**A Framework for Assessing Social Acceptability of Industry 4.0 Technologies for the Development of Digital Manufacturing**

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**Abstract**

The manufacturing sector has undergone a significant transformation using revolutionary Industry 4.0 (I4.0) technologies that have profoundly changed production processes and operations. To unlock the digitalization of sustainable production systems, manufacturing organizations are keen to adopt digital technologies to enhance performance. This paper analyses the social acceptability dimensions of I4.0 in the context of digital manufacturing (DM) and proposes a novel framework. The dimensions were identified through an extensive literature review. A data set of 121 responses was collected from different Indian manufacturing units and exploratory factor analysis was employed with dimensions structured into seven categories - safety, psychological, behavioural, compliance, cultural, employee and market. To develop inter-relationships among the main dimensions, a fuzzy decision-making trial and evaluation laboratory technique was utilized. Based on the priority order, 'security breaches' are the most significant dimension, followed by 'data theft'. The study contributes to both the theory of socio-technical transition (TSTT) and social cognition theory (SCT) by describing the impact of I4.0 technologies on social and personal behaviour. The study findings make significant contributions to both the practical and managerial perspectives of I4.0 technologies for the growth of DM. This paper provides fruitful insights for decision-makers and industry practitioners to develop a DM environment.

***Keywords:*** Industry 4.0; social dimensions; empirical analysis; digital manufacturing; socio-technical transition; revolution

1. **Introduction**

In the current business scenario, organizations are keen to enhance their productivity through the use of digital manufacturing (Shakeel et al., 2020). Adopting digital manufacturing enables rapid development of a consumer-specific product with real-time tracking. It will also reduce the risk associated with the production system while protecting the environment (Moktadir et al., 2018). In this sense, Industry 4.0 (I4.0) concepts are gaining more importance because of their numerous advantages in production systems and environmental protection. The widely used definition of I4.0 is *“… real-time, intelligent and digital networking of people, equipment and objects for the management of business processes and value-creating networks*” (Vinodh et al., 2021). The rapid growth in I4.0 now significantly influences manufacturing operations and decision-making (Reinhard et al., 2016). In this regard, the adoption of digital manufacturing provides numerous benefits in terms of increased efficiency, flexibility and speed (Dalenogare et al., 2018; Zhou et al., 2021). The principles of automation, computation, connectivity and integration enable digital manufacturing to transform a traditional system into a smart system (Gillani et al., 2020)

I4.0 has been widely adopted by many German firms like BMW, Daimler and Volkswagen. The Chinese government has also adopted a strategy named "made in China 2025". Many other countries such as the US, UK and Japan have adopted similar initiatives to enhance their business operations (Bag et al., 2018). The adoption of I4.0 technologies brings new opportunities to improve organizational performance levels (Vinodh et al., 2020; Sabri-Laghaie et al., 2020). I4.0 concepts allow the adoption of digital technologies into the production system to integrate the virtual network with the physical world. This integration enhances the system's modularity, customization of products and services that benefit both the manufacturing and logistics sectors. Analysing the social acceptability of new technologies is crucial for their adoption without any hurdles. As per the theory of socio-technical transition (TSTT), the transition of technologies will not emerge alone but will also influence changes in society, such as changes in infrastructure, norms and industrial regulations (Jurgilevich et al., 2016; Liu et al., 2018; Tijan et al., 2021). Based on TSTT, the transition from the third industrial revolution to the fourth industrial revolution will also impact on societal factors such as increased job opportunities, process safety and emotional intelligence (Moktadir et al., 2018). Social cognition theory (SCT) defines the three elements of social integration as personal behaviour, individual cognition and social behaviour (Butt et al., 2017; Liu et al., 2018). Social integration is an important aspect that should be considered for the adoption of any new technologies. Personal behaviour and individual cognition have essential roles in the adoption of digital technologies. Personal behaviour, such as social interaction and interdisciplinary thinking, are the key drivers for adopting I4.0 technologies successfully (Birkel et al., 2019). The increasing population, scarcity of resources, pollution and climate changes are primary concerns for the whole world. Due to government regulations and increasing consumer awareness, organizations are forced to adopt sustainable practices (Mardani et al., 2020a). One of the critical drivers of I4.0 is sustainability. Several studies are available on the environmental and economic aspects of sustainability in adopting digital manufacturing (Mashhadi and Behdad, 2018; Birkel et al., 2019; Mao et al., 2020). Yet, none of these studies has been conducted to analyse the social issues associated with the adoption of I4.0 for digital manufacturing. This existing literature gap motivates us to analyse the social issues associated with the implementation of I4.0 in the context of digital manufacturing. Therefore, this study aims to investigate the social dimensions of I4.0. In this context, this paper seeks to address the following research questions.

*RQ1*: What are the social dimensions for the adoption of I4.0 to support digital manufacturing?

*RQ2*: How can these social dimensions be analysed to determine their priority to forecast the nexus for digital manufacturing?

*RQ3*: What are the implications of social dimensions in the adoption of I4.0 for the growth of digital manufacturing?

To analyse these research questions, this article sets out the following objectives:

* To identify the social dimensions for the adoption of I4.0 technologies to enable digital manufacturing
* To conduct an empirical study to develop a structured model of the identified social dimensions and analyse the inter-relationships in the adoption of I4.0 to enable digital manufacturing

The social dimensions for adoption of I4.0 to enable digital manufacturing need to be identified at the outset. Several of these dimensions have been ascertained from a literature review. A survey was conducted to analyse and validate the applicability of social dimensions. Further, exploratory factor analysis (EFA) was carried out to group social dimensions into different categories. A reliability test was then conducted to check the reliability of the collected survey data. Social dimensions were analysed using the fuzzy theory-based decision-making trial and evaluation laboratory technique (F-DEMATEL) method. The F-DEMATEL method aims to establish a structural model illustrating causal connections among various criteria in a fuzzy environment (Malekzadeh et al., 2016; Vinodh and Wankhede, 2021). This method has been widely utilized for selection problems (Singh and Bhanot., 2019). The advantage of using the F-DEMATEL approach is its ability to convert the correlation of causes and effects of criteria from an unpredictable to a justified model of a study. In addition to this, the F-DEMATEL approach will decrease the computation for the number of considered criteria, helping an organization to increase the productivity of the criteria. The F-DEMATEL approach considers influential power of factors and develops cause-effect diagrams of factors. F-DEMATEL also categorizes the factors into cause-and-effect groups. The approach generates causal diagrams which enable clear understanding of inter-relationships between factors. The priority order thus established can help in proposing research implications to enhance the social acceptability of digital manufacturing.

This article starts by introducing the social dimensions for I4.0 enabling digital manufacturing in section 1. Section 2 discusses a literature review on the social dimensions of digital manufacturing. Section 3 discusses the research methodology. Analysis and results are presented in section 4. Section 5 describes the discussion and implications of the study. Conclusions and future work are then considered in section 6.

1. **Literature review**

This section includes a review of previous articles in the field of social aspects associated with I4.0. This section is further divided into three sub-sections.

***2.1 Review on the adoption of I4.0 to enable digital manufacturing***

I4.0 principles allow integrating the virtual network with the physical environment by incorporating emerging technology into the production system. This integration improves the modularity of the system and the customization of goods and services for manufacturing and logistics industries. With this in mind, Tupa et al. (2017) aimed to analyse the risks associated with I4.0 technologies. They found that a common risk associated with I4.0 is related to information security. The study recommended developing a framework on key performance indicators of I4.0 for effective risk management of the system. The challenges for adopting I4.0 technologies in the manufacturing sector were analysed by Moktadir et al. (2018). Their study considers a Bangladesh-based leather industry and analyses the challenges. The study found that a lack of technology infrastructure is the most critical challenge in implementing I4.0. The potential of I4.0 in value creation for sustainable development was analysed by Stock et al. (2018). The study presents a systematic literature review on I4.0 value creation for sustainable development. Further, the study analyses the social and environmental aspects of I4.0.

Mashhadi and Behdad (2018) analysed the negative environmental impact associated with I4.0 technologies. The review uses the life cycle assessment (LCA) package to examine the total environmental effects related to smart manufacturing. The enablers of I4.0 were analysed by Bag et al. (2018) to enhance the sustainability of the supply chain. This study presented a literature survey on relevant articles and identified 13 critical enablers of I4.0 to improve the supply chain's sustainability. Further, the authors developed a research framework to bridge the identified literature gaps. Industries' challenges in adopting I4.0 technologies were analysed by Sanchez (2019). The most critical challenges associated with the adoption of I4.0 were identified; these are unemployment generation, the vulnerability of data and device interconnection. Braccini and Margherita (2019) analysed the impact of I4.0 technologies on sustainability aspects. Their study showed that I4.0 supports triple bottom line sustainability benefits by enhancing productivity, energy monitoring and a safe working environment. Birkel et al. (2019) developed a risk framework associated with the adoption of I4.0. The study identified several risks and categorized them into three areas - ecological, environmental and social. Poor investment and increased competition were recognized as critical economic risks. Increased energy consumption was identified as a potential environmental risk. Job losses were identified as a crucial social risk in the adoption of I4.0. Ivanov and Dolgui (2020) contributed to supply chain risk management research by enhancing predictive decisions through the visualization of the supply chain. The focus of the study was to create a digital supply chain twin to manage risks associated with digitalization. Moeuf et al. (2020) aimed to identify and analyse risks and opportunities related to I4.0 in the small and medium scale enterprises (SMEs) sector. The study uses the Delphi method and identifies the critical risk associated with I4.0 - lack of expertise and short-term strategy. Further, the study recommended proper training for the workforce; they suggested that this would lead to the successful adoption of I4.0 projects.

The adoption of digital manufacturing is significantly affected by technological, economic and environmental factors (Gillani et al., 2020; Meindl et al., 2021). Digital twin technology can be integrated with intelligent manufacturing to enable real-time failure prediction (He and Bai, 2021). This enhances the sustainability of digital manufacturing. The digital twin model was also adopted by Liu et al. (2021) to enhance the efficiency of digital manufacturing. Digital twin was also adopted to enhance the planning process (Guerra-Zubiaga et al., 2021). The adoption of I4.0 technologies with sustainable manufacturing concepts will significantly influence productivity and will enable sustainable development (Bag et al., 2021).

