**Assessing challenges for implementing Industry 4.0: implications for process safety and environmental protection**

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**Abstract**: Researchers and practitioners are giving significant attention to Industry 4.0 due to its numerous benefits to manufacturing organizations. Several aspects of Industry 4.0 have been studied in the literature. However, studies on the challenges for implementing Industry 4.0 in manufacturing operations have received less attention. To address this gap, this study identifies a set of challenges (framework) for implementing Industry 4.0 in manufacturing industries. This framework is evaluated in the leather industry of Bangladesh aided by a novel multi-criteria decision-making method named Best-Worst method (BWM). The findings of the study showed that ‘lack of technological infrastructure’ is the most pressing challenge that may hurdle the implementation of Industry 4.0 whereas ‘environmental side-effects’ is the less among the challenges that may hinder implementation of Industry 4.0 in the Bangladeshi leather industry. This result may help decision makers, industrial mangers and practitioners in the Bangladeshi leather industry to realize the actual challenges confronting them when attempting to implement Industry 4.0 and focus their attention on how to address these challenges to pave ways for a successful implementation of Industry 4.0.

**Keywords:** Best worst method (BWM); Challenges; Environmental protection; Industry 4.0; Internet of Things (IoT); Leather industry; Smart technology.

1. **Introduction**

In today’s competitive business environment, many business organizations are paying a significant attention to adopt smart technology in their production systems for improving the productivity, reducing risks and protecting the environment along with better quality products (Kolberg and Zühlke, 2015; Lu, 2017; Stock and Seliger, 2016; Varghese and Tandur, 2014). Hence, the concept of Industry 4.0 is becoming much popular among organizations due to its advantages in manufacturing processes as well as environmental protection. The development towards Industry 4.0 has greatly influenced manufacturing companies operations and decisions (Ford, 2015; Reinhard et al., 2016). The rapid development of information and communication technology (ICT) and internet of things (IoT) do facilitate the adoption of new technologies by manufacturing companies’ to automate their manufacturing systems.

This development may impart immense opportunities for manufacturers to protect and control environmental impacts using smart technology, which can be developed via ICT and IoT (Lee et al., 2015; Reinhard et al., 2016; Schumacher et al., 2016). Yet, incorporating ICT and IoT based smart technology in manufacturing systems are not easily achieved by these companies due to some significantly challenges (Chen et al., 2014; Lee and Lee, 2015; Qian and Wang, 2012). Therefore, it is requisite to identify and examine the challenges faced by these manufacturing companies when attempting to implement Industry 4.0.

Several researchers have conducted a number of studies on the initiatives to implementing Industry 4.0 but none have until now identified and examined the challenges confronted by organizations when attempting to implement Industry 4.0. This has warranted and motivated the need to carry out this research. For example, Waibel et al., (2017) investigated the effect of smart production system in Industry 4.0 whereas Stock and Seliger, (2016) ascertained the opportunities of sustainable manufacturing in Industry 4.0. Faller and Feldmúller, (2015) in their study, investigated the learning factor of Industry 4.0 for regional Small and Medium Enterprises (SMEs). Lu, (2017) conducted a comprehensive review on Industry 4.0. These are some latest examples of studies conducted that are relevant to Industry 4.0 but clearly depicting the lack of studies on identifying and examining the challenges for Industry 4.0 implementation. To help fill this research gap, this study proposes a framework to investigate the challenges for implementing Industry 4.0 within the context of Bangladeshi leather industry. In this study, the challenges for implementing Industry 4.0 are assessed and ranked using a novel multi-criteria decision making (MCDM) tool named the ‘best-worst method’ (BWM).

The Bangladeshi leather industry was considered as the case industry due to several reasons. Firstly, the Bangladeshi leather industry is one of the most pollutant industrial sectors in the world (Hoque and Clarke, 2013). It is evident that the leather industry is largely responsible for the water, air and soil pollution as a result of their several chemical operations of raw hides and skins. Secondly, the Bangladeshi leather industry is one of the significant industrial sectors which contributes to Bangladesh foreign exchange with less amount of investment (Moktadir et al., 2017; Moktadir et al., 2018). Thirdly, the Bangladeshi leather industry is emergent and requires sustainable manufacturing practices such as smart manufacturing to help them make strategic decisions to minimize their environmental impacts thereby reshaping the industry’s negative environmental reputations. Therefore, this research contributes to the state-of-the-art literature by addressing the following specific objectives:

1. To identify the challenges for implementing Industry 4.0 in the Bangladeshi leather industry.
2. To assess and rank these challenges using a novel multi criteria decision making based Best-Worst method.
3. To suggest some practical and managerial implication of the study for implementing Industry 4.0.

To help address these objectives, the related literature is studied to identify some potential crucial challenges for implementing Industry 4.0 in the leather industry. To select the most crucial challenges, we conducted a series of brainstorming sessions with a group of industrial managers from the Bangladeshi leather industry. Then, evaluated and ranked the identified critical challenges using BWM. The reason for selecting the BWM are provided as follows: i) it needs less number of pairwise comparison matrices which minimizes the evaluation time; and ii) the obtain results are more consistent compared to other MCDM tools (Marley, 2008; Rezaei, 2015a, 2015b).

The reminder of the paper is structured as follows. In Section 2, the theoretical background of Industry 4.0, technologies used in Industry 4.0 and challenges to the implementation of Industry 4.0 are presented. Research methodology, composed of research design and the best-worst method are presented in Section 3. In Section 4, the application of the proposed challenges framework to a real world case problem in the Bangladeshi leather industry is provided, with results and discussions given in Section 5. Finally, conclusion, practical implications and recommendation for future research are highlighted in Section 6.

1. **Theoretical Background**
   1. **Industry 4.0**

The term ‘Industry 4.0’ refers to the fourth industrial revolution which is derived from the project related to computerized manufacturing of the future in the year 2011 (Vaidya et al., 2018; Tjahjono et al., 2017). This project was operated by German ministry of education and research. The applicability of the term 'Industry 4.0' is popular in European countries especially in Germany’s manufacturing sector (Gilchrist, 2016; Roblek et al., 2016; Rüßmann et al., 2015). The term Industry 4.0 is based on the concept of Internet of services, Internet of Things, industrial internet and cyber physical systems, artificial intelligent (Davies, 2015; Lee et al., 2015; Rüßmann et al., 2015b). The basic characteristics of Industry 4.0 can be explained by four dimensions: (1) vertical integration across the entire value chain and smart production system, (2) horizontal integration via new generation across the entire value chain networks, (3) Through-engineering across the entire product life cycle and (4) acceleration via smart technology (Deloitte, 2015).

Vertical integration across the entire value chain and smart production system refers to the digitization and intelligent integration of the manufacturing plant via cyber physical production system and thus can create dynamic production system by considering rapid changes of demand and stock level (Ahuett-Garza and Kurfess, 2018; Wang et al., 2015; Zezulka et al., 2016). In this system, the resources and products are networked via vertical integration. Here, the smart sensor technology is used to monitor the whole system.

