. Results and Discussion

Transcripts from the interviews were evaluated to derive the various industry 4.0 implementation barriers mentioned by the different participants, which were compared with the results from the SLR analysis. Additionally, data on criteria ranks, cost estimates and decision alternatives was derived from the forms filled by the participants.

### 5.1 MCDA Modelling

#### 5.1.1. Defining the Decisionmaker and the Problem

To kickstart the analysis, the decisionmaker was determined to be a Business Manager (BM) of an SME business, who is responsible for developing strategies to optimize operational performance. Thus, the selection, ranking and weighting of the criteria, that is, the factors affecting the decision, were determined from the perspective of the BM. The BM is faced with the problem of determining the best approach to adopting industry 4.0 for the company, amongst multiple alternatives. The best alternative is the one that satisfies at least two of the criteria that are considered most important to the decision-maker.

#### 5.1.2 Determination of Decision Alternatives: Routes to I 4.0 Adoption

Decision alternatives comprise of the different options available to the decision-maker based on the defined problem. Suggested routes/options to be weighed against each other were provided by the participants during the interviews and are outlined in Table 1 below.

Table 1. MCDA Decision Alternatives

| **Decision Alternatives/ Options** | **Route to Industry 4.0 Adoption** |
| --- | --- |
| Option 1 – Do Nothing | *Maintain the existing technology in the business*. This is mostly ideal where the company has recently invested in the technologies and is therefore still rolling it out. This would also be preferred where the decision-makers perceive the existing solution as operationally optimal, hence there is no need to change it. Maintaining existing technology especially beyond 3 years, however, creates a risk of obsolescence as new technologies continue to emerge in the market. |
| Option 2 – Modify | *Upgrade or modify parts of the existing technology solution*. This prevents obsolescence risk as the upgraded versions of the technology can be licensed from the different providers in the market. Since the company only obtains the right to use the technology, the licensing route is most ideal for a decisionmaker who is concerned about availability of finances to invest in I4.0 as no capital investment is required. The downside of this option is the risk of incompatibility as the new technology package may not match the specifications of the old technology. |
| Option 3 – Off-the-shelf Purchase | *Purchase new off-the-shelf (OTS) technology solution*. This involves scouting the market for the various I4.0 technologies available and purchasing the most suitable one for the business. Thus, a capital expense will be incurred. Since the technology is OTS, it means it is a standardized solution, hence there is risk of incompatibility or failure to meet all the requirements of the business. |
| Option 4 – Purchase then Customize | *Purchase and customize the technology*. This involves first assessing the areas not met by the OTS technology and engaging a developer for customization, hence eliminating incompatibility risk. However, the challenge with this option is that the customization process is time consuming, and the developer selected may not fully comprehend the customer requirements. It will also involve arranging for funds to pay the developer. |
| Option 5 – Design and Build | *Develop a new technology solution in-house*. This option is most ideal where there is no solution in the market that suits the unique business needs of the company. The option is highly capital intensive as it requires setting up a research and development unit within the business. However, the company will have control over the data storage and privacy, hence improving reliability. |

### 5.1.3 Determination and Weighting the Decision Criteria

A total of 8 decision criteria were selected based on the interviews analysis namely, (C1) technology acquisition cost, (C2) technology annual maintenance cost, (C3) availability of relevant skilled personnel, (C4) data security and privacy risk, (C5) technology reliability and sustainability, (C6) degree of job disruption, (C7) expected benefit/Return on Investment (ROI), and (C8) availability of supporting infrastructure (hardware, software etc.).

Weighting of criteria in the MCDA process enables the determination of the factors that are most important to the decision-maker (Mohamed, 2018). This research relied on input from industry players, which made the analysis more robust. The 8 participants were each asked to rank the criteria in order of significance based on their experience and business priority areas. The most preferred criterion was assigned a rank of 1, while the least preferred 8. The Geometric Mean Method (GMM) was applied to determine a combined ranking per criterion. Kumar, Vrat and Shankar (2021a) posit that GMM is widely used by researchers seeking to amalgamate individual responses from experts when applying an MCDA method. Table 2 shows the criteria rankings.