***2.2 Review on the social acceptability of I4.0 in enabling digital manufacturing***

The technological transformation will not occur in isolation; it will affect societal changes such as infrastructure, norms and industrial regulations. Therefore, the importance of social acceptability in the implementation of emerging technology needs to be analysed. In this regard, Bonekamp and Sure (2015) presented a review of the analysis of the impact of I4.0 on human labour. The study showed that I4.0 technologies might decrease in low-skilled activities and increase in high-skilled activities, enhancing planning and control of information technology (IT) related activities. Badri et al. (2018) aimed to integrate occupational health and safety in the I4.0 scenario. The study recommended focusing on the emergent occupational risks associated with production to enhance firms' sense of social responsibility. The educational requirement in the era of I4.0 was analysed by Benešová et al. (2018). I4.0 technologies require high skills and education for controlling and monitoring the system. I4.0 is not only changing the labour market but also the education system needed. For these reasons, the authors presented a term called ‘education 4.0’; the study analyses risks associated with education 4.0. Stock et al. (2018) proposed a review on I4.0 technologies and their sustainability impact. The study analyses the sustainability value creation from I4.0 through expert interviews. The study reveals that value creation from I4.0 leads to sustainable development. Brocal et al. (2019) presented the emerging risk associated with the human factor in the I4.0 scenario. The study demonstrated risk management to enhance human performance. The authors also showed various risks associated with I4.0, such as industrial and occupational risks linked with human behaviour.

The role of human, relational and structural capital in balancing innovation and exploitation projects was analysed by Mahmood and Mubarik (2020). The study conducts a questionnaire survey on 217 Pakistan-based SMEs and analyses the survey data using partial least square-structural equation modelling (PLS-SEM). The findings reveal the significant impact of intellectual capital on organization ambidexterity. The study recommended developing policies for the firm's intellectual capital to balance innovation and exploitation projects. Mao et al. (2020) presented a survey to analyse the importance of innovations in society. The survey results show that innovations provide benefits to society by enhancing the communication and productivity of the supply chain. Adedoyin et al. (2020) aimed to analyse how information and communication technologies (ICTs) can improve the impact of foreign direct investment (FDI) on the gross domestic product (GDP). The results show a positive relationship between the I4.0 scenario and ICT tools used to enhance productivity. Tortorella et al. (2020) analysed the barriers to adopt I4.0 technologies in hospitals. The study presented a survey of 159 managers from 16 hospitals located in different countries. Popkova and Sergi (2020) analysed the importance of human capital and artificial intelligence in entrepreneurship associated with I4.0. The study models the optimum ratio of human intellect and artificial intelligence in social entrepreneurship in the I4.0 scenario. Bogoviz (2020) has also analysed human and artificial intellect collaboration with respect to I4.0.

The health and safety risks associated with the adoption of I4.0 technologies were analysed by Adem et al. (2020). The study further prioritizes identified risks using a fuzzy analytic hierarchy process (F-AHP). Mental fatigue and psychological pressure were identified as the most critical risks associated with I4.0. Saniuk et al. (2020) aimed to analyse social expectations and development-related changes related to I4.0. Product personalization was the key area identified by the authors in the development of I4.0. Gomes et al. (2020) presented a study on adopting I4.0 technologies in Brazilian dam operations. The study identifies environmental, economic and social benefits associated with the adoption of artificial intelligence in these dam operations. The study recommended that artificial intelligence (AI) adoption in dam operations could enhance decision-making and bring many sustainable benefits. Various multi-criteria decision making (MCDM) techniques have been adopted in the I4.0 environment but this study focuses on the social acceptability of I4.0. Table 1 highlights a review of I4.0 studies related to the social aspect using different MCDM methods.

**Table 1:** Review on I4.0 studies on social aspect using MCDM

|  |  |  |
| --- | --- | --- |
| **Studies** | **MCDM Technique used** | **Contributions** |
| Nara et al. (2021) | Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) | Identified the key performance indicators of sustainable development and analysed the impact of the adoption of different I4.0 technologies on identified key performance indicators |
| Khokhar et al. (2020) | Best worst method  | Analysed the social sustainability of the supply chain in I4.0 environment. |
| Vinodh and Wankhede (2021) | Fuzzy DEMATEL  | Examined the workforce attributes for the I4.0 environment |
| Sriram and Vinodh (2021) | Complex Proportionality Assessment (COPRAS)  | Examined the readiness factors of I4.0 technologies to enable digital manufacturing |
| Adem et al. (2020). | Fuzzy AHP | Investigated the health and safety risks associated with the adoption of I4.0 technologies  |
| Kumar et al. (2020) | DEMATEL | Evaluated the challenges in the adoption of I4.0 technologies for smooth production with ethical and sustainable operations. |

***2.3 Research Gaps***

From an extensive literature review, we have found that most researchers have adopted I4.0 to address the technical difficulties or risks associated with its implementation (Tupa et al., 2017; Ivanov and Dolgui, 2020; Moeuf et al., 2020). Some authors have also attempted to discuss the potential challenges of I4.0 based value creation in an organization (Moktadir et al., 2018; Sanchez, 2019). The analysis of drivers and barriers in the adoption of digital manufacturing has also been explored in current literature (Bag et al., 2018). The educational requirements for the I4.0 scenario also demonstrate how this leads to long-term benefits being achieved Concerning the social aspects, very few authors attempted to address issues such as human skills requirement in the I4.0 era, occupational health and process safety risks associated with I4.0, human, relational and structural capital in balancing the innovation and exploitation projects (Badri et al., 2018; Brocal et al., 2019; Mahmood and Mubarik, 2020). No studies reported a critical analysis of the social acceptability dimensions required for I4.0 acceptance in industries. Therefore, it is essential to analyse the social dimensions of I4.0 for the smooth adoption of digital manufacturing. Therefore, there is a need to identify and analyse the social acceptability dimensions of I4.0 adoption. This research gap is carried forward in this study. Hence, the present study demonstrates the critical identification of social acceptability dimensions related to I4.0 through a literature review with further examination using exploratory analysis. The F-DEMATEL technique has been adopted to prioritize the social acceptability dimensions of I4.0 for the growth of digital manufacturing.

1. **Research Methodology**

In this work, a three-phase study was conducted, as shown in Figure 1

Develop cause and effect digraphs

Discussions, implications and conclusions of the study

Sensitivity analysis to check reliability of DEMATEL

Develop total relationship matrix

Calculate row and column summation of total relationship matrix

Data collection from experts based on defined scale

Calculate the average and normalize relationship matrix

Analyse survey data to validate social dimensions

Exploratory factor analysis to group social dimensions in different social acceptability categories

Selection of expert panel for further analysis of social dimensions

Development of survey questionnaire to validate the identified social dimensions

Conduct of survey

Literature review on social dimensions of Industry 4.0

Identification of social acceptability dimensions for adoption of Industry 4.0

Identification of social acceptability dimensions

Empirical Study

Analysis of social acceptability dimensions based on Fuzzy DEMATEL method

Phase - I

Phase - II

Phase - III

**Figure 1:** Flow of study

Figure 1 shows the flow of the presented research. In the first phase of the study, we examined state-of-the-art literature to identify social dimensions for the adoption of I4.0. We used SCOPUS and the Web of Science databases to identify articles about the social aspect of I4.0 to collect social acceptability dimensions. The identified social acceptability dimensions, along with their descriptions, are presented in Table 2. In the second phase, we performed an empirical study by collecting data from industry experts, researchers and academia. Primary data was collected from 125 respondents to analyse the feasibility of social dimensions. Further, a structural factor model was planned to develop the use of exploratory factors analysis (EFA). We shortlisted several social dimensions for further analysis from EFA by eliminating some dimensions that were not relevant to the study. In the third phase, we used the F-DEMATEL approach to analyse and prioritize the shortlisted social dimensions of I4.0. For prioritization of social dimensions, we collected data from ten experts and formed a cause-effect relationship map. This will help industrial practitioners and researchers to understand the social acceptability of I4.0 for the growth of digital manufacturing.

**Table 2:** Identified social acceptability dimensions of I4.0

|  |  |  |  |
| --- | --- | --- | --- |
| **S. No.** | **Social acceptability dimensions** | **Description** | **References** |
|  | Complex procedures to obtain approvals | The organization has a complex hierarchy to obtain approvals | Qin et al. (2016); Rane et al. (2019) |
|  | Collaborative relationships | The mutual understanding between different stakeholders will result in the successful adoption of I4.0 technologies | Lintukangas et al. (2016); Kumar et al. (2018); Kumar et al. (2019) |
|  | Skilled management team  | A skilled management team ensures the successful adoption of I4.0 technologies | Hecklau et al. (2016); Moktadir et al. (2018) |
|  | Strategy towards I4.0  | Strategic plan for the adoption of I4.0 in the manufacturing sector | Zhao et al. (2016); Moktadir et al. (2018) |
|  | Acceptance of innovations | The willingness to accept the adoption of I4.0 technologies | Quinton et al. (2018); Moeuf et al. (2020) |
|  | Long and uncertain amortization | High cost and uncertain amortization significantly influence the adoption of I4.0 technologies | Ghanbari et al. (2017); Birkel et al. (2019) |
|  | Core competencies | Core competencies are the ability to adopt changes in technologies | Elkington (1998); Birkel et al. (2019) |
|  | Greater number of qualified workers | Adoption of I4.0 technologies requires more qualified workers | Tupa et al. (2017); Matt et al. (2020) |
|  | Skilled labour | Proper awareness and understanding of I4.0 concepts from a labour viewpoint | Zhao et al. (2016); Kaur et al. (2018); Rane et al. (2019); Kumar et al. (2019)  |
|  | Building job opportunities  | Adoption of I4.0 technologies enhances robustness to the system and creates many job opportunities | Waibel et al. (2017); Moktadir et al. (2018) |
|  | Failures of government policies | Failure of government policies will significantly impact the adoption of I4.0 technologies | Rostamzadeh et al. (2018); Kumar et al. (2019)  |
|  | Less awareness | Less awareness about I4.0 technologies  | Birkel et al. (2019); Mardani et al. (2020b) |
|  | Diminishing barriers to market entrance | Diminishing barriers to the market entrance are the key drivers for the adoption of I4.0 technologies | Hartmann and Moeller (2014); Birkel et al. (2019) |
|  | Delay in project completion | I4.0 technologies enhance productivity, thereby minimizing delay in project completion | Chanter and Swallow (2007); Rane et al. (2019) |
|  | Responsiveness to sudden demand | I4.0 technologies enable quick responses to sudden change by making process robust | Aljanabi and Ghafour (2020) |
|  | Interdisciplinary thinking | Multiple disciplinary thinking is the key driver for the adoption of I4.0 technologies | Birkel et al. (2019); Kaur et al. (2020) |
|  | Social interaction | New design thinking and innovations can be enhanced by social interaction | Birkel et al. (2019); Kaur et al. (2020) |
|  | Psychological pressure  | Psychological pressure comes with competitive companies to enhance operational efficiency | Ben-Daya et al. (2019); Adem et al. (2020) |
|  | Fearless attitude | The fearless attitude of employees enables them to showcase creativity | Birkel et al. (2019) |
|  | Work readiness skill | Skills of workers to adopt working with I4.0 technologies | Vinodh and Wankhede (2021) |
|  | Distrust in AI | Fear of what will happen if AI doesn't work well | Birkel et al. (2019) |
|  | Irresponsible use of land and facilities | Showing irresponsible usage of facilities in the adoption of I4.0 technologies | Mishra et al. (2012); Kumar et al. (2019)  |
|  | Manipulation of communication | Manipulation of communication refers to the inappropriate information flow | Yang et al. (2016); Niesen et al. (2016); Rane et al. (2019) |
|  | Security breaches | Access to any machine without authorization is termed a security breach. With the adoption of I4.0 technologies, security breaches can be minimized | Zhao et al. (2016); Niesen et al. (2016) |
|  | Data theft | The inability of the system to ensure data safety | Zhao et al. (2016); Niesen et al. (2016) |
|  | Ensuring a safe work environment | Adoption of I4.0 technologies would enhance human-robot interaction which enables a safe working environment | Mani et al. (2016); Sangwan and Bhatia (2020) |
|  | Ensuring a hygienic workplace | A hygienic workplace ensures the good health of the workers | Mani et al. (2016); Papetti et al. (2020) |
|  | Ensuring proper sanitation and clean water | These are necessary requirements of employees working in an organization | Mani et al. (2016) |
|  | Ensuring the health of machines | Ensuring the health of machines increases the life of machines as well as productivity | Silvestri et al. (2020) |
|  | Process safety | Process safety avoids accidents | Silvestri et al. (2020) |
|  | Commitment towards work | The enthusiasm of employees towards their assigned work | Yadav et al. (2020) |
|  | Acceptability towards change | The attitude of employees to accept changes | Yadav et al. (2020); Vinodh and Wankhede (2021) |
|  | Flexibility | The ability of the operator to work with different machines and technologies | Yadav et al. (2020); Fragapane et al., (2020) |
|  | Emotional intelligence | An optimistic way to handle emotions to manage new technologies | Karacay et al. (2018); Vinodh and Wankhede (2021) |
|  | Social-emotional learning | The ability to handle emotions about self-control for effective decision making | Karacay et al. (2018); Vinodh and Wankhede (2021) |