Horizontal integration via new generation across the entire value chain networks refers to the integration of intra- and inter-organizational intelligent and digitization throughout the value chain of a product life cycle (Erol et al., 2016; Ganzarain and Errasti, 2016). This system creates optimized networks that facilitate integrated transparency and offer high level of flexibility. Horizontal integration creates the dynamic production system across the entire process chain-from purchasing through production to sales.

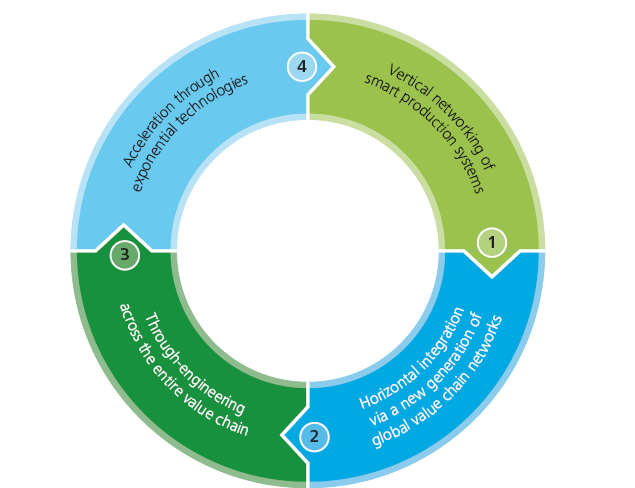


Fig. 1. The characteristics of Industry 4.0 (adopted from Deloitte 2015).

The third Industry 4.0 characteristic, through-engineering across the entire product life cycle refers to the intelligent integration and digitization across the entire product life chain, that is, from the raw materials purchasing to end of the product life. In this stage, data may be available at all phases of product life cycle and facilitate the generation of more flexible production process (Gilchrist, 2016; Lasi et al., 2014).

The fourth important characteristic is acceleration via smart technology. The impact of smart technology in industrial production systems is so high. Smart technology can accelerate the entire production system by optimizing the production time, minimizing the production cost. Industry 4.0 requires introducing automation in the production system. Smart technology like advanced robotics, artificial intelligence, sensor technologies etc. can be used to be more autonomous in production process (Ahuett-Garza and Kurfess, 2018; Pereira et al., 2017; Fernández-Miranda et al., 2017; de Sousa Jabbour et al., 2018; Zhong et al., 2017).

For environmental protection and control, smart manufacturing system and cleaner technology can help companies to minimize waste and negative environmetal impact. Thefereore, adoption of Industry 4.0 in Bangladeshi leather industry’s supply chain is more important to help minimize water, soil, and air pollution.

* 1. **Technologies used in Industry 4.0**

The world is experiencing advanced technological revolution such as Industry 4.0. There are several technologies for Industry 4.0 adaptation in manufacturing companies such as big data analytics (BDA), robotics, simulation, industrial internet of things, cyber-security, cloud computing, additives manufacturing, augmented reality, machine learning etc. (Ahuett-Garza and Kurfess, 2018; Rüßmann et al., 2015; Witkowski, 2017). Many companies are adopting such technologies in their production system towards Industry 4.0 implementation. As for example, Google, Amazon, Netflix are used BDA to monitor the customer’s choice for decision making process. **BDA** tools help analyze the real data to enhance the productivity and reduce the uncertainty in decision making process (Zhong et al., 2017). This tool helps various companies including, manufacturing, pharmaceutical, chemical, and automotive to make supply chain more efficient and sustainable.

**Autonomous robot** is a key technology for Industry 4.0 journey. An autonomous robot helps to operate operations with more precisely where the workers are unable or restricted to deal the operations more precisely (Ahuett-Garza and Kurfess, 2018; Witkowski, 2017; Zhong et al., 2017). Several companies are using autonomous robot in their manufacturing plant, as for example, Gomtec used ‘Roberta’ robot for efficient automation in manufacturing, Rethink Robotics used ‘Baxter’ robot for packaging operation, Kuka used ‘Kuka LBR iiwa’ robot for sensitive industrial tasks (Vaidya et al., 2018).

**Simulation** is the imitation of the manufacturing operations of a real world system in where machines, human, and products are included (Vaidya et al., 2018; Mourtzis et al., 2014; Ruiz et al., 2014). It is widely used in variety of fields like simulation of technology for optimizing the design process, safety engineering for system security, and scientific modeling for visualizing the operational system (Heilala et al., 2008). 2D and 3D simulations now are widely used in industrial task for simulation of process cycle time, ergonomic design, energy consumption and efficiency (Rodič, 2017). It is evident that uses of simulation in Industry 4.0 journey may help to reduce the production process down time, waste generation and the production failure quantity.

In Industry 4.0 journey, **internet of things (IoT)** has a significant contribution in manufacturing industry. Sometimes IoT is defined as an industrial internet in where every components of internet like Internet of Manufacturing Service (IoMs), Intenet of People (IoP), Internet of Service (IoS) and communication technologies are integrated to facilitate the production system (Zhong et al., 2017; Vaidya et al., 2018). IoT helps to integrate the data for operational purpose from the virtual word which may assist the manufacturing activities for continuous improvement (Chen et al., 2014; Gubbi et al., 2013; Minerva et al., 2015). IoT based software are used for intelligent planning and control of machines.

**Cyber-security** is a major challenge in Industry 4.0 implementation because of in industry 4.0, it is necessary to connect and use standard communication protocol for operational purpose. To protect the industrial manufacturing system from cyber security threats, more secured, sophisticated and reliable frameworks are necessary for machines and operators (Zhong et al., 2017; Vaidya et al., 2018). In industry 4.0 journey, it is essential to connect the physical system to digital data for system optimization, planning and quality control in the manufacturing industry (Sridhar et al., 2012). The cyber-physical system helps to integrate the physical system to computerized system. In manufacturing industry, smart vehicle based on cyber-physical system is used for warehouse management whereas data mining helps to predict the route (Zhong et al., 2017).

Today’s businesses are largely depending on real-time data analysis and data storage facility. In Industry 4.0, **cloud computing** helps to storage such real time massive data which is collected from various sources for industrial manufacturing purposes (Gao and Zhao, 2011). It can help to link and share of communication devices from one company to other to facilitate the manufacturing plant. The concept of digital production can be achieved via cloud computing based connection among companies from each country to other (Vaidya et al., 2018).

**Additives manufacturing** based technologies like selective laser sintering (SLS), fused deposition method (FDM), selective laser melting (SLM) are those used to faster and cheaper the production system (Thomas-Seale et al., 2018). It helps manufacturing companies to produces small amount of customized products with design optimization. Additives manufacturing also can help to reduce the transport distances and stock on hand (Vaidya et al., 2018). The demand of customers is changing day by day and additives manufacturing helps to fulfill the demand of customers by continuously changing the design of products (Leary et al., 2015). Now-a-days several manufacturing companies used additives manufacturing system to fulfill the customer demand very quickly. As for example, various automotive industries used additives manufacturing system.

**Augmented reality** is a service system which helps to support the industry via communication devices. To improve the work facility and analyze the multiple decisions, augmented reality helps industry to collect real time data from customers (Vaidya et al., 2018). Augmented reality is best suited for repair operations and it helps to workers to know the instructions of repair operations.