Table 2. Participants Criteria Rankings

| Criterion | Decision Criteria (most common barriers from SLR analysis) | Participants' Scores Ranking of Criteria Based on Priority | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | I | II | III | IV | V | VI | VII | VIII | Geometric Mean of Ranks | Combined Rank |
| C1 | Tech. acquisition cost | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2.00 | 2 |
| C2 | Tech. annual maintenance cost | 3 | 8 | 8 | 6 | 3 | 5 | 4 | 3 | 4.62 | 5 |
| C3 | Skilled personnel required | 7 | 4 | 3 | 7 | 5 | 4 | 1 | 6 | 4.04 | 4 |
| C4 | Data security and privacy risk | 6 | 3 | 6 | 5 | 4 | 6 | 6 | 5 | 5.00 | 6 |
| C5 | Technology reliability and sustainability | 4 | 5 | 4 | 4 | 1 | 3 | 3 | 8 | 3.51 | 3 |
| C6 | Degree of job disruption | 8 | 7 | 5 | 8 | 6 | 7 | 8 | 7 | 6.92 | 8 |
| C7 | Expected benefit (ROI) | 1 | 1 | 1 | 1 | 7 | 1 | 7 | 1 | 1.63 | 1 |
| C8 | Supporting infr. required | 5 | 6 | 7 | 3 | 8 | 8 | 5 | 4 | 5.47 | 7 |

To determine the criteria weights the hierarchical weighted value (HWV) approach was employed within the V.I.S.A software (Valerie Belton and Visual Thinking International Limited, 2001). The HWV approach assigns criteria weights on the basis of comparative importance, commonly referred to as a swing methodology. For modelling purposes, the ranks above were converted into arbitrary scores which were then normalized and fed into V.I.S.A$^{TM}$. The resulting weights are indicated in the value tree in Figure 2 below where also four main criteria categories were created based on the nature of the 8 criteria identified by the interviewees. These categories include *Cost*, *Resource Requirement*, *Impact* and *Benefit*.