**4. Analysis and results**

**4.1 Empirical Analysis**

An empirical study helps in developing the theoretical base for the given research. This study used a mixed qualitative and quantitative approach to enhance the theoretical base (Field, 2009). This work aims to analyse the information collected from the respondents of the conducted survey. In this study, an attempt has been made to collect and analyse the social dimensions of I4.0. Initially, the social dimensions of I4.0 were collected from an exhaustive literature survey and are presented in Table 2. To validate the applicability of identified social dimensions, an empirical analysis was conducted. The questionnaire was developed based on the specified dimensions with our research team conducting the survey. Data was collected from different industries, experts, researchers and academia through an online system. We have used the Cronbach alpha value to validate data reliability (Hair et al., 2010). The steps of the empirical analysis are presented in the following sub-sections.

***4.1.1 Questionnaire formation***

An empirical study was conducted to validate the applicability of collected social dimensions. Several questionnaires were prepared to collect opinions from participants to validate these social dimensions. The responses were collected for each questionnaire on a Likert scale ranging from 1 to 5, where 1 represents ‘strongly disagree’ and 5 represents ‘strongly agree’. We held discussions with academic professors regarding the survey questionnaire structure in the initial stage; all of these professors have more than years of research and development experience. Based on their suggestions, we restructured parts of the survey questionnaire to enhance its clarity and comprehension.

* + 1. ***Data collection***

As the present work is designed to analyse social dimensions associated with the adoption of I4.0, the survey participants must have good knowledge of the considered topic. The designed survey questionnaire was sent to different Indian manufacturing units to get the responses from those working in the area of research of this study. A purposive and snowball sampling method was used to collect data from these experts. Initially, appropriate respondents were contacted; through them, the research team was able to access other operatives working in the same area. Through this process of sampling, 250 respondents were contacted for the survey. Out of the total contacted, 121 responses were collected in a period of two months (December 2020 - January 2021) ; these were used to validate the social dimensions in the adoption of I4.0 to enable digital manufacturing. The details of the respondents are presented in Table 3.

**Table 3:** Details of survey respondents

|  |  |  |
| --- | --- | --- |
| **Profile of respondents** | **Total** | **Percentage** |
| Age Group | Between 20-25 | 5 | 4.132 |
| Between 26-31 | 42 | 34.711 |
| Between 32-37 | 39 | 32.231 |
| Between 38-45 | 25 | 20.661 |
| Above 45 | 10 | 8.264 |
| Gender | Male | 90 | 74.380 |
| Female | 31 | 25.620 |
| Current Position | Chief Executive Officer/ Chief Operating Officer/ Chief Information Officer | 4 | 3.306 |
| Managing Director/Executive Director | 2 | 1.653 |
| Senior Vice President/ Vice President /Additional Vice President | 13 | 10.744 |
| Manager/Consultant | 38 | 31.405 |
| Specialist/Analyst/Engineer | 38 | 31.405 |
| Supervisor/Coordinator | 18 | 14.876 |
| Others | 8 | 6.612 |
| Work Experience | Less than 5 | 33 | 27.273 |
| 5 to 10 | 32 | 26.446 |
| 10 to 15 | 26 | 21.488 |
| 15 to 20 | 15 | 12.397 |
| More than 20 | 15 | 12.397 |
| Organization Type | Automotive | 52 | 42.975 |
| Logistics and Supply Chain | 28 | 23.140 |
| Pharmaceutical and Healthcare | 18 | 14.876 |
| Food and Beverages | 12 | 9.917 |
| Chemical | 7 | 5.785 |
| Others | 4 | 3.306 |

***4.1.3 Reliability and Validity analysis***

Reliability and validity analysis need to be carried out to check the integrity of the respondents’ data. This will check the accuracy of data being collected through a survey. Factor loading has been used to check the validity of any data that is received. A factor loading value of more than 0.5 is acceptable (Hair et al., 2010). Similarly, to analyse the reliability of data, we used the Cronbach alpha value. A Cronbach alpha value greater than 0.8 is considered to be reliable (Chen, 2008). We calculated factor loading for each social dimension and found that factor loading is more than 0.5 for all dimensions; this shows the consistency and validation of data. Further, we calculated Cronbach alpha for each dimension and found that the value for each dimension lies between 0.840 and 0.912. This shows that the data is reliable and suitable for further study.

***4.1.4 Exploratory factor analysis (EFA)***

The development of factor structure is carried out using EFA. EFA is the most widely used multivariate analysis technique to obtain a group of factor structures from a number of dimensions without losing crucial information (Hair et al., 2010; Bryman and Bell, 2015). The present study focuses on utilising EFA to compute the criteria of all the identified social acceptability dimensions of I4.0 adoption within an organization. The reliability tests and EFA were performed. The Kaiser-Meyer-Olkin (KMO) and Bartlett's test findings revealed that the Kaiser-Meyer-Olkin measure of sampling adequacy value equals 0.927; this is significant and fulfils the minimum recommended value of 0.5 (Bryman and Bell, 2015). The KMO measure of sampling adequacy represents an index for deciding the sample size required for factor analysis (Field, 2009; Effendi et al., 2019). Thus, the value confirmed that the sample size considered in the present study was sufficient. The KMO and Bartlett's test also show sphericity significance with a *p*-value less than 0.01. This signifies the suitability of the sample for EFA. Finally, the communalities were computed for each social acceptability dimension of the I4.0 adoption. Data with high communalities without cross-loadings is considered robust data. From the present study, each dimension's communalities were above 0.3, confirming each dimension's significance (Tabachnick et al., 2007; Effendi et al., 2019). The EFA results are presented in Table 4.

**Table 4:** Exploratory factor analysis result

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Social Dimensions**  | **Sub-Dimensions (Code)** | **Mean** | **S.D** | **Communalities** | **Factor loading** | **Cronbach alpha** |
| Cultural Acceptability (CA) | Complex procedures to obtain approvals (CA1) | 4.074 | 0.877 | 0.565 | 0.751 | 0.858 |
| Collaborative relationships (CA2) | 4.091 | 0.785 | 0.618 | 0.786 |
| Skilled management team (CA3) | 4.140 | 0.820 | 0.695 | 0.834 |
| Strategy towards I4.0 (CA4) | 4.140 | 0.869 | 0.624 | 0.790 |
| Acceptance of innovations (CA5) | 4.132 | 0.939 | 0.698 | 0.835 |
| Employee Acceptability (EA) | Long and uncertain amortization (EA1) | 4.033 | 0.795 | 0.549 | 0.741 | 0.840 |
| Core competencies (EA2) | 4.033 | 0.884 | 0.653 | 0.808 |
| More qualified workers (EA3) | 4.041 | 0.879 | 0.581 | 0.762 |
| Skilled labour (EA4) | 4.000 | 0.876 | 0.553 | 0.744 |
| Building job opportunity (EA5) | 4.000 | 0.931 | 0.714 | 0.845 |
| Market Acceptability (MA) | Failures of government polices (MA1) | 3.868 | 0.948 | 0.687 | 0.829 | 0.893 |
| Less awareness (MA2) | 3.777 | 0.908 | 0.689 | 0.830 |
| Diminishing barriers to market entrance (MA3) | 3.744 | 0.971 | 0.686 | 0.828 |
| Delay in project completion (MA4) | 3.711 | 0.908 | 0.697 | 0.835 |
| Responsiveness to sudden demand (MA5) | 3.860 | 0.907 | 0.746 | 0.864 |
| Psychological Acceptability (PA) | Interdisciplinary thinking (PA1) | 4.058 | 0.925 | 0.670 | 0.819 | 0.910 |
| Social interaction (PA2) | 4.083 | 0.833 | 0.795 | 0.892 |
| Psychological pressure (PA3) | 4.033 | 0.930 | 0.752 | 0.867 |
| Fearless attitude (PA4) | 4.124 | 0.812 | 0.745 | 0.863 |
| Work readiness skill (PA5) | 4.107 | 0.804 | 0.731 | 0.855 |
| Compliance Acceptability (CoA) | Distrust in AI (CoA1) | 4.050 | 0.845 | 0.606 | 0.778 | 0.882 |
| Irresponsible use of land and facilities (CoA2) | 4.140 | 0.907 | 0.702 | 0.838 |
| Manipulation of communication (CoA3) | 4.025 | 0.814 | 0.634 | 0.796 |
| Security breaches (CoA4) | 4.033 | 0.948 | 0.747 | 0.864 |
| Data theft (CoA5) | 4.140 | 0.916 | 0.714 | 0.845 |
| Safety Acceptability (SA) | Ensuring safe work environment (SA1) | 4.248 | 0.906 | 0.679 | 0.824 | 0.912 |
| Ensuring hygienic workplace (SA2) | 4.331 | 0.800 | 0.781 | 0.884 |
| Ensuring proper sanitation and clean water (SA3) | 4.314 | 0.807 | 0.747 | 0.864 |
| Ensuring health of machines (SA4) | 4.215 | 0.766 | 0.757 | 0.870 |
| Process safety (SA5) | 4.066 | 0.920 | 0.762 | 0.873 |
| Behaviour Acceptability (BA) | Commitment towards work (BA1) | 4.066 | 0.920 | 0.739 | 0.860 | 0.887 |
| Acceptability towards change (BA2) | 4.074 | 0.941 | 0.709 | 0.842 |
| Flexibility (BA3) | 4.223 | 0.821 | 0.743 | 0.862 |
| Emotional intelligence (BA4) | 4.157 | 0.895 | 0.668 | 0.818 |
| Social emotional learning (BA5) | 4.066 | 0.793 | 0.594 | 0.771 |

The identified social acceptability dimensions were analysed based on seven distinct areas - cultural acceptability, employee acceptability, market acceptability, compliance acceptability, psychological acceptability, safety acceptability and behaviour acceptability. For analysis of social acceptability dimensions, data was collected from an expert panel. An input sheet was prepared for the F-DEMATEL approach and sent to an expert panel to collect data.