**Machine learning** is a dynamic computer based techniques that can extract useful information and best decision from big data, the massive data, both structured and unstructured, that can be achieved from a business at a given time (Cardenas et al., 2013; Lavalle et al., 2011; Russom, 2011). Machine learning has a sufficient impact in the manufacturing system to monitor the defect, detection of faults, and predicting of future needs (Ahuett-Garza and Kurfess, 2018). Many authors showed the various machine learning techniques for various purposes. As for example, Qu et al., (2014) showed the comparison of vibrations sensors and acoustic emissions to perform fault diagnosis on gearbox, Zhou et al., (2017) presented a model based on a hierarchical deep neural network for fault severity recognition and fault source location. Hence, the applications of machine learning are necessary for manufacturing companies to analyze defect as well as for better performance in operations.

* 1. **Problem description and challenges for Industry 4.0**

There are lots of challenges regarding adaptation of smart manufacturing process in the leather industry. The concept of Industry 4.0 in the leather industry is not well established in literature and practice (Laka and Gonzalez, 2015; Lee et al., 2015). To protect the environment, the concept of Industry 4.0 may help companies in the leather industry to minimize waste in all forms. In addition, the concept of Industry 4.0 in the leather industry may help to improve the operational performance and enhance the global reputations.

The leather industry is one of the most polluting industrial sectors in Bangladesh where extensive chemical operations are necessary to produce finished leather (Moktadir et al., 2017). From the collection of raw hides and skins of domestic animals to finishing of raw hides and skins, multiple chemical operations are involved leading to the production of huge environmental pollutants (Dixit et al., 2015; Thanikaivelan et al., 2005; Xu et al., 2010) including solid waste such as fleshing, hair, lime, chrome split, shavings etc. and leather waste liquor containing heavy metals, some gases such as H2S (Hydrogen sulfide), NH3 (Ammonia), Cl2 (Chlorine) gas etc. (Bosnic et al., 2000; Lofrano et al., 2013; Maurice, 2001; Hoque and Clarke, 2013). Hence, to control and minimize these environmental pollutions, the concept of Industry 4.0 may help the companies in the leather industry to enhance their operational practices by adopting automation and cleaner technology.

The lack of literature on challenges for Industry 4.0 implementation and the huge environmental impact of the leather industry do warrants and is the main motivation of this research. To help control the pollution and save the environment, this study will help decision makers and industrial managers in the leather industry to grasp the key elements of Industry 4.0. It will further provide them with some challenges for implementing Industry 4.0 and means to address these challenges. Several researchers have tried to present the importance of adaptation of smart manufacturing practices for sustainable manufacturing. As examples, Qin et al., (2016) have focused on the basic concept of Industry 4.0 and the state of current manufacturing practices whereas Lee et al., (2015) have proposed a multi-level framework for cyber physical production system implementation. Rüßmann et al., (2015) have conducted a study to show the effect of Industry 4.0 on productivity and growth in manufacturing. Dilberoglu et al., (2017) have investigated the role of additive manufacturing in Industry 4.0 whereas Trstenjak and Cosic, (2017) have proposed a process planning framework for implementing Industry 4.0. Much more of this literature stream does exist but none have specifically attempted to investigate the challenges to the implementation of Industry 4.0, especially in the leather industry. Some other studies on Industry 4.0 are presented in Table 1.

Table 1: Some literature on Industry 4.0

|  |  |
| --- | --- |
| Authors | Contributions |
| (Santos et al., 2017) | Assessment of opportunities of product development processes in Industry 4.0. |
| (Lu, 2017) | A literature review on technologies, applications and research issues in Industry 4.0. |
| (Hofmann and Rüsch, 2017) | The current status and future prospects on logistics issues in Industry 4.0. |
| (Tupa et al., 2017) | Design of risk assessment framework to manage risk in Industry 4.0. |
| (Man and Strandhagen, 2017) | Sustainable business models in Industry 4.0. |
| (Stock and Seliger, 2016) | Sustainability manufacturing opportunities in Industry 4.0. |
| (Lom et al., 2016) | Industry 4.0 as a part of smart cities. |
| (Benešová and Tupa, 2017) | Human resource requirement in Industry 4.0. |
| (Sanders et al., 2016) | Linking Industry 4.0 to lean manufacturing practices. |
| (Wagner et al., 2017) | The impacts of Industry 4.0 on lean production systems. |
| (Dilberoglu et al., 2017) | The role of additive manufacturing in the era of Industry 4.0. |

The extant literature reveals that there is still the lack of study that has examined the challenges for implementing Industry 4.0. Therefore, this study contributes to the state-of-the-art literature by identifying using brainstorming and assessing some of the challenges faced by companies in the leather industry when attempting to implement Industry 4.0 using BWM. The simplified descriptions of the identified challenges for implementing Industry 4.0 are presented in Table 2.

**Table 2:** Challenges for implementing Industry 4.0

|  |  |  |  |
| --- | --- | --- | --- |
| **No** | **Challenges** | **Reference** | **Brief descriptions** |
| 1 | Data insecurity (CH1) | (Gölzer et al., 2015; Constantine, 2014; Zhou et al., 2016) | Lack of systems to ensure enough data protection for the manufacturing companies during the implementation of Industry 4.0. |
| 2 | High investment (CH2) | (Zhou et al., 2016; (Koch et al., 2014) | Industry 4.0 initiatives in the manufacturing industry require huge capital investment. |
| 3 | Lack of technological infrastructure (CH3) | (Varghese and Tandur, 2014; Zhou et al., 2016; Waibel et al., 2017) | Nonexistence of technological infrastructure to support the manufacturing companies implementation of Industry 4.0. |
| 4 | Unstable connectivity among companies (CH4) | (Deloitte, 2015; Khan et al., 2017; Zhou et al., 2016) | Insecure connectivity impairs real time communication among manufacturing companies challenging the implementation of Industry 4.0. |
| 5 | Decreasing job opportunity (CH5) | (Zhou et al., 2016;Waibel et al., 2017; Zezulka et al., 2016) | Industry 4.0 implementation in manufacturing industry takes away some job opportunities due to the replacement of humans with robots and intense use of automation in the production system. |
| 6 | Lack of strategy towards Industry 4.0 (CH6) | (Koch et al., 2014; Zhou et al., 2016) | Lack of dynamic strategic plan to support the adoption of Industry 4.0 in the manufacturing Industry. |
| 7 | Environmental side-effects (CH7) | (Weyer et al., 2015; Deloitte, 2015) | Huge automation usages in manufacturing operations in Industry 4.0 implementation may create serious environment impacts. |
| 8 | Complexity in reconfiguring of production pattern (CH8) | (Lee et al., 2015; Lu, 2017; Qin et al., 2016; Sanders et al., 2016) | Lack of capabilities to reconfigure the production pattern for the successful implementation of Industry 4.0 in the manufacturing companies. |
| 9 | Lack of skilled management team (CH9) | (Hecklau et al., 2016; Deloitte, 2015) | Nonexistence of skilled management team to execute the new and inventive business models in Industry 4.0. |
| 10 | Complexity in integrating IT and OT (CH10) | (Lee et al., 2015, 2014; Lu, 2017) | Intricacy in the integration of information technology (IT) and operational technology (OT). |

1. **Methodology**
   1. **Research design**

Assessing the challenges for the implementation of Industry 4.0 is a multi-criteria decision analysis problem. This study investigated the challenges for implementing Industry 4.0 in the context of the leather industry of Bangladesh. Several challenges for implementing Industry 4.0 were identified based on a combination of literature review and industrial managers' feedback. These managers include experts in supply chain management, operations management and information technology (IT). The identified challenges were evaluated via novel BWM method. The proposed novel BWM-based MCDM method is briefly described in the following section.