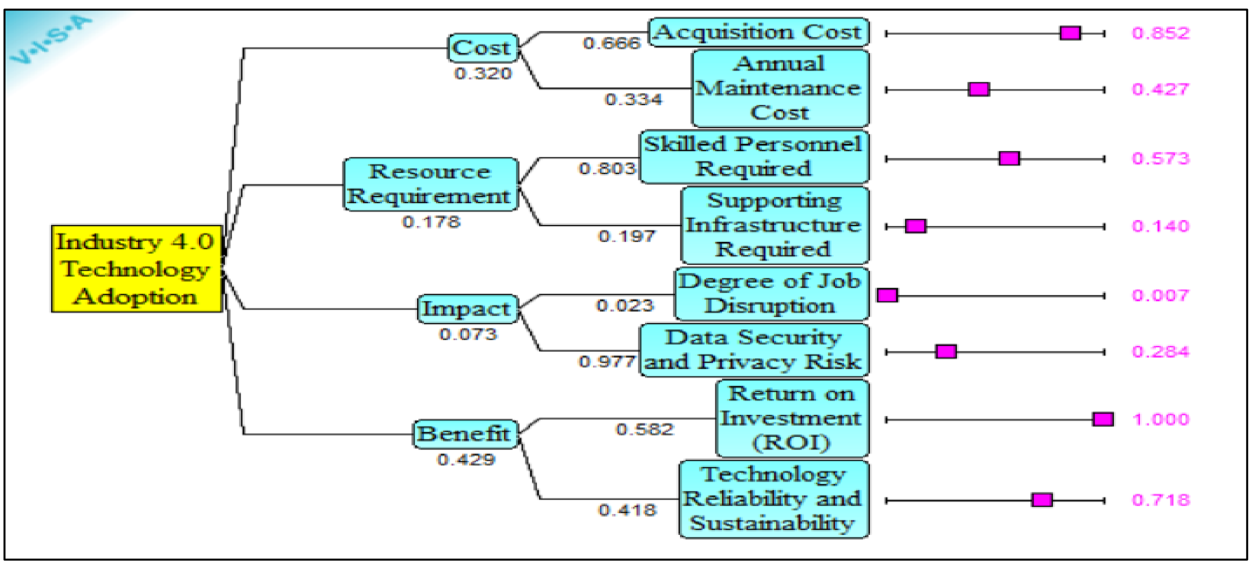


Figure 2. MCDA Value Tree

### 5.1.4 Defining Scoring Scales

To be able to measure alternatives against the defined criteria, a scoring scale must be defined for each criterion. The purpose of the scale is to be able to assign a score of between 0 to 100 for each criterion for purposes of standardization. A score of zero represents the worst outcome, while a score of 100 represents the best outcome. Different scales were created for each of the 4 criteria categories, depending on the nature of the respective criteria, as shown in Table 3 below.

Table 3. MCDA Scoring Scales

| **Criteria Group** | **Criteria under Group** | **Scoring Method** | **Scale** |
|---|---|---|---|
| Cost | C1: Technology acquisition cost. | Linear scale | Best (100) - $ 0;<br>Worst (0) - $ 200,000 |
| | C2: Technology annual maintenance cost. | | Best (100) - $ 1,000;<br>Worst (0) - $ 20,000 |
| Resource Requirement | C3: Skilled personnel required.<br><br>C8: Supporting infrastructure required. | Linear Scale | Best (100) – 0;<br>Worst (0) - 100 |
| Impact | C4: Data security and privacy risk.<br><br>C6: Degree of job disruption. | Qualitative Scale | 0 – Very High;<br>25 – High;<br>50 – Moderate;<br>75 – Low;<br>100 – Very Low |
| Benefit | C5: Technology reliability and sustainability.<br><br>C7: Expected Return on Investment. | Qualitative Scale | 0 – Very Low;<br>25 – Low;<br>50 – Moderate;<br>75 – High;<br>100 – Very High |

The cost estimates were obtained from the semi-structured interviews with the different participants stating that the cost of technology acquisition can go up to $200,000. The scale for resource requirements was defined by comparing the different decision alternatives with each other on how much they satisfy a specific criterion and ranking them from the best to worst. The highest in the rank gets a score of 100 while the lowest was assigned a score of zero. Finally for the qualitative scales 5 sub-categories were created to describe intensity and each category was assigned a value between 0 and 100.

## 5.2 Numerical Results

Once the scales had been defined, each alternative was scored against every criterion on the basis of the scales in Table 4 as shown in Table 5 below.

Table 4. Raw Alternative Scores Against Criteria

| **Raw scores** | **Criterion** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Alternatives** | **Tech Acquisition Cost ($)** | **Tech. Annual Maint. Cost** | **Skilled Personnel Req.** | **Supporting Infrastr. Req.** | **Degree of Job Disruption** | **Data Security and Privacy Risk** | **Return on Inv. (ROI)** | **Tech. Reliability & Sustainability** |
| **Maintain existing technology** | 0 | 1K | 100 | 100 | Very Low | Very Low | Very Low | Very Low |
| **License solution from third party providers** | 50K | 5K | 75 | 100 | Very Low | Moderate | Low | Low |
| **Purchase new off-the-shelf solution** | 100K | 10K | 50 | 75 | Moderate | Very High | Moderate | Moderate |
| **Purchase and customize off-the-shelf solution** | 150K | 15K | 25 | 25 | High | Moderate | High | High |
| **Design and build internal solution** | 200K | 20K | 0 | 0 | Very High | Very Low | Very High | Very High |

To provide a common ground for comparison, the scores were converted to the respective numbers between 0 and 100, as guided by the scales defined in Table 5, as shown in Figure 3 below:

Table 5. Standardized Alternative Scores Against Criteria

| Raw scores | Criterion | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Alternatives** | **Tech Acquisition Cost ($)** | **Tech. Annual Maint. Cost ($)** | **Skilled Personnel Req.** | **Supporting Infrastr. Req.** | **Degree of Job Disruption** | **Data Security and Privacy Risk** | **Return on Inv. (ROI)** | **Tech. Reliability & Sustainability** |
| **Maintain existing technology** | 100 | 100 | 100 | 100 | 100 | 100 | 0 | 0 |
| **License solution from third party providers** | 75 | 75 | 75 | 100 | 100 | 50 | 25 | 25 |
| **Purchase new off-the-shelf solution** | 50 | 50 | 50 | 75 | 50 | 0 | 50 | 50 |
| **Purchase and customize off-the-shelf solution** | 25 | 25 | 25 | 25 | 25 | 50 | 75 | 75 |
| **Design and build internal solution** | 0 | 0 | 0 | 0 | 0 | 100 | 100 | 100 |
| **Weights** | 0.852 | 0.427 | 0.573 | 0.14 | 0.007 | 0.284 | 1.000 | 0.718 |

The generated scores were then computed against the weights to determine the weighted scores of each alternative, which was succeeded by an analysis of the results. After scoring the alternatives against the set criteria, the resulting performance graph is illustrated in Figure 3 below:

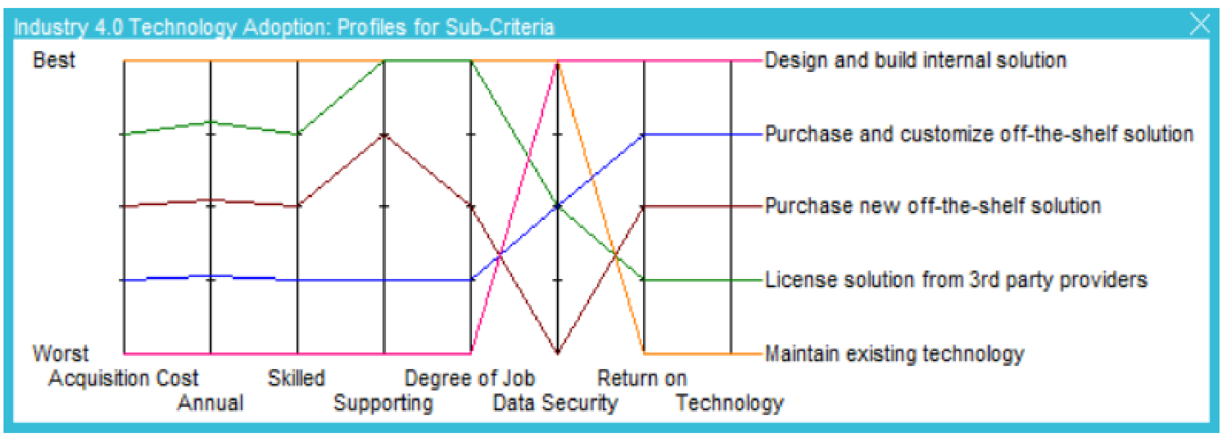


Figure 3. MCDA Ranking of Alternatives based on Criteria Scores

From Figure 4, maintaining the existing technology (orange line) may be perceived to be the most preferred option given that it ranks highest in 6 out of the total 8 criteria. These include costs (acquisition and maintenance, the level of resources required (people and supporting infrastructure), degree of disruption and level of data security risk. However, the same option ranks the least on the benefit criteria (expected ROI and technology reliability) where designing and building an internal solution is the most preferred option (pink line). It is therefore difficult to tell the overall most preferred option as the ranking varies depending on the criterion being analysed. Thus, there is a need to extend this analysis by factoring in weights, to make it easier for the decision-maker to identify the most ideal alternative. The solution to this is a sensitivity analysis.

## 5.3 Validation

To evaluate the impact on alternatives ranking caused by varying the criterion weights at a time, sensitivity graphs were plotted. The graph on Figure 4 (A) shows the sensitivity of alternatives against the weighting on total cost. At the current cost category weight (0.320 per value tree), the most ideal alternative would be to purchase a new off-the-shelf solution. This is because the maroon line is the highest point on the dotted line of the current weighting. This means that on average, cost ranked moderately by the participants (it was not the highest ranked criterion). It could be because the participant SME companies are part of a Group, hence they can access funding via the intercompany route from their associate entities. However, the sensitivity graph shows that if the weighting was increased to 0.5 and above, indicating that the decisionmaker is very concerned about cost, maintaining the existing technology would be most preferred (orange line). Literature shows that this is the case for most SME companies as access to capital is still a challenge due to their perceived risk profile by financial institutions (Kumar, Vrat and Shankar, 2021a). The sensitivity of alternatives against the weighting on benefit was also plotted as shown in the graph in Figure 4 (B).