**4.2 Analysis of the cause-effect relationship among dimensions**

The prioritization weights and causal relationships of identified factors related to social acceptability in I4.0 are evaluated using Fuzzy Decision-Making Trial and Evaluation Laboratory (F-DEMATEL), a Multi-Criteria Decision Making (MCDM) technique. In the present study, the F-DEMATEL approach has been used in a fuzzy environment to overcome any ambiguities in the expert opinions and, thus, justified weights of the criteria achieved through the calculation. Because of these advantages, the general applications of F-DEMATEL can be seen in recognizing the competencies of global management (Wu and Lee., 2007), decisions related to supplier selection (Dalalah et al., 2011), risk assessment of knowledge-based networks (Abbasi et al., 2013), ranking environmental performance in the printed circuit board industry (Tsai et al., 2015), selection in Lean Six Sigma project (Vinodh and Sawarnakar, 2015), modelling organizational intelligence (Malekzadeh et al., 2016), prioritizing I4.0 workforce attributes (Vinodh and Wankhede, 2021) and prioritizing factors associated with service innovation in manufacturing (Feng and Ma, 2020). The problem in the study is formulated by defining *m* social acceptability factors, with each factor evaluated against identified *n* criteria.

The methodological steps of F-DEMATEL are presented below:

**Step 1:** The fuzzy ratings in the form of linguistic terms are collected from '*e*' experts and developed as the initial direct relation matrix '*M'.*  Each expert is asked to provide inputs in the form of linguistic expression for one criterion against another i.e. a pairwise comparison is made between criteria influencing one over another. The decision matrix *'X*', *n×n* positive matrix, for each expert is denoted by:

|  |  |  |
| --- | --- | --- |
|  | $$X^{k}= \left[x\_{ij}^{k}\right]$$ | (1) |

where, *i* = 1, 2, 3….*n*, *j* = 1, 2, 3…..*n* and *k* = 1, 2, 3…..*e*.

*K* is the expert number contributing to the evaluation process with 1 ≤ *k* ≤ *e*.

As mentioned, ratings are gathered from the experts in the form of a linguistic variable. The linguistic expression is further transformed into fuzzy numbers for computation. Here, Triangular Fuzzy Numbers (TFNs) define the linguistic expression, as shown in Table 5.

**Table 5:** Fuzzy input scale

|  |  |  |
| --- | --- | --- |
| **Linguistic variable** | **Score** | **Triangular fuzzy number** |
| No influence | 0 | (0.0, 0.1, 0.3) |
| Very low influence | 1 | (0.1, 0.3, 0.5) |
| Low influence | 2 | (0.3, 0.5, 0.7) |
| High influence | 3 | (0.5, 0.7, 0.9) |
| Very high influence | 4 | (0.7, 0.9, 1) |

The cause-effect relationship among the identified social acceptability dimensions were determined by collecting data from experts. A panel of ten experts was formed (two senior managers, three managers, two industrial engineers, one production head and two supervisors). The experts were selected based on subject knowledge and relevant industrial expertise. All ten experts were asked to provide data for analysing social acceptability dimensions in adopting I4.0. The average data collected from all ten experts for social acceptability groups is presented in Table 6. The average data collected for each sub-group of social acceptability dimensions is presented in Appendix Table A1-A8.

**Table 6:** The average triangular fuzzy number for direct relation matrix of social acceptability

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **CA** | **EA** | **MA** | **PA** | **CoA** | **SA** | **BA** |
| **CA** | (0,0.1,0.3) | (0.5,0.77,1) | (0.5,0.77,1) | (0.3,0.72,1) | (0.3,0.57,0.9) | (0.3,0.57,0.9) | (0.3,0.76,1) |
| **EA** | (0.3,0.64,1) | (0,0.15,0.3) | (0.5,0.74,1) | (0.3,0.57,0.9) | (0.3,0.68,1) | (0.3,0.61,0.9) | (0.3,0.63,1) |
| **MA** | (0.3,0.53,0.9) | (0.3,0.57,0.9) | (0,0.1,0.3) | (0.3,0.61,0.9) | (0.3,0.72,1) | (0.3,0.61,0.9) | (0.3,0.71,1) |
| **PA** | (0.3,0.57,0.9) | (0.5,0.81,1) | (0.3,0.8,1) | (0,0.1,0.3) | (0.3,0.68,1) | (0.3,0.61,0.9) | (0.5,0.81,1) |
| **CoA** | (0.3,0.64,1) | (0.3,0.65,0.9) | (0.5,0.7,0.9) | (0.5,0.74,1) | (0,0.1,0.3) | (0.5,0.81,1) | (0.3,0.65,0.9) |
| **SA** | (0.5,0.77,1) | (0.3,0.64,1) | (0.3,0.64,1) | (0.3,0.72,1) | (0.5,0.77,1) | (0,0.1,0.3) | (0.5,0.77,1) |
| **BA** | (0.3,0.72,1) | (0.3,0.69,1) | (0.5,0.74,1) | (0.5,0.77,1) | (0.3,0.69,1) | (0.3,0.65,0.9) | (0,0.1,0.3) |

The fuzzy number data $X\_{ij}$ (a, b, c) is then converted into a crisp number using Equation 2.

$ X\_{ij}=\frac{(a+4\*b+c)}{6} $ (2)

The direct relationship matrix in crisp value for social acceptability dimensions of I4.0 is presented in Table 7.

**Table 7:** The direct relationship matrix of social acceptability in crisp number

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **CA** | **EA** | **MA** | **PA** | **CoA** | **SA** | **BA** |
| **CA** | 0.117 | 0.766 | 0.766 | 0.699 | 0.581 | 0.581 | 0.724 |
| **EA** | 0.646 | 0.148 | 0.741 | 0.581 | 0.668 | 0.608 | 0.638 |
| **MA** | 0.557 | 0.581 | 0.117 | 0.608 | 0.699 | 0.608 | 0.691 |
| **PA** | 0.581 | 0.793 | 0.750 | 0.117 | 0.668 | 0.608 | 0.793 |
| **CoA** | 0.646 | 0.636 | 0.700 | 0.741 | 0.117 | 0.793 | 0.636 |
| **SA** | 0.766 | 0.646 | 0.646 | 0.699 | 0.766 | 0.117 | 0.766 |
| **BA** | 0.699 | 0.675 | 0.741 | 0.766 | 0.675 | 0.636 | 0.117 |

**Step 2:** Once the initial direct relation matrix elements are computed as mentioned in Step 1, the normalized initial direct-relation matrix elements are determined. The normalized initial direct-relation matrix is denoted by, $= \left[n\_{ij}\right]$ . The normalized initial direct-relation matrix N elements (as shown in Equation 4) are computed using Equations 5 and 6. The normalized relationship matrix for social acceptability dimensions of I4.0 is presented in Table 8.

|  |  |  |
| --- | --- | --- |
|  | $$N=\left[\begin{matrix}n\_{11}&n\_{12}&\cdots &n\_{1n}\\n\_{21}&n\_{22}&\cdots &n\_{2n}\\\cdots &\cdots &\cdots &\cdots \\n\_{n1}&n\_{n2}&\cdots &n\_{nn}\end{matrix}\right]$$ | (4) |
|   | $$n\_{ij}= \frac{x\_{ij}}{R}$$ | (5) |
|  | $R=max (\sum\_{j=1}^{n}x\_{ij} $) | (6) |

**Table 8:** The normalized relationship matrix of social acceptability

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **CA** | **EA** | **MA** | **PA** | **CoA** | **SA** | **BA** |
| **CA** | 0.026 | 0.172 | 0.172 | 0.157 | 0.131 | 0.130 | 0.162 |
| **EA** | 0.145 | 0.033 | 0.166 | 0.132 | 0.151 | 0.136 | 0.143 |
| **MA** | 0.125 | 0.130 | 0.026 | 0.136 | 0.157 | 0.136 | 0.155 |
| **PA** | 0.130 | 0.178 | 0.168 | 0.026 | 0.15 | 0.136 | 0.178 |
| **CoA** | 0.145 | 0.143 | 0.157 | 0.166 | 0.026 | 0.178 | 0.143 |
| **SA** | 0.172 | 0.145 | 0.145 | 0.157 | 0.172 | 0.026 | 0.172 |
| **BA** | 0.157 | 0.151 | 0.166 | 0.172 | 0.151 | 0.143 | 0.026 |

**Step 3:** Further, the total relation fuzzy matrix ($T)$ is computed using Equation 7.

|  |  |  |
| --- | --- | --- |
|  | $$T= N (I- N)^{-1}$$ |  (7) |

From Equation 7, the total relation fuzzy matrix $(\overbar{T})$ is represented as shown in Equation 8. The calculated total relationship matrix for social acceptability dimensions of I4.0 is presented in Table 9.

|  |  |  |
| --- | --- | --- |
|  | $$T=\left[\begin{matrix}t\_{11}&t\_{12}&\cdots &t\_{1n}\\t\_{21}&t\_{22}&\cdots &t\_{2n}\\\cdots &\cdots &\cdots &\cdots \\t\_{n1}&t\_{n2}&\cdots &t\_{nn}\end{matrix}\right]$$ |  (8) |

$t\_{ij}$ represents the elements of the total direct relation matrix.