* 1. **Best worst method**

There are lots of MCDM tools available in the literature. One of the best tools is the “Best Worst” MCDM tool developed by Professor Rezaei in 2015 (Rezaei, 2015a). This technique works better in solving multi criteria decision making problem as compared to other tools like analytical hierarchy process (AHP). There are some unique advantages of this method over the other tools. The results derived from this method are more consistent than other MCDM techniques and it needs lesser pairwise comparison matrices to obtain better outcome which helps decision makers and researchers to get more reliable results with less time (Rezaei, 2015a, 2016). The above mentioned advantages are the key fuel regarding the selection of this MCDM tool in this research.

The BWM literature is well established. Several researchers have used this methodology in various domains. For example Abouhashem-Abadi et al. (2018) have utilized BWM to investigate the medical tourism development strategy. Badri Ahmadi et al., (2017) used BWM to evaluate supply chains social sustainability whereas Guo and Zhao (2017) have applied fuzzy-based BWM in MCDM problem. Rezaei et al., (2016) employed the BWM to select supplier by integrating environmental and traditional criteria. Torabi et al. (2016) used BWM to develop risk assessment framework. Some other applications of BWM include the selection of biomass technology (van de Kaa et al., 2017), evaluation of external forces in oil and gas supply chains for sustainability (Wan Ahmad et al., 2017), evaluation of the benefits of eco-industrial parks (Zhao et al., 2017) and so on. The whole procedure of BWM can be summarized as follows (Rezaei, 2015; Gupta et al., 2017):

* + 1. **Determination of the decision making criteria**

In this step, a set of decision making criteria  necessary to aid the decision towards the objective of the study are determined.

* + 1. **Determination of the best criteria (e.g., most important, most desirable) and the worst criteria (e.g., least important, least desirable).**

In this step, the assigned decision makers identify the most important and least important criteria without any comparison matrix. Decision makers just indicate the most- and least-important criteria and no value is required to identify the decision criteria.

* + 1. **Determination of the best criterion over the other criteria using a 1-9 point rating scale.**

In this step, decision makers determine the resulting best-to-others vector. The rating scale indicates the preference of one criterion over the other criterion. The rating scale 1 indicates that the best criterion is equally preferable to the other criterion. The rating scale 9 indicates that the best criterion is strongly preferable over the other criterion. The resulting best-to-others (BO) vector of criteria can be written as follows:



Where, represents the preference of best criterion over the criterion j. Hence, .

* + 1. **Determination of the preference of all the other criteria over the worst criterion using a 1-9 point rating scale**

In this step, decision makers determine the resulting others-to-worst vector. Therefore resulting others-to-worst vector can be represented by the given notation:



Where,indicates that the preference of the j criteria over the worst criteria and .

* + 1. **Computed the optimal weights** 

The optimal weights of the criteria should satisfy the stated conditions: for each pair of  and  and the best possible solution is where and. Hence, to obtain the best possible solution, the maximum should be minimized among the set of  , and the problem can be expressed as follows:

min 

Subject to,

 (1)

 for all j.

The above mentioned problem Eq. (1) can be transformed into linear programming problem and are shown as follows:

min, 

Subject to,

for all j

for all j

 (2)

 for all j

The optimal weights and  can be obtained by solving the above mentioned liner programming (LP) problem. The notation  indicates the consistency of the comparison matrices. If the value of  is closer to the zero, it indicates the system is more consistence and hence reliable comparison, and vice versa.

1. **Real world case application**

***4.1 Determination of the decision criteria***

In this phase, the challenges for implementing Industry 4.0 were determined via a combination of extant literature review and industrial manager’s feedback. The potential challenges identified through literature review were tabulated in a semi-structured questionnaire form and sent to industrial mangers (respondents) in the Bangladeshi leather industry. These respondents were asked to express their opinions in refining the challenges by assigning a ‘Yes’ (affirmative) or ‘No’ (negative). An agreed threshold is established and that any challenge that exceeds or meets this threshold after the analysis is maintained, otherwise deleted. The final affirmed challenges are listed in Table 2. The respondent managers were chosen from four large leather processing companies in Bangladesh. The four Bangladeshi leather processing companies were selected based on a combination of convenience sampling approach due to their accessibility and their intense interest to examine the challenges for implementing Industry 4.0. Consequently, the industrial mangers were sampled from these four leather processing companies. These respondents were selected based on a combination of purposive sampling - respondents that are particularly informative and knowledgeable on the subject matter so they can contribute significantly to the study; and self-selection sampling - respondents willing and desiring to partake in the study, reaffirming their commitments to the study. Email and phone call invitations were sent to twenty purposive sampled respondents for their self-selection. Eight out of twenty respondents accepted to participate in the study after several email reminders and follow-up phone calls over two months period, with the number of accepted respondents within the proposed 4-10 respondents’ required for having credible data from interview as argued by Rezaei et al., (2018). Coincidentally, two of the eight respondents are from each of the four companies. These eight respondents were involved in both the refinement of the challenges (framework) for implementing Industry 4.0 and the evaluation of the framework within their companies. The profile of each respondent and the selected companies are shown in Table 3.

**Table 3**: Profile of selected companies and respondents

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Name of company | Description of companies | Industrial mangers (respondents) | Year of experience | Area of expertise | Types of products |
| Company A | It is a larger leather processing company in Bangladesh. Its annual production capacity is 12,000,000 square feet of leather. In fiscal year 2016-2017, this company earned USD 45 million. | Production manager | 12 years | Production and control | Wet blue, crust and finished leather |
| Technologist | 15 years | Leather processing and quality control |
| Company B | This company is equipped with modern Italian machineries. This is the first **ISO9001:2008** certified tannery of Bangladesh in where annual production exceeds 32 million square meters. Its annual turnover is around USD 40 million. | Supply chain manager | 11 years | Procurement, sourcing, distribution | Wet blue, crust and finished leather |
| Logistics manager | 9 years | Transportation and distribution |
| Company C | This company is one of legendary company of Bangladesh in tannery sector. Its annual production capacity is approximately 42 million square meter of leather. Annual turnover of this company is USD 35 million. | Operations manager | 7 years | Production and maintenance | Wet blue, crust and finished leather |
| Technologist | 14 years | Leather processing, quality control |
| Company D | It is a well-equipped tannery industry of Bangladesh which produces 100% export oriented finished leather. Annual production capacity is around 30 million square meter of leather. Annual turnover of this company is approximately USD 27 million. | Production manager | 13 years | Production and control | Wet blue, crust and finished leather |
| Logistics manager | 10 years | Transportation and distribution |

***4.2 Determination of the best challenges and worst challenges***

In this phase, each of the eight managers/decision makers were asked to determine the most important criteria (severe challenge) and the least important criteria (less severe challenge) using a survey instrument. The resulting severe challenges and less severe challenges by managers/decision makers 1-8 are listed in Table 4.