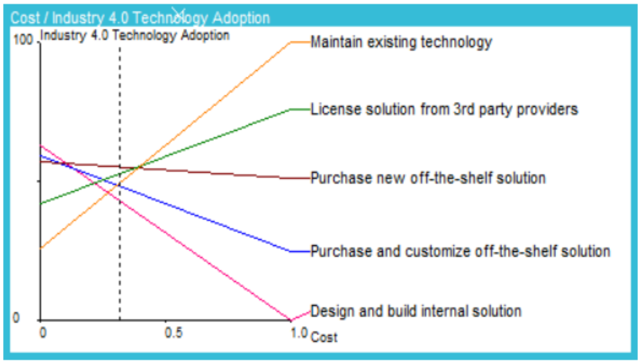


Figure 4 (A). Sensitivity to Changes in Cost Weighting

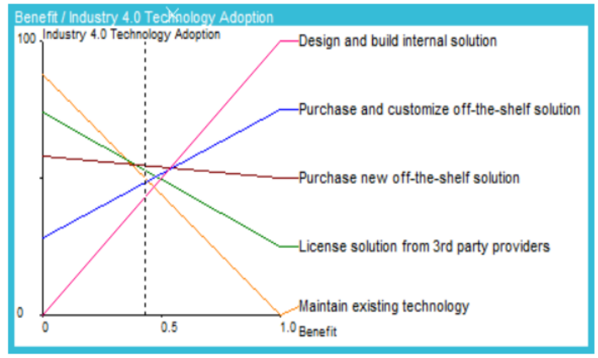


Figure 4 (B). Sensitivity to Changes in Benefit Weighting

At the current weight of the benefit category (0.429 per value tree), purchasing a new off-the-shelf solution is the most preferred option (maroon line). The weighting on both the cost and benefit category are close (0.32 and 0.429 respectively), which explains arriving at the same ideal options in the two sensitivity graphs. This means that SMEs on average look for a balance between cost and benefit when making investment decisions. If the benefit category weight was to be increased to about 0.6, the most ideal alternative would be to design and build the solution as it would mean a higher expected ROI and the creation of a reliable technology solution that is scalable in the medium term as new technologies continue to emerge.

## 6. Conclusion and future research

This research aimed to evaluate the barriers to I4.0 adoption by SMEs. This research has also proposed MCDA as a robust decision support model for managers to determine the most ideal route to I4.0 adoption, including the option to maintain the existing technology depending on the decision-maker's circumstances. An empirical study was carried out to show the systematic process of conducting the MCDA methodology. This will provide a reference point for future decision-makers in need of a decision support model to help in solving complex issues.

To effectively apply MCDA for decision support, it is recommended that managers collaborate so as to arrive at a consensus on the ideal criteria rankings and weights. Additionally, when evaluating the I4.0 technologies to adopt, businesses should ensure that the intervention selected does not lead to layoffs above a certain threshold. This is because technologies are not meant to replace human beings, but to enable them to carry out their tasks more efficiently. Finally, to reduce data security risk, it is recommended that decision-makers seek to first understand the technology before adopting. This would include asking questions such as: What data is required? How will the data be used? How will it be stored? How can it be monitored to ensure legitimacy of results? The responses to these questions should be captured in the agreement so that it is binding between the parties, and legal recourse can be sought in the event of any breach.

The output of this research is an initial step for future research that aims to validate and generalize the proposed MCDA using in-depth case studies. There will also be a need to improve the proposed MCDA to focus on a specific technology, based on the given context. Future research will also consider how the uncertainty of decision makers about the benefits and the cost of different technologies can be taken into account.

## Acknowledgment

This paper is based on an academic dissertation that was submitted to the University of Strathclyde in 2023 by the first author, and conceptualized and supervised by the second author.

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## Biographies

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