**Table 9:** The total relationship matrix of social acceptability

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **CA** | **EA** | **MA** | **PA** | **CoA** | **SA** | **BA** |
| **CA** | 2.117 | 2.356 | 2.458 | 2.328 | 2.293 | 2.187 | 2.403 |
| **EA** | 2.134 | 2.139 | 2.355 | 2.214 | 2.215 | 2.105 | 2.292 |
| **MA** | 2.048 | 2.154 | 2.155 | 2.146 | 2.148 | 2.036 | 2.225 |
| **PA** | 2.246 | 2.396 | 2.493 | 2.249 | 2.344 | 2.227 | 2.452 |
| **CoA** | 2.247 | 2.357 | 2.471 | 2.360 | 2.222 | 2.249 | 2.413 |
| **SA** | 2.330 | 2.423 | 2.530 | 2.418 | 2.413 | 2.177 | 2.502 |
| **BA** | 2.270 | 2.379 | 2.494 | 2.379 | 2.348 | 2.234 | 2.324 |

**Step 4:** In this step, a row and column summation operation is performed on the total relation matrix ($T)$. Row summation *D* and column summation $R$ are computed using Equations 9 and 10. The row and column summation of each social acceptability, along with their cause-effect group, is presented in Table 10.

|  |  |  |
| --- | --- | --- |
|  | $$D= \sum\_{i=1}^{n} t\_{ij}$$ | (9) |
|  | $$R= \sum\_{j=1}^{n} t\_{ij}$$ | (10) |

**Table 10:** The prominence and relation for cause and effect category

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **D** | **R** | **D+R** | **D-R** | **Group** |
| **CA** | 16.142 | 15.392 | 31.535 | 0.750 | Cause |
| **EA** | 15.454 | 16.204 | 31.658 | -0.750 | Effect |
| **MA** | 14.913 | 16.956 | 31.869 | -2.043 | Effect |
| **PA** | 16.406 | 16.094 | 32.500 | 0.312 | Cause |
| **CoA** | 16.319 | 15.983 | 32.302 | 0.336 | Cause |
| **SA** | 16.792 | 15.214 | 32.006 | 1.577 | Cause |
| **BA** | 16.429 | 16.612 | 33.041 | -0.183 | Effect |

**Step 5**: Development of digraph among dimensions to eliminate minor effects.

In this step, we calculate the threshold value (α) using Equation 11:

$α=\frac{\sum\_{i=1}^{n}\sum\_{j=1}^{n}\left[T\_{ij}\right]}{N}=2.295$ (11)

The digraph is developed to present the relationship between elements of the total relationship matrix (T). The threshold value α is calculated for the matrix (T). The elements in the matrix (T) whose values are greater than α show a significant relationship. The threshold value is calculated and is found to be 2.295. All elements whose values are more significant than 2.295 are plotted in the digraph. A causal relationship matrix is developed for social dimension groups as shown in Figure 2. For instance, the value between CA and EA is 2.355, which is greater than 2.295; this shows a significant relationship between CA and EA. Similarly, all matrix (T) elements were compared with a threshold value and a causal relationship matrix is thus developed, as shown in Figure 2.

Similarly, the F-DEMATEL method was applied to each sub-group of social acceptability. The row summations and column summations of each social acceptability dimension are presented in Table 11. The categorization of cause and effect groups for each social acceptability dimension based on the positive and negative value of (D-R) is shown in Table 11.

**Figure 2:** Causal relationship for main social acceptability dimensions

**Table 11:** Impact result for each social dimensions of all social acceptability

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Social Dimensions** | **Code** | **D** | **R** | **D+R** | **D-R** | **Impact** |
| Cultural Acceptability (CA) | CA1 | 6.213 | 7.308 | 13.521 | -1.096 | Effect |
| CA2 | 8.488 | 7.276 | 15.764 | 1.212 | Cause |
| CA3 | 8.208 | 7.411 | 15.619 | 0.797 | Cause |
| CA4 | 7.463 | 8.117 | 15.579 | -0.654 | Effect |
| CA5 | 7.808 | 8.068 | 15.876 | -0.260 | Effect |
| Employee Acceptability (EA) | EA1 | 5.918 | 6.529 | 12.447 | -0.611 | Effect |
| EA2 | 9.083 | 9.449 | 18.532 | -0.366 | Effect |
| EA3 | 9.082 | 8.577 | 17.659 | 0.505 | Cause |
| EA4 | 9.281 | 8.506 | 17.787 | 0.775 | Cause |
| EA5 | 8.979 | 9.282 | 18.261 | -0.303 | Effect |
| Market Acceptability (MA) | MA1 | 6.314 | 6.412 | 12.725 | -0.098 | Effect |
| MA2 | 6.933 | 5.730 | 12.663 | 1.203 | Cause |
| MA3 | 5.302 | 5.807 | 11.108 | -0.505 | Effect |
| MA4 | 5.232 | 6.963 | 12.195 | -1.731 | Effect |
| MA5 | 6.812 | 5.681 | 12.493 | 1.131 | Cause |
| Psychological Acceptability (PA) | PA1 | 12.370 | 12.160 | 24.530 | 0.210 | Cause |
| PA2 | 11.875 | 12.766 | 24.641 | -0.891 | Effect |
| PA3 | 11.232 | 10.800 | 22.032 | 0.432 | Cause |
| PA4 | 12.373 | 11.881 | 24.255 | 0.492 | Cause |
| PA5 | 11.787 | 12.030 | 23.816 | -0.243 | Effect |
| Compliance Acceptability (CoA) | CoA1 | 4.842 | 5.457 | 10.299 | -0.614 | Effect |
| CoA2 | 3.461 | 3.391 | 6.852 | 0.071 | Cause |
| CoA3 | 5.587 | 5.184 | 10.771 | 0.403 | Cause |
| CoA4 | 6.279 | 6.244 | 12.523 | 0.035 | Cause |
| CoA5 | 5.771 | 5.665 | 11.436 | 0.106 | Cause |
| Safety Acceptability (SA) | SA1 | 11.974 | 11.223 | 23.197 | 0.750 | Cause |
| SA2 | 11.645 | 10.950 | 22.595 | 0.695 | Cause |
| SA3 | 10.985 | 10.722 | 21.707 | 0.263 | Cause |
| SA4 | 10.587 | 11.349 | 21.936 | -0.763 | Effect |
| SA5 | 10.490 | 11.436 | 21.926 | -0.946 | Effect |
| Behavioural Acceptability (BA) | BA1 | 18.259 | 18.662 | 36.921 | -0.403 | Effect |
| BA2 | 18.058 | 18.931 | 36.988 | -0.873 | Effect |
| BA3 | 17.886 | 18.779 | 36.666 | -0.893 | Effect |
| BA4 | 18.839 | 16.881 | 35.720 | 1.959 | Cause |
| BA5 | 17.296 | 17.086 | 34.382 | 0.210 | Cause |

The cause and effect digraph for each sub-group of social acceptability dimensions is derived and presented in Figure 3.

**Figure 3:** Causal relationship for social acceptability dimensions

**Step 6:** Based on the results obtained from Equations 7 and 8, each criterion's weights are calculated. The method proposed by Kobryń (2017) is used to determine the criterion weights as described below. The local weight of each sub-group social acceptability is calculated using Equations 12 and 13. The global weights of each social acceptability dimension are computed by multiplying social acceptability weights with local social dimensions weights. The global weight and ranking of social acceptability dimensions are presented in Table 12.

|  |  |  |
| --- | --- | --- |
|  | $$T\_{average}=\frac{\left(D+R\right)+(D-R)}{2} $$ | (12) |
|  | $$W\_{i}=\frac{T\_{average}}{\sum\_{i=1}^{n}T\_{i}^{average}}$$ | (13) |

Equation 13 gives the weights of each criterion where, $\sum\_{i=1}^{n}W\_{i}=1$

**Table 12:** Ranking of social dimensions

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Social Dimensions**  | **Weights** | **Sub- Dimensions** | **Local weight** | **Local Ranking** | **Global weight** | **Global Ranking** |
| Cultural Acceptability (CA) | 0.144 | CA1 | 0.163 | 5 | 0.023 | 31 |
| CA2 | 0.222 | 1 | 0.032 | 4 |
| CA3 | 0.215 | 2 | 0.031 | 7 |
| CA4 | 0.195 | 4 | 0.028 | 26 |
| CA5 | 0.205 | 3 | 0.029 | 18 |
| Employee Acceptability (EA) | 0.137 | EA1 | 0.140 | 5 | 0.019 | 35 |
| EA2 | 0.215 | 2 | 0.029 | 15 |
| EA3 | 0.214 | 3 | 0.029 | 16 |
| EA4 | 0.219 | 1 | 0.030 | 11 |
| EA5 | 0.212 | 4 | 0.029 | 20 |
| Market Acceptability (MA) | 0.133 | MA1 | 0.206 | 3 | 0.027 | 29 |
| MA2 | 0.227 | 1 | 0.030 | 12 |
| MA3 | 0.173 | 4 | 0.023 | 32 |
| MA4 | 0.171 | 5 | 0.023 | 33 |
| MA5 | 0.223 | 2 | 0.030 | 13 |
| Psychological Acceptability (PA) | 0.146 | PA1 | 0.207 | 2 | 0.030 | 10 |
| PA2 | 0.199 | 3 | 0.029 | 21 |
| PA3 | 0.188 | 5 | 0.027 | 28 |
| PA4 | 0.207 | 1 | 0.030 | 9 |
| PA5 | 0.198 | 4 | 0.029 | 23 |
| Compliance Acceptability (CoA) | 0.145 | CoA1 | 0.187 | 4 | 0.027 | 30 |
| CoA2 | 0.133 | 5 | 0.019 | 34 |
| CoA3 | 0.215 | 3 | 0.031 | 5 |
| CoA4 | 0.242 | 1 | 0.035 | 1 |
| CoA5 | 0.222 | 2 | 0.032 | 2 |
| Safety Acceptability (SA) | 0.149 | SA1 | 0.215 | 1 | 0.032 | 3 |
| SA2 | 0.209 | 2 | 0.031 | 6 |
| SA3 | 0.197 | 3 | 0.029 | 17 |
| SA4 | 0.190 | 4 | 0.028 | 24 |
| SA5 | 0.188 | 5 | 0.028 | 25 |
| Behaviour Acceptability (BA) | 0.146 | BA1 | 0.202 | 2 | 0.030 | 14 |
| BA2 | 0.200 | 3 | 0.029 | 19 |
| BA3 | 0.198 | 4 | 0.029 | 22 |
| BA4 | 0.209 | 1 | 0.030 | 8 |
| BA5 | 0.191 | 5 | 0.028 | 27 |

* 1. ***Sensitivity Analysis***

The developed model has been validated by performing sensitivity analysis. To analyse the robustness of the model, it is necessary to analyse the model under different conditions (Kumar et al., 2018). In this study, we have performed a sensitivity analysis by making changes in the expert input and then analyzing the deviation in results.

As can be seen in Table 12, it is found that safety acceptability (SA) has more weightage i.e. 0.149. So, we analyse the variation in output by changing SA weight. Hence, in this instance, social acceptability weight has been changed from 0.149 to 0.015 (0.149\*0.9=0.134, 0.149\*0.8=0.119, 0.149\*0.7=0.105, 0.149\*0.6=0.090, 0.149\*0.5=0.075, 0.149\*0.4=0.060, 0.149\*0.3=0.045, 0.149\*0.2=0.03, 0.149\*0.1=0.015).