**Table 4:** Best (severe) and worst (less severe) challenges recognized by Managers 1-8

|  |  |  |
| --- | --- | --- |
| **Name of challenge with code** | **Best (severe) challenges identified by experts** | **Worst (less severe) challenges identified by experts** |
| Data insecurity (CH1) |  | 2 |
| High investment (CH2) | 8 |  |
| Lack of technological infrastructure (CH3) | 1, 2, 4 |  |
| Unstable connectivity among companies (CH4) |  |  |
| Decreasing job opportunity (CH5) |  | 1, 3, 6, 8 |
| Lack of strategy towards Industry 4.0 (CH6) |  |  |
| Environmental side-effects (CH7) |  | 4, 5 |
| Complexity in reconfiguring of production pattern (CH8) | 3, 5, 6, 7 |  |
| Lack of skilled management team (CH9) |  |  |
| Complexity in integrating IT and OT (CH10) |  | 7 |

***4.3 Determination of the best (severe) challenge over the other challenges***

In this phase, the managers were asked to indicate their preferences of the best (severe) challenge over the other challenges using 1-9 point rating scale. The identified best challenge over the other challenges of manager-1 is shown in Table 5.

**Table 5:** Best challenge over the other challenges determined by manager-1

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Best to others | CH1 | CH2 | CH3 | CH4 | CH5 | CH6 | CH7 | CH8 | CH9 | CH10 |
| Best challenge (CH3) | 3 | 4 | 1 | 5 | 7 | 5 | 9 | 2 | 6 | 8 |

***4.4 Determination of the other challenges over the worst (less severe) challenge***

In this phase, the managers were asked to indicate their preferences of the other challenges over the worst (less severe) challenge using 1-9 point rating scale. Table 6 shows the response of managers-1.

**Table 6:** Other challenges to worst challenge determined by manager-1

|  |  |
| --- | --- |
| Others to worst | Worst (less severe) challenge (CH5) |
| CH1 | 4 |
| CH2 | 7 |
| CH3 | 8 |
| CH4 | 2 |
| CH5 | 1 |
| CH6 | 6 |
| CH7 | 9 |
| CH8 | 3 |
| CH9 | 6 |
| CH10 | 4 |

***4.5 Determination of the optimal weights of decision criteria***

In this phase, the optimal weights of each challenge are computed by fulfilling the above mentioned model and constraints (Eq. 2) for all eight managers. As for example, the model for manager-1 is given below:

min, 

Subject to,



The optimal weights of objective function and challenges for manager-1 are displayed in Table 7.

**Table 7:** Optimal weights of identified challenges computed with manager-1’s response

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| w(CH1) | w(CH2) | w(CH3) | w(CH4) | w(CH5) | w(CH6) | w(CH7) | w(CH8) | w(CH9) | w(CH10) |  |
| 0.129116 | 0.09683667 | 0.259953 | 0.077469 | 0.018937 | 0.077469 | 0.043039 | 0.184205 | 0.064558 | 0.048418 | 0.127394 |

Within this phase, we also computed the simple averages of the optimal weights of the challenges using all the eight managers’ individual optimal weights of challenges results. The final optimal weights are presented in Table 8. The value of  is the objective function of the constructed LP model. The closer the value of  to zero indicates the more consistent and the reliability of the obtained results. The lower values of standard deviation indicates the homogeneity among the eights respondents.

**Table 8:** Optimal average weights of challenges for the 8 respondents

|  |  |  |
| --- | --- | --- |
| Challenges of environmental protection and control in Industry 4.00 | Weights | Standard deviation |
| Data insecurity (CH1) | 0.1228 | 0.0287 |
| High investment (CH2) | 0.1225 | 0.0497 |
| Lack of technological infrastructure (CH3) | 0.2284 | 0.0741 |
| Unstable connectivity among companies (CH4) | 0.0780 | 0.0153 |
| Decreasing job opportunity (CH5) | 0.0415 | 0.0197 |
| Lack of strategy towards Industry 4.0 (CH6) | 0.0659 | 0.0098 |
| Environmental side-effects (CH7) | 0.0369 | 0.0136 |
| Complexity in reconfiguring of production pattern (CH8) | 0.1900 | 0.0838 |
| Lack of skilled management team (CH9) | 0.0674 | 0.0191 |
| Complexity in integrating IT and OT (CH10) | 0.0465 | 0.0128 |
|  | 0.1445 |  |

1. **Results and sensitivity analysis**

**5.1 Results and discussion**

Table 8 presents the final results of the study. This result can help managers and decision makers to formulate strategies for addressing these challenges and implementing Industry 4.0. It is evident from Table 8 that, “lack of technological infrastructure (CH3)” is the challenge with the highest weights of 0.2284. Therefore, lack of technological infrastructure is the most crucial challenge that needs to be addressed to enable the Bangladeshi leather industry to implementation Industry 4.0.

Smart technology, an example of Industry 4.0 (Hofmann and Rüsch, 2017; Lu, 2017), would require strong technological infrastructure development to support smart production. In addition, smart manufacturing process may help to limit the environmental pollutions while improving the environmental sustainability benefits (Jazdi, 2014; Varghese and Tandur, 2014; Bai et al., 2017). For control and environmental protection, Industry 4.0 tools that sit on technological infrastructure may help in the development of smart manufacturing processes and environmental conscious Industry. “Complexity in reconfiguring of production pattern (CH8)” was identified as the second highest ranked challenge with weight of 0.1900. The high rank of this challenge indicates that the companies in the Bangladeshi leather industry will face this seriously hurdle during adaptation of smart manufacturing practices in Industry 4.0. For this reason, in Industry 4.0 implementation, production pattern reconfiguring is necessary as a means to deal with the inherent challenge due to the incorporation of the latest automated technology in the production system (Zhou et al., 2016). This challenge was followed by “Data insecurity (CH1)” and “High investment (CH2)” with optimal weights of 0.1228 and 0.1225 respectively.

The implication of this result to companies in the Bangladeshi leather industry is that lack of technological infrastructure, the foundational, central and critical challenge hindering the implementation of smart technologies, necessities an urgent attention during adaptation of Industry 4.0. Once technological infrastructure challenge has been overcome, it will pave ways for the other challenges to be addressed resulting in the elimination of the entire challenges. It also mean that if the involving Bangladesh companies want to implementation Industry 4.0 in their operations, they ought to build a stronger supporting technological infrastructure base to take up or stand the revolution. As argued by Weiss and Birnbaum, (1989), technology aspect of a firm’s strategy requires the development of infrastructure to support the technological change and strategic capability. This therefore means that technological infrastructure development is extremely important to implement a technological strategy successfully (Byrd and Turner, 2000).