**Table 13:** Social acceptability weights by varying safety acceptability (SA) weight

|  |  |
| --- | --- |
| **Social Dimensions** | **Incremental Changes** |
| **Normal** | **Run 1** | **Run 2** | **Run 3** | **Run 4** | **Run 5** | **Run 6** | **Run 7** | **Run 8** | **Run 9** |
| CA | 0.144 | 0.146 | 0.149 | 0.151 | 0.154 | 0.156 | 0.159 | 0.161 | 0.164 | 0.166 |
| EA | 0.137 | 0.14 | 0.142 | 0.145 | 0.147 | 0.149 | 0.152 | 0.154 | 0.157 | 0.159 |
| MA | 0.133 | 0.135 | 0.137 | 0.140 | 0.142 | 0.144 | 0.147 | 0.149 | 0.151 | 0.154 |
| PA | 0.146 | 0.148 | 0.151 | 0.154 | 0.156 | 0.159 | 0.161 | 0.164 | 0.166 | 0.169 |
| CoA | 0.145 | 0.148 | 0.150 | 0.153 | 0.155 | 0.158 | 0.16 | 0.163 | 0.165 | 0.168 |
| SA | **0.149** | **0.134** | **0.119** | **0.105** | **0.090** | **0.075** | **0.060** | **0.045** | **0.030** | **0.015** |
| BA | 0.146 | 0.149 | 0.151 | 0.154 | 0.156 | 0.159 | 0.161 | 0.164 | 0.167 | 0.169 |

**Table 14:** Sensitivity analysis by changing safety acceptability weight from 0.149 to 0.015 through incremental change

| **Codes** | **Normal** | **Run 1** | **Run 2** | **Run 3** | **Run 4** | **Run 5** | **Run 6** | **Run 7** | **Run 8** | **Run 9** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| CA1 | 31 | 31 | 34 | 26 | 26 | 26 | 26 | 26 | 26 | 26 |
| CA2 | 4 | 3 | 25 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| CA3 | 7 | 5 | 26 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| CA4 | 26 | 22 | 32 | 21 | 21 | 21 | 21 | 21 | 21 | 21 |
| CA5 | 18 | 15 | 28 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| EA1 | 35 | 35 | 35 | 33 | 30 | 30 | 30 | 30 | 30 | 30 |
| EA2 | 15 | 13 | 29 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| EA3 | 16 | 14 | 30 | 14 | 14 | 14 | 14 | 14 | 14 | 14 |
| EA4 | 11 | 9 | 27 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| EA5 | 20 | 17 | 31 | 17 | 17 | 17 | 17 | 17 | 17 | 17 |
| MA1 | 29 | 26 | 8 | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
| MA2 | 12 | 10 | 1 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| MA3 | 32 | 32 | 22 | 27 | 27 | 27 | 27 | 27 | 27 | 27 |
| MA4 | 33 | 33 | 23 | 28 | 28 | 28 | 28 | 28 | 28 | 28 |
| MA5 | 13 | 11 | 3 | 11 | 11 | 11 | 11 | 11 | 11 | 11 |
| PA1 | 10 | 8 | 7 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| PA2 | 21 | 18 | 12 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| PA3 | 28 | 25 | 20 | 23 | 23 | 23 | 23 | 23 | 23 | 23 |
| PA4 | 9 | 7 | 6 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| PA5 | 23 | 20 | 13 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| CoA1 | 30 | 27 | 24 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| CoA2 | 34 | 34 | 33 | 32 | 29 | 29 | 29 | 29 | 29 | 29 |
| CoA3 | 5 | 4 | 18 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| CoA4 | 1 | 1 | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| CoA5 | 2 | 2 | 11 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| SA1 | 3 | 21 | 2 | 29 | 31 | 31 | 31 | 31 | 31 | 31 |
| SA2 | 6 | 24 | 5 | 30 | 32 | 32 | 32 | 32 | 32 | 32 |
| SA3 | 17 | 28 | 9 | 31 | 33 | 33 | 33 | 33 | 33 | 33 |
| SA4 | 24 | 29 | 14 | 34 | 34 | 34 | 34 | 34 | 34 | 34 |
| SA5 | 25 | 30 | 16 | 35 | 35 | 35 | 35 | 35 | 35 | 35 |
| BA1 | 14 | 12 | 15 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| BA2 | 19 | 16 | 17 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| BA3 | 22 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| BA4 | 8 | 6 | 10 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| BA5 | 27 | 23 | 21 | 22 | 22 | 22 | 22 | 22 | 22 | 22 |

Based on changes in safety acceptability (SA) weights, other social acceptability weights have been calculated and are presented in Table 13. After calculating each social acceptability's weights, all social dimensions' rankings have been calculated as shown in Table 14. Table 14 concludes that maximum changes are found in social dimensions SA2 and SA3, i.e. 'Ensuring hygienic workplace' and 'Ensuring proper sanitation and clean water'. The sensitivity analysis result is also presented in the radar chart, as shown in Figure 4.

**Figure 4:** Sensitivity Analysis Result

**5. Discussion and Implications**

A two-stage approach has been followed in the present study to identify the critical social dimensions of I4.0. In the first stage, an empirical study has been performed by conducting EFA to validate the applicability of collected social dimensions. From the analysis, all the collected social dimensions are validated and considered for further research. The second stage of the study deals with applying F-DEMATEL to prioritize the social dimensions and their criteria. Based on F-DEMATEL, among all the criteria, 'cultural acceptability (CA)', 'psychological acceptability (PA)', 'compliance acceptability (CoA)' and 'safety acceptability (SA)' criteria are found to be in the cause group whereas criteria such as 'employee acceptability (EA)', 'market acceptability (MA)' and 'behavioural acceptability (BA)' fall under the effect group. This suggests industrial managers should focus on the 'employee acceptability (EA)', 'market acceptability (MA)' and 'behavioural acceptability (BA)' criteria to stabilize other social aspects related to I4.0 enabling digital manufacturing. Among all the criteria, the analysis revealed 'safety acceptability (SA)' as the most influential cause with a weight of 14.9%, followed by 'psychological acceptability (PA)', 'compliance acceptability (CoA)' and 'cultural acceptability (CA)'. 'Behavioural acceptability (BA)' is the main priority criterion due to its highest weight, 14.6%, in the effect group. This indicates that efforts should be concentrated towards behavioural acceptability dimensions to support digital manufacturing successfully. Workforce attitude towards I4.0 is an essential consideration in accepting proposed change. Each criterion has its respective social dimensions which are also prioritized using F-DEMATEL based on their local weights. The cause-effect relationship among dimensions has also been established.

***5.1 Safety acceptability dimensions***

The criterion 'safety acceptability (SA)' belongs to the cause group. It is the highest with a weight of 14.9%. The present study depicted it as the most influential criteria related to the social aspects of digital manufacturing. There are five social dimensions identified under this criterion; namely, 'ensuring safe work environment (SA1)', 'ensuring hygienic workplace (SA2)', 'ensuring proper sanitation and clean water (SA3)', 'ensuring the health of machines (SA4)' and 'process safety (SA5)'. Based on the local weights, their priority order was SA1 > SA2 > SA3 > SA4 > SA5. The social dimensions SA1, SA2 and SA3 were found to be in the cause group, whereas SA4 and SA5 were found to be in the effect group. Among all the cause group SA social dimensions, ‘ensuring safe work environment (SA1)’ is the most influential with a local weight of 21.5%, followed by SA2 (20.9%) and SA3 (19.7%).

***5.2 Psychological acceptability dimensions***

The criterion, psychological acceptability (PA), belongs to the cause group. It is second highest with a weight of 14.6%. There are five social dimensions identified under this criterion; namely, ‘interdisciplinary thinking (PA1)’, ‘social interaction (PA2)’, ‘psychological pressure (PA3)’, ‘fearless attitude (PA4)’ and ‘work readiness skill (PA5)’. Based on local weights, their priority order was found to be PA1 > PA4 > PA2 > PA5 > PA3. The social dimensions PA1, PA3 and PA4 were found to be in the cause group, whereas PA2 and PA5 were found to be in the effect group. Among all the cause group PA social dimensions, ‘interdisciplinary thinking (PA1)’, is the most influential with local weight of 20.7%, followed by ‘fearless attitude (PA4)’ and ‘psychological pressure (PA3)’.

***5.3 Behavioural acceptability dimensions***

The criterion 'behavioural acceptability (BA)' belongs to the effect group. It is ranked third with a weight of 14.6%. There are five social dimensions identified under this criterion; namely, ‘commitment towards work (BA1)’, ‘acceptability towards change (BA2)’, ‘flexibility (BA3)’, ‘emotional intelligence (BA4)’ and ‘social-emotional learning (BA5)’. Based on local weights, their priority order was BA4 > BA1 > BA2 > BA3 > BA5. The social dimensions BA4 and BA5 were found to be in the cause group, whereas BA1, BA2 and BA3 were found to be in the effect group. Among the cause group BA social dimensions, 'emotional intelligence (BA4)' is the most influential with a local weight of 20.9%.

***5.4 Compliance acceptability dimensions***

The criterion 'compliance acceptability (CA)' belongs to the cause group. It is the fourth highest with a weight of 14.5%. There are five social dimensions identified under this criterion; namely, ‘distrust in AI (CoA1)’, ‘irresponsible use of land and facilities (CoA2)’, ‘manipulation of communication (CoA3)’, ‘security breaches (CoA4)’ and ‘data theft (CoA5)’. Based on local weights their priority order was found to be CoA4 > CoA5 > CoA3 > CoA1 > CoA2. The social dimensions CoA2, CoA3, CoA4 and CoA5 were found to be in the cause group, whereas CoA1 was found to be in the effect group. Among all the cause groups, the CoA social dimension ‘security breaches (CoA4)' is the most influential with a local weight of 24.2%.

***5.5 Cultural acceptability dimensions***

The criterion 'cultural acceptability (CA)' belongs to the cause group. It is ranked fifth with a weight of 14.4%. There are five social dimensions identified under this criterion; namely, ‘complex procedures to obtain approvals (CA1)’, ‘collaborative relationships (CA2)’, ‘skilled management team (CA3)’, ‘strategy towards I4.0 (CA4)’ and ‘acceptance of innovations (CA5)’. Based on local weights, their priority order was found to be CA2 > CA3 > CA5 > CA4 > CA1. The social dimensions CA2 and CA3 were found to be in the cause group, whereas CA1, CA4, and CA5 were found to be in the effect group. Among all the cause groups, CA social dimension ‘collaborative relationships (CA2)’ is the most influential, with local weight of 22.2%, followed by CA3 (21.5%).

***5.6 Employee acceptability dimensions***

The criteria employee acceptability (EA) belongs to the effect group. It is ranked fifth with a weight of 13.7%. There are five social dimensions identified under this criterion; namely, ‘long and uncertain amortization (EA1)’, ‘core competencies (EA2)’, ‘more qualified workers (EA3)’, ‘skilled labor (EA4)’ and ‘building job opportunities (EA5)’. Based on the local weights, their priority order was EA4 > EA2 > EA3 > EA5 > EA1. The social dimensions EA3 and EA4 were found to be in the cause group, whereas EA1, EA2 and EA5 were found to be in the effect group. Among all the cause group EA social dimensions, skilled labor (EA4) is the most influential with local weight of 21.9% followed by EA3 (21.4%).

***5.7 Market acceptability dimensions***

The criteria 'market acceptability (MA)' belongs to the effect group. It is ranked last with a weight of 13.3%. The present study depicted it as the least influential criteria related to social aspects of I4.0. There are five social dimensions identified under this criterion; namely, ‘failures of government policies (MA1)’, ‘less awareness (MA2)’, ‘diminishing barriers to the market entrance (MA3)’, ‘delay in project completion (MA4)’ and ‘responsiveness to sudden demand (MA5)’. Based on the local weights, their priority order was MA2 > MA5 > MA1 > MA3 > MA4. The social dimensions MA2 and MA5 were found to be in the cause group, whereas MA1, MA3 and MA4 were found to be in the effect group. Among all the cause groups, MA social dimension ‘less awareness (MA2)’ is most influential with a local weight of 22.7%, followed by MA5 (22.3%). As shown in Table 8, the priority order of all social dimensions based on their global weights are presented as follow: security breaches (CoA4) > data theft (CoA5) > ensuring safe work environment (SA1) > collaborative relationships (CA2) > manipulation of communication (CoA3) > ensuring hygienic workplace (SA2) > skilled management team (CA3) > emotional intelligence (BA4) > interdisciplinary thinking (PA1) > fearless attitude (PA4) > skilled labour (EA4) > less awareness (MA2) > core competencies (EA2) > greater number of qualified workers (EA3) > responsiveness to sudden demand (MA5) > ensuring proper sanitation and clean water (SA3) > commitment towards work (BA1) > acceptance of innovations (CA5) > acceptability towards change (BA2) > building job opportunity (EA5) > social interaction (PA2) > flexibility (BA3) > work readiness skill (PA5) > ensuring health of machines (SA4) > strategy towards I4.0 (CA4) > process safety (SA5) > social emotional learning (BA5) > psychological pressure (PA3) > failures of government polices (MA1) > distrust in AI (CoA1) > complex procedures to obtain approvals (CA1) > diminishing barriers to market entrance (MA3) > delay in project completion (MA4) > irresponsible use of land and facilities (CoA2) > long and uncertain amortization (EA1).

The study investigated the social acceptability dimensions related to I4.0 adoption enabling digital manufacturing in an organization. The present study utilizes a three-phase approach for prioritization of the influential social acceptability dimensions for I4.0 adoption. Initially, various potential social acceptability dimensions have been identified from an extensive literature review. EFA has then been deployed to validate and group the specified social acceptability dimensions. EFA has confirmed the importance of all the identified social acceptability dimensions for ease of digital manufacturing adoption in the organization. Later, the study prioritized the social acceptability dimensions using F-DEMATEL to guide decision-makers in the industry while implementing I4.0. The study's findings reveal 'safety acceptability (SA)' as the most influential criteria for enabling digital manufacturing in the organization. Moeuf et al. (2020) suggested using I4.0 technologies to monitor the machines' health, ensuring that employees' safety aspects are considered, while supporting the smooth implementation of I4.0. Besides, incorporating I4.0 technologies in an organization's corporate social responsibility helps address the social criteria identified in this study (Potocan et al., 2020). Among the various safety acceptability dimensions, ‘ensuring safe work environment (SA1)’, 'ensuring hygienic workplace (SA2)', 'ensuring proper sanitation and clean water (SA3)', 'ensuring the health of machines (SA4)' and 'process safety (SA5)' are recommended as key aspects during implementation. Badri et al. (2018) have supported the present study since they noted that a solely technology focused I4.0 implementation in an organization might increase the risk of an accident. Thus, the safety experts need to collaborate with the technical experts for the smooth transition of I4.0. ‘Psychological acceptability (PA)’, ‘behaviour acceptability (BA)’, ‘cultural acceptability (CA)’ and ‘employee acceptability (EA)’ are social dimensions that also need to be considered while implementing I4.0. The workforce attributes of I4.0 are essential and must be addressed before the technological implementation of I4.0. This can help to smooth the implementation process and create a motivational environment for managing the psychological, behaviour, cultural and employee acceptability criteria (Vinodh and Wankhede, 2021). The comparison of the present study with other studies is presented in Table 15.

**Table 15.** Comparison of the present study with previous studies

|  |  |  |  |
| --- | --- | --- | --- |
| Study | Focus | Method used | Contributions |
| Present study | Social acceptability dimensions of I4.0 in the context of digital manufacturing. | Survey from different Indian manufacturing units. Exploratory factor analysis was employed, and seven main acceptability dimensions were identified. Further, F-DEMATEL was used to prioritize and develop inter-relationships among the social acceptability dimensions. | This study analyses the social acceptability dimensions of I4.0 in the context of digital manufacturing. Based on the priority order, 'security breaches' are the most significant dimension followed by 'data theft' and 'ensuring safe work environment' in second and third positions. |
| Bonekamp and Sure (2015) | I4.0 technologies and their social impacts. | Literature review approach | The authors suggested adopting a continuous learning process with training and education to enable the workforce to manage digital manufacturing. |
| Brocal et al. (2019) | The emerging risk associated with the human factor in the I4.0 scenario. | Risk management models to analyse the risks associated with the human factor. | The study demonstrated risk management in I4.0 scenario to enhance human performance.  |
| Adem et al. (2020) | The social risk associated with the adoption of I4.0 technologies. | Hesitant F-AHP method. | The study identified social risks associated with the adoption of I4.0 technologies to enable digital manufacturing. Mental fatigue and psychological pressure were identified as the critical risks associated with the adoption of digital manufacturing. |
| Mahmood and Mubarik (2020) | Human, relational and structural capital in the adoption of digital manufacturing. | Survey to analyse the intellectual capital; survey data analysed using structural equation modelling (SEM) | The study aimed to analyse human, relational and structural capital in the adoption of digital manufacturing. The study's findings show that all intellectual capital has a significant impact on the adoption of digital manufacturing. |

* 1. ***Implications***

In the present study, the various social dimensions enabling digital manufacturing for I4.0 adoption have been identified from a literature review and further investigated by performing empirical analysis. In addition to this, the most influential social dimensions and their respective criteria have been determined using the F-DEMATEL approach. The study findings contribute to both practical and managerial perspectives for adopting I4.0 in industries and provide fruitful insights for decision-makers and industry practitioners.

***5.8.1 Implications and theoretical contributions***

The future is unpredictable and uncertain. The developments in digital manufacturing can address these uncertain situations by influencing the speed of technological and social change. Various organizations are striving hard to forecast future changes to contribute to building nation economies. Thus, forecasting the social change instead of the technological change would streamline the adoption process of I4.0. I4.0 and its related technologies are expected to grow significantly in terms of both a technical and socio-economic impact. Many researchers have discussed the technical aspects of I4.0. Still, very few studies focus on social factors such as cultural, safety, physiological etc. that are responsible for the successful implementation of I4.0 (Mohelska and Sokolova, 2018). I4.0 adoption requires continuous innovation and learning which should be embedded into the organization's culture. Theoretically, the present study contributes to analyzing the social acceptability dimension of I4.0 adoption. The present study utilizes the integration of exploratory and normative methods which can help in forecasting the social acceptability dimensions related to I4.0. To achieve this, the study has critically examined various social acceptability dimensions using EFA and identified seven different criteria: safety, psychological, behaviour, compliance, cultural, employee and market. The study further utilized the F-DEMATEL technique in the fuzzy environment to prioritize the criteria and their respective social acceptability dimensions, developing inter-relationships using cause-effect diagrams. This paper contributes to the success of I4.0 due to its dependability on both technical feasibility and social acceptability during the entire transition process (Horváth and Szabó, 2019). Moreover, if technological changes are not integrated with socio-economic changes, then the organization's social structure may deteriorate.

The present study supported the social theories of TSTT and SCT. As per the theory of TSTT, the evolution of technologies will not emerge alone; it also influences changes in society, such as changes in infrastructure, norms and industrial regulations (Jurgilevich et al., 2016; Liu et al., 2018). From the present study, the major social acceptability issues such as security breaches (CoA4), data theft (CoA5), ensuring a safe work environment (SA1), collaborative relationships (CA2), manipulation of communication (CoA3), ensuring hygienic workplace (SA2), skilled management team (CA3), emotional intelligence (BA4), interdisciplinary thinking (PA1), fearless attitude (PA4) and skilled labor (EA4) should be the focus of the social aspects of I4.0 for successful technology implementation. Based on TSTT, the transition from the third industrial revolution to the fourth industrial revolution will also impact on areas of society, such as increased job opportunities, process safety and emotional intelligence (Moktadir et al., 2018). Based on SCT, the three elements of social integration are personal behavior, individual cognition and social behavior (Butt et al., 2017; Liu et al., 2018). Social integration is an important aspect that should be considered for the adoption of any new technologies. Personal behavior and individual cognition have an essential role in the adoption of I4.0 technologies. Social acceptability dimensions such as less awareness (MA2), core competencies (EA2), a greater number of qualified workers (EA3), responsiveness to sudden demand (MA5), ensuring proper sanitation and clean water (SA3), commitment towards work (BA1), acceptance of innovations (CA5), acceptability towards change (BA2), building job opportunity (EA5), social interaction (PA2), flexibility (BA3) and work readiness skill (PA5) depict the social integration aspects which, if addressed properly, will help to improve the social recognition of I4.0 implementation in the organization. Personal behavior such as social interaction and interdisciplinary thinking are the key drivers for adopting I4.0 technologies (Birkel et al., 2019).

***5.8.2 Implications and practical contributions***

Despite the advancements in technologies in this digital manufacturing era, speculations and uncertainties about future sustainability remain. Changes in social dimensions such as cultural, behaviour, physiological, safety etc. may lead to instability in organizations. Thus, periodic forecasting is required to cope with social changes in industries. In this regard, the study results have provided a clear view of the social acceptability dimensions of I4.0 adoption within an organization. The prioritized criteria and dimensions can help industry practitioners and managers in exploring some novel initiatives required for I4.0 adoption. The present study can guide the policymakers of organizations to develop suitable supportive policies to create a robust social structure of I4.0. The identified criteria for social acceptability dimensions encourage industry practitioners towards social innovations and practices to positively tackle social barriers affecting organizations, society and individuals. Moreover, the present study helps industry planners in developing technical and socio-economic business models of practical value.