The next most pressing challenge is “unstable connectivity among companies (CH4)” with optimal weight of 0.0780. In Industry 4.0, vertical and horizontal integration need strong and stable connectivity among companies to support real time communication (Facchinetti et al., 2005). Managers and decision makers may focus much attention and invest enough resources in addressing this challenge during adaptation of Industry 4.0. Some important strategic decision such as having in place a service management support contract with the service provider responsible for ensuring stable operations of the internet may help to overcome this challenge for the successful implementation of smart technology. From Table 8, “lack of skilled management team (CH9)” and “lack of strategy towards Industry 4.0 (CH6)” are the sixth and seventh pressing challenges with optimal weights of 0.0674 and 0.0659 respectively. It is not surprising that these two challenges followed in that order due to the fact that availability of skilled manpower is required for the development of strategic policy for Industry 4.0.

Therefore, for companies in Bangladeshi leather industry planning to implement Industry 4.0 in their operations is required to build a strong management team to manage the smart technologies and formulate strategic decisions towards Industry 4.0. In Industry 4.0, managers and decision makers may face some critical situations such as tackling of complex technology due to competitive business environment which requires some technical manpower skill set to deal them. Therefore, the successfully implementation of Industry 4.0 may strongly depend on the skilled IT personnel. It is therefore clear that these two challenges need critical attention by companies and industrial managers due to their strong interrelationship and dependency.

The eighth and ninth challenges are “complexity of integration of IT and OT (CH10)” and “decreasing job opportunity (CH5)” with weights of 0.0465 and 0.0415 respectively. The complexity of integrating IT and OT is a key challenge to minimize the environmental impact through the implementation of Industry 4.0 (Bahrin et al., 2016; Keller et al., 2014; Zhou et al., 2016). In Bangladeshi leather industry, though complexity of integration of IT and OT is identified as one of the challenges, it seems that this is not much of a pressing issue due to the fact that it is ranked relatively low (eighth position). Therefore with a little effort this challenge can be duly overcome enabling the incorporation of Industry 4.0 in the manufacturing process. Smart technology based raw hides and skins processing may help to minimize the environmental pollution as compared to conventional leather processing system (Kolomaznik et al., 2008; Mengistie et al., 2016; Raghava Rao et al., 2003; Rajput, 2009). On the other hand, these smart technology based manufacturing systems may create job losses due to replacement of humans with for example robots and hence, have the potential of decreasing job opportunities (Zhou et al., 2016). Hence, it can also be seen as the significant challenge for the Bangladeshi leather industry as well as for other industrial sectors. Next is the challenge, “environmental side-effects (CH7)” with the least optimal weight of 0.0369. This indicates that an environmental impact may occur even with the implementation of Industry 4.0 due to increasing use of technologies as huge energy are used that can cause millions of tons of greenhouse gas emissions daily (Bai et al., 2017). It is evident that the conventional system may hamper the environment greatly as compared to smart technology. Therefore, this challenge got the least pressing and importance priority ranking among the challenges. Chemical handling in the leather operations may create some serious diseases such as skin cancer, allergy etc. Hence, the smart production system may help decrease the human contacts and controls of the chemical operations, improving the safety of employees and may also facilitate the reduction of environment pollutions caused to water bodies, air and soil.

**5.2 Sensitivity analysis**

In MCDM technique, it is requisite to investigate the biasness in the obtained results. For this reason, several researchers suggested sensitivity analysis for MCDM technique via changing weights of top ranked criteria at the range of 0.1 to 0.9 and observe the effect on other criteria (Mangla et al., 2015; Prakash and Barua, 2015). This sensitivity analysis ensures decision makers that the obtained results are more robust or vice versa. In this study, the weight of “Lack of technological infrastructure (CH3)” has been varied from 0.1 to 0.9 and investigates the effect on other selected challenges for implementing Industry 4.0. Table 9 shows the weights of all challenges for implementing Industry 4.0 when weight of “Lack of technological infrastructure (CH3)” challenge is varied from 0.1 to 0.9. At the same time, weights of other challenges are varied accordingly. Table 10 shows the ranking of selected challenges for implementing Industry 4.0 based on sensitivity analysis. It is evident from the Table 10 and Fig. 3 that during sensitivity analysis, the challenge “Lack of technological infrastructure (CH3)” is occupying 1st rank and the challenge “Environmental side-effects (CH7)” is carrying last rank most of the time. Fig. 1 and Fig. 3 show the weight changes and ranking during sensitivity analysis subsequently.

Table 9: Weights of challenges for implementing Industry 4.0 during sensitivity analysis

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Selected Challenges | Values of preference weights for selected challenges of Industry 4.0 | | | | | | | | | |
|  | Normal (0.2284) | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| CH1 | 0.1228 | 0.1433 | 0.1273 | 0.1114 | 0.0955 | 0.0796 | 0.0637 | 0.0478 | 0.0318 | 0.0159 |
| CH2 | 0.1225 | 0.1429 | 0.1270 | 0.1112 | 0.0953 | 0.0794 | 0.0635 | 0.0476 | 0.0318 | 0.0159 |
| CH3 | 0.2284 | 0.1000 | 0.2000 | 0.3000 | 0.4000 | 0.5000 | 0.6000 | 0.7000 | 0.8000 | 0.9000 |
| CH4 | 0.0780 | 0.0910 | 0.0809 | 0.0708 | 0.0607 | 0.0506 | 0.0405 | 0.0303 | 0.0202 | 0.0101 |
| CH5 | 0.0415 | 0.0484 | 0.0430 | 0.0376 | 0.0322 | 0.0269 | 0.0215 | 0.0161 | 0.0107 | 0.0054 |
| CH6 | 0.0659 | 0.0769 | 0.0683 | 0.0598 | 0.0513 | 0.0427 | 0.0342 | 0.0256 | 0.0171 | 0.0085 |
| CH7 | 0.0369 | 0.0430 | 0.0383 | 0.0335 | 0.0287 | 0.0239 | 0.0191 | 0.0143 | 0.0096 | 0.0048 |
| CH8 | 0.1900 | 0.2216 | 0.1970 | 0.1724 | 0.1477 | 0.1231 | 0.0985 | 0.0739 | 0.0492 | 0.0246 |
| CH9 | 0.0674 | 0.0786 | 0.0699 | 0.0612 | 0.0524 | 0.0437 | 0.0349 | 0.0262 | 0.0175 | 0.0087 |
| CH10 | 0.0465 | 0.0542 | 0.0482 | 0.0422 | 0.0362 | 0.0301 | 0.0241 | 0.0181 | 0.0121 | 0.0060 |
| **Total** | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table 10: Ranking of selected challenge for implementing Industry 4.0 though sensitivity analysis

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Selected Challenges | Ranking | | | | | | | | | |
| Normal (0.2284) | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| CH1 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| CH2 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| CH3 | 1 | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| CH4 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 5 |
| CH5 | 9 | 9 | 9 | 9 | 9 | 9 | 8 | 9 | 9 | 9 |
| CH6 | 7 | 7 | 7 | 7 | 7 | 7 | 6 | 7 | 7 | 7 |
| CH7 | 10 | 10 | 10 | 10 | 10 | 10 | 8 | 10 | 10 | 10 |
| CH8 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| CH9 | 6 | 6 | 6 | 6 | 6 | 6 | 4 | 6 | 6 | 6 |
| CH10 | 8 | 8 | 8 | 8 | 8 | 8 | 6 | 8 | 8 | 8 |

Weights

Fig. 2: Weights of challenges for implementing Industry 4.0 during sensitivity analysis

Fig. 3: Ranking of challenges during sensitivity analysis

It is concluded that the results acquired via BWM are consistent and free from any biasness

1. **Conclusions, implications for process safety and environmental protection, practical implications and recommendation for future research**

In this section, we discuss details on conclusions, implications for process safety and environmental protection, practical implications and recommendation for future research.

***6.1 Conclusions***

Traditional industrial activities are largely responsible for the distraction of the environment by polluting air, water and soil. To remedy this occurrence and protect the environment, the concept of Industry 4.0 is the way to go. In implementing Industry 4.0, some challenges are faced by many companies. Hence, these companies ought to deal with these existing challenges before attempting to incorporate smart production system into their operations. This study has investigated the challenges faced by companies in the Bangladeshi leather industry when attempting to implement Industry 4.0. These challenges for implementing Industry 4.0 were identified through brainstorming and assessed within one of the most pollutant industrial sectors; the leather industry using novel BWM. The use of several chemicals for raw hides and skins produce large amount of pollutant which may dramatically pollute the water bodies, soil and air quality. Hence, smart production processes and cleaner technology are needed to deal with this huge environmental impact through the implementation of Industry 4.0.

The finding of the study reveals that ‘lack of technological infrastructure’ is the most pressing challenge among the others faced by companies in Bangladeshi leather industry given the highest optimal weight. This outcome indicates the importance of developing technological infrastructure for supporting the implementation of Industry 4.0. For this reason, it is strongly advisable that, before implementing Industry 4.0 in an existing supply chains, companies should initially develop the supporting infrastructure to aid in the adoption of the technological changes in the production layout (Weiss and Birnbaum, 1989). This result may help industrial manager to understand the importance of the technological infrastructure for the adaptation of smart technology in Industry 4.0. In this study, the environmental side-effects challenge received the least relative weight considered as the least pressing challenge compared to other identified challenges.

***6.2 Implications for process safety and environmental protection***

Leather industry is the second most polluted industrial sector in Bangladesh and this requires extensive chemical operations. Those chemical operations are responsible for environmental pollutions and it is harmful for operators. It can be concluded that this research has significant implications for process safety and environmental protection due to the implementation of Industry 4.0 in the leather industry can minimize the environmental pollutions and can safeguard the employees from harmful chemical operations. This research will help industrial decision makers to know the importance of implementing Industry 4.0 in the leather industry supply chain and how the Industry 4.0 concept can help for process safety and environmental protection. It will help industry owner and researcher to develop Industry 4.0 technology based on smart technology, robotics and IoT to facilitate the leather processing system and thus will help minimize the human contact in operational procedure for risk minimization and process safety. Smart technology based cleaner production technology also can facilitate leather industry to improve the current practices.

Recently, the new established leather zone is also trying to convert the traditional system to more sustainable system to protect the environment by integrating center effluent treatment plant (CFTP). This indicates that leather industry is going to be sustainable manufacturing practices. Hence, this study will further assist to know the benefits of implementing Industry 4.0 in leather industry for process safety and environment protection. The major implications of this research for process safety and environmental protection can be summarized as follows:

1. This study on Industry 4.0 can help develop more environment-friendly leather processing technology by observing demand of Industry 4.0 technologies in its production system. Industry 4.0 implementation may help reduces the negative environmental impact of leather industry.
2. This study on Industry 4.0 may also assist decision makers and government to give special attention to develop smart technology and cleaner processing technology to assist the implementation of Industry 4.0.
3. Industry 4.0 concepts can help greatly leather industry to minimize the waste in all forms including harmful gasses emission, waste generation, air pollutions and water pollutions. and can help the operator to minimize the handling of chemicals operations. In this sense automation technology can help the operator to make the production system more sustainable and safer.

***6.3 Practical implications***

The proposed framework may help companies in the leather industry and other industries in emerging economies to build the necessary guidelines for implementing Industry 4.0. Most especially, this study will provide industrial managers and practitioners in developing country with a means to evaluate and examine the impact of the identified challenges for implementing Industry 4.0. This research may help other industrial sectors to realize the importance of assessing and addressing these challenges before venturing into implementing Industry 4.0. It may further help industrial managers to formulate some managerial policies to improve the current conditions of the Bangladeshi leather industry as well as emerging economies:

* ***Paying attention to develop IT infrastructure in Industry 4.0***: As the IT infrastructure received a significant optimal weight, it is undoubtedly that decision makers and industrial managers need to invest enough resources to develop it for supporting the introduction of automation in their existing manufacturing process.
* ***Fixing strategic policies for reconfiguring production pattern:*** For implementing Industry 4.0, it is necessary to reconfigure the production pattern due to the incorporation of smart manufacturing process lines. It is not an easy task to accomplish as exhibited in this research. Therefore, policy makers may gain some level of understanding of the nature of these challenges from this study which will help them put together strategy to overcome this hurdles.
* ***Motivating industrial managers to adopt smart technologies***: In the conventional production process, companies may not be able to minimize significantly their waste. In the era of Industry 4.0, new technology can help to minimize the waste streams generation as well as reduce energy consumption. This study can motivate industrial mangers to adopt smart technologies. Additionally and most importantly, governments have to provide some tax incentives to manufacturing companies especially the leather industry to motivate the adoption of Industry 4.0.

***6.4 Limitations and recommendation for future research***

This research is not free from limitations. In this research, we have investigated the challenges for implementing Industry 4.0 in the leather industry of Bangladesh. We have only considered ten most pressing challenges to justify the actual nature of challenges in the context of the leather industry. The results may vary from industry to industry and country to country as this study may not be generalizable in nature. The above mentioned limitation may be overcome by conducting further research in other industries. We hope this study may guide managers to advance the understanding and implementation of concept of Industry 4.0 in theirs and that of other industrial domains.

**References**

Abouhashem Abadi, F., Ghasemian Sahebi, I., Arab, A., Alavi, A., Karachi, H., 2018. Application of best-worst method in evaluation of medical tourism development strategy. Decis. Sci. Lett. 77–86. doi:10.5267/j.dsl.2017.4.002

Ahuett-Garza, H., Kurfess, T., 2018. A brief discussion on the trends of habilitating technologies for Industry 4.0 and Smart manufacturing. Manuf. Lett. doi:https://doi.org/10.1016/j.mfglet.2018.02.011

Badri Ahmadi, H., Kusi-Sarpong, S., Rezaei, J., 2017. Assessing the social sustainability of supply chains using Best Worst Method. Resour. Conserv. Recycl. 126, 99–106. doi:10.1016/j.resconrec.2017.07.020

Bahrin, M.A.K., Othman, M.F., Azli, N.H.N., Talib, M.F., 2016. Industry 4.0: A review on industrial automation and robotic. J. Teknol. doi:10.11113/jt.v78.9285

Bai, C., Kusi-Sarpong, S., Sarkis, J., 2017. An implementation path for green information technology systems in the Ghanaian mining industry. J. Clean. Prod. 164, 1105–1123. doi:10.1016/j.jclepro.2017.05.151

Benešová, A., Tupa, J., 2017. Requirements for Education and Qualification of People in Industry 4.0. Procedia Manuf. 11, 2195–2202. doi:10.1016/j.promfg.2017.07.366

Bosnic, M., And, J.B., Daniels, R.P., 2000. Pollutants in tannery effluents. UNITED NATIONS Ind. Dev. Organ. 9, 26.