1. **Conclusion**

I4.0 and its related technologies are expected to grow significantly in terms of both a technical and socio-economic impact. The advancements in digital manufacturing technologies have led to speculations and uncertainties about its future sustainability. Although previous studies have presented the technological viewpoint of I4.0, there are very few scientific studies that have tried to forecast social changes from a digital manufacturing perspective. Changes in social dimensions such as cultural, behaviour, physiological or safety may lead to instability in organizations. Thus, the present study contributes to the analysis of the social acceptability dimension of I4.0 adoption. To achieve this, the study has critically examined various social acceptability dimensions using EFA; seven dimensions of social acceptability have been identified. The study further utilized the F-DEMATEL technique in the fuzzy environment to prioritize the criteria and their respective social acceptability dimensions, developing inter-relationships using cause-effect diagrams. A two-stage approach has been followed in this study to identify the critical social acceptability dimensions of I4.0 adoption. In the first stage, an empirical study has been performed by conducting EFA to validate the applicability of collected social dimensions. From the analysis, all collected social dimensions are validated and considered for further analysis. The second stage of the study deals with applying F-DEMATEL to prioritize these social dimensions and their criteria. The cause and effect relationships among dimensions have also been established.

The present study has limitations in terms of the number of social acceptability dimensions considered and responses-based validation. In future, a similar analysis could be conducted by considering cross cultural studies. The study utilized EFA and F-DEMATEL to compute the priority order of considered social acceptability dimensions. Future studies may be performed using confirmatory factor analysis and integrated solution methodology with other prioritization methods. The focus on analysing the technical and social integration factors responsible for I4.0 adoption could also be explored. Despite these limitations, the present study can help organizations to consider various social aspects and their association with technology; this in turn can contribute to the success of I4.0 adoption. The present study was carried out in the Indian automotive sector. In future, it can be expanded by considering a global survey. Also, the proposed social acceptability dimensions can be applied to other industries to enable a more generalized study. Further, in this study, we have considered only social acceptability dimensions; in future, environmental and economic dimensions could also be integrated to establish the triple bottom line benefits. In the present study, the social acceptability dimensions model was made for developing countries such as India. In future, a mixed model can be developed which is applicable to both developing and developed countries.

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**Appendix**

**Table A1:** Input Average data for social acceptability

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **CA** | **EA** | **MA** | **PA** | **CoA** | **SA** | **BA** |
| **CA** | (0,0.1,0.3) | (0.5,0.77,1) | (0.5,0.77,1) | (0.3,0.72,1) | (0.3,0.57,0.9) | (0.3,0.57,0.9) | (0.3,0.76,1) |
| **EA** | (0.3,0.64,1) | (0,0.15,0.3) | (0.5,0.74,1) | (0.3,0.57,0.9) | (0.3,0.68,1) | (0.3,0.61,0.9) | (0.3,0.63,1) |
| **MA** | (0.3,0.53,0.9) | (0.3,0.57,0.9) | (0,0.1,0.3) | (0.3,0.61,0.9) | (0.3,0.72,1) | (0.3,0.61,0.9) | (0.3,0.71,1) |
| **PA** | (0.3,0.57,0.9) | (0.5,0.81,1) | (0.3,0.8,1) | (0,0.1,0.3) | (0.3,0.68,1) | (0.3,0.61,0.9) | (0.5,0.81,1) |
| **CoA** | (0.3,0.64,1) | (0.3,0.65,0.9) | (0.5,0.7,0.9) | (0.5,0.74,1) | (0,0.1,0.3) | (0.5,0.81,1) | (0.3,0.65,0.9) |
| **SA** | (0.5,0.77,1) | (0.3,0.64,1) | (0.3,0.64,1) | (0.3,0.72,1) | (0.5,0.77,1) | (0,0.1,0.3) | (0.5,0.77,1) |
| **BA** | (0.3,0.72,1) | (0.3,0.69,1) | (0.5,0.74,1) | (0.5,0.77,1) | (0.3,0.69,1) | (0.3,0.65,0.9) | (0,0.1,0.3) |

**Table A2:** Input Average data for cultural acceptability dimensions

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Cultural Acceptability** | CA1 | CA2 | CA3 | CA4 | CA5 |
| CA1 | (0,0.1,0.3) | (0.1,0.48,0.9) | (0.3,0.57,0.9) | (0.1,0.52,0.9) | (0.1,0.55,0.9) |
| CA2 | (0.3,0.72,1) | (0,0.1,0.3) | (0.5,0.74,1) | (0.5,0.86,1) | (0.5,0.86,1) |
| CA3 | (0.3,0.6,1) | (0.5,0.74,1) | (0,0.1,0.3) | (0.5,0.81,1) | (0.5,0.81,1) |
| CA4 | (0.3,0.6,1) | (0.3,0.64,1) | (0.3,0.6,1) | (0,0.1,0.3) | (0.3,0.8,1) |
| CA5 | (0.3,0.63,1) | (0.3,0.69,1) | (0.3,0.69,1) | (0.5,0.81,1) | (0,0.1,0.3) |

**Table A3:** Input Average data for employee acceptability dimensions

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Employee Acceptability** | EA1 | EA2 | EA3 | EA4 | EA5 |
| EA1 | (0,0.1,0.3) | (0.1,0.44,0.9) | (0.1,0.33,0.7) | (0.1,0.37,0.7) | (0.1,0.39,0.9) |
| EA2 | (0.1,0.52,0.9) | (0,0.1,0.3) | (0.3,0.69,1) | (0.3,0.72,1) | (0.5,0.77,1) |
| EA3 | (0.1,0.49,1) | (0.5,0.77,1) | (0,0.1,0.3) | (0.3,0.69,1) | (0.3,0.72,1) |
| EA4 | (0.1,0.33,0.7) | (0.5,0.86,1) | (0.3,0.69,1) | (0,0.1,0.3) | (0.5,0.86,1) |
| EA5 | (0.1,0.45,0.7) | (0.5,0.74,1) | (0.5,0.74,1) | (0.3,0.69,1) | (0,0.1,0.3) |

**Table A4:** Input Average data for market acceptability dimensions

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Market Acceptability** | MA1 | MA2 | EM3 | MA4 | MA5 |
| MA1 | (0,0.1,0.3) | (0.1,0.55,0.9) | (0.1,0.44,0.9) | (0.5,0.86,1) | (0.3,0.6,1) |
| MA2 | (0.5,0.77,1) | (0,0.1,0.3) | (0.3,0.61,0.9) | (0.5,0.77,1) | (0.3,0.57,0.9) |
| MA3 | (0.3,0.5,0.7) | (0.3,0.5,0.7) | (0,0.1,0.3) | (0.1,0.41,0.7) | (0.1,0.52,1) |
| MA4 | (0.1,0.55,0.9) | (0.3,0.5,0.7) | (0.1,0.48,0.9) | (0,0.1,0.3) | (0.1,0.41,0.7) |
| MA5 | (0.3,0.69,1) | (0.3,0.6,1) | (0.3,0.64,1) | (0.3,0.76,1) | (0,0.1,0.3) |

**Table A5:** Input Average data for psychological acceptability dimensions

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Psychological Acceptability** | PA1 | PA2 | PM3 | PA4 | PA5 |
| PA1 | (0,0.1,0.3) | (0.5,0.81,1) | (0.3,0.64,1) | (0.5,0.77,1) | (0.5,0.74,1) |
| PA2 | (0.5,0.77,1) | (0,0.1,0.3) | (0.3,0.6,1) | (0.3,0.69,1) | (0.5,0.74,1) |
| PA3 | (0.3,0.64,1) | (0.5,0.74,1) | (0,0.1,0.3) | (0.3,0.6,1) | (0.3,0.6,1) |
| PA4 | (0.5,0.81,1) | (0.5,0.81,1) | (0.3,0.6,1) | (0,0.1,0.3) | (0.5,0.74,1) |
| PA5 | (0.3,0.69,1) | (0.5,0.74,1) | (0.3,0.6,1) | (0.5,0.74,1) | (0,0.1,0.3) |

**Table A6:** Input Average data for compliance acceptability dimensions

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Compliance Acceptability** | CoA1 | CoA2 | CoM3 | CoA4 | CoA5 |
| CoA1 | (0,0.1,0.3) | (0.1,0.33,0.7) | (0.1,0.44,0.9) | (0.3,0.57,0.9) | (0.1,0.57,1) |
| CoA2 | (0,0.24,0.5) | (0,0.1,0.3) | (0,0.35,0.9) | (0,0.35,0.9) | (0,0.33,0.7) |
| CoA3 | (0.1,0.65,1) | (0,0.37,0.9) | (0,0.1,0.3) | (0.5,0.7,0.9) | (0.3,0.61,0.9) |
| CoA4 | (0.3,0.72,1) | (0,0.26,0.7) | (0.3,0.65,0.9) | (0,0.22,0.9) | (0.5,0.86,1) |
| CoA5 | (0.3,0.64,1) | (0,0.26,0.7) | (0.3,0.64,1) | (0.5,0.81,1) | (0,0.1,0.3) |

**Table A7:** Input Average data for Safety acceptability dimensions

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Safety Acceptability** | SA1 | SA2 | SM3 | SA4 | SA5 |
| SA1 | (0,0.1,0.3) | (0.5,0.86,1) | (0.5,0.86,1) | (0.5,0.81,1) | (0.5,0.77,1) |
| SA2 | (0.5,0.81,1) | (0,0.1,0.3) | (0.5,0.74,1) | (0.5,0.81,1) | (0.5,0.77,1) |
| SA3 | (0.5,0.77,1) | (0.5,0.77,1) | (0,0.1,0.3) | (0.3,0.68,1) | (0.3,0.68,1) |
| SA4 | (0.3,0.69,1) | (0.3,0.64,1) | (0.3,0.6,1) | (0,0.1,0.3) | (0.5,0.86,1) |
| SA5 | (0.3,0.76,1) | (0.3,0.63,1) | (0.3,0.6,1) | (0.5,0.74,1) | (0,0.1,0.3) |

**Table A8:** Input Average data for behavioural acceptability dimensions

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Behavioural Acceptability** | BA1 | BA2 | BM3 | BA4 | BA5 |
| BA1 | (0,0.1,0.3) | (0.5,0.81,1) | (0.5,0.81,1) | (0.3,0.69,1) | (0.3,0.65,0.9) |
| BA2 | (0.5,0.81,1) | (0,0.1,0.3) | (0.5,0.86,1) | (0.3,0.65,0.9) | (0.3,0.61,0.9) |
| BA3 | (0.5,0.74,1) | (0.5,0.81,1) | (0,0.1,0.3) | (0.3,0.64,1) | (0.3,0.64,1) |
| BA4 | (0.5,0.74,1) | (0.5,0.74,1) | (0.5,0.74,1) | (0,0.1,0.3) | (0.5,0.81,1) |
| BA5 | (0.3,0.72,1) | (0.3,0.72,1) | (0.3,0.65,0.9) | (0.3,0.69,1) | (0,0.1,0.3) |