Byrd, T.A., Turner, D.E., 2000. Measuring the ﬂexibility of information technology infrastructure: exploratory analysis of a construct. J. Manag. Inf. Syst. 17, 167–208. doi:10.1080/07421222.2000.11045632

Cardenas, A. a., Manadhata, P.K., Rajan, S.P., 2013. Big Data Analytics for Security. IEEE Secur. Priv. 11, 74–76. doi:10.1109/MSP.2013.138

Chen, S., Xu, H., Liu, D., Hu, B., Wang, H., 2014. A vision of IoT: Applications, challenges, and opportunities with China Perspective. IEEE Internet Things J. doi:10.1109/JIOT.2014.2337336

Constantine, C., 2014. Big data: An information security context. Netw. Secur. doi:10.1016/S1353-4858(14)70010-8Feature

Davies, R., 2015. Industry 4.0. Digitalisation for productivity and growth. Eur. Parliam. Res. Serv. 10.

Deloitte, 2015. Industry 4.0. Challenges and solutions for the digital transformation and use of exponential technologies. Deloitte 1–30.

de Sousa Jabbour, A.B.L., Jabbour, C.J.C., Foropon, C., Filho, M.G., 2018. When titans meet – Can industry 4.0 revolutionise the environmentally-sustainable manufacturing wave? The role of critical success factors. Technol. Forecast. Soc. Change. doi:https://doi.org/10.1016/j.techfore.2018.01.017

Dilberoglu, U.M., Gharehpapagh, B., Yaman, U., Dolen, M., 2017. The Role of Additive Manufacturing in the Era of Industry 4.0. Procedia Manuf. 11, 545–554. doi:10.1016/j.promfg.2017.07.148

Dixit, S., Yadav, A., Dwivedi, P.D., Das, M., 2015. Toxic hazards of leather industry and technologies to combat threat: A review. J. Clean. Prod. 87, 39–49. doi:10.1016/j.jclepro.2014.10.017

Erol, S., Jäger, A., Hold, P., Ott, K., Sihn, W., 2016. Tangible Industry 4.0: A Scenario-Based Approach to Learning for the Future of Production, in: Procedia CIRP. pp. 13–18. doi:10.1016/j.procir.2016.03.162

Facchinetti, T., Buttazzo, G., Almeida, L., 2005. Dynamic resource reservation and connectivity tracking to support real-time communication among mobile units. Eurasip J. Wirel. Commun. Netw. 2005, 712–730. doi:10.1155/WCN.2005.712

Fernández-Miranda, S.S., Marcos, M., Peralta, M.E., Aguayo, F., 2017. The challenge of integrating Industry 4.0 in the degree of Mechanical Engineering. Procedia Manuf. 13, 1229–1236. doi:https://doi.org/10.1016/j.promfg.2017.09.039

Faller, C., Feldmúller, D., 2015. Industry 4.0 learning factory for regional SMEs, in: Procedia CIRP. pp. 88–91. doi:10.1016/j.procir.2015.02.117

Ford, M., 2015. Industry 4.0: Who Benefits? SMT Surf. Mt. Technol. 30, 52–55.

Ganzarain, J., Errasti, N., 2016. Three stage maturity model in SME’s towards industry 4.0. J. Ind. Eng. Manag. 9, 1119–1128. doi:10.3926/jiem.2073

Gao, L., Zhao, Y., 2011. Application on cloud computing in the future library, in: CCIS2011 - Proceedings: 2011 IEEE International Conference on Cloud Computing and Intelligence Systems. pp. 175–177. doi:10.1109/CCIS.2011.6045055

Gilchrist, A., 2016. Introducing Industry 4.0, in: Industry 4.0. pp. 195–215. doi:10.1007/978-1-4842-2047-4\_13

Gölzer, P., Cato, P., Amberg, M., 2015. Data Processing Requirements of Industry 4 . 0 –. Eur. Conf. Inf. Syst. ECIS 0, 1–13.

Gubbi, J., Buyya, R., Marusic, S., Palaniswami, M., 2013. Internet of Things (IoT): A vision, architectural elements, and future directions. Futur. Gener. Comput. Syst. 29, 1645–1660. doi:10.1016/j.future.2013.01.010

Guo, S., Zhao, H., 2017. Fuzzy best-worst multi-criteria decision-making method and its applications. Knowledge-Based Syst. 121, 23–31. doi:10.1016/j.knosys.2017.01.010

Gupta, P., Anand, S., Gupta, H., 2017. Developing a roadmap to overcome barriers to energy efficiency in buildings using best worst method. Sustain. Cities Soc. 31, 244–259. doi:10.1016/j.scs.2017.02.005

Hecklau, F., Galeitzke, M., Flachs, S., Kohl, H., 2016. Holistic Approach for Human Resource Management in Industry 4.0, in: Procedia CIRP. pp. 1–6. doi:10.1016/j.procir.2016.05.102

Heilala, J., Vatanen, S., Tonteri, H., Montonen, J., Lind, S., Johansson, B., Stahre, J., 2008. Simulation-based sustainable manufacturing system design. Winter Simul. Conf. 1922–1930. doi:10.1109/WSC.2008.4736284

Hofmann, E., Rüsch, M., 2017. Industry 4.0 and the current status as well as future prospects on logistics. Comput. Ind. 89, 23–34. doi:10.1016/j.compind.2017.04.002

Hoque, A., Clarke, A., 2013. Greening of industries in Bangladesh: Pollution prevention practices. J. Clean. Prod. 51, 47–56. doi:10.1016/j.jclepro.2012.09.008

Jazdi, N., 2014. Cyber physical systems in the context of Industry 4.0. 2014 IEEE Autom. Qual. Testing, Robot. 2–4. doi:10.1109/AQTR.2014.6857843

Keller, M., Rosenberg, M., Brettel, M., Friederichsen, N., 2014. How Virtualization, Decentrazliation and Network Building Change the Manufacturing Landscape: An Industry 4.0 Perspective. Int. J. Mech. Aerospace, Ind. Mechatron. Manuf. Eng. 8, 37–44. doi:10.1016/j.procir.2015.02.213

Khan, M., Wu, X., Xu, X., Dou, W., 2017. Big data challenges and opportunities in the hype of Industry 4.0, in: 2017 IEEE International Conference on Communications (ICC). pp. 1–6. doi:10.1109/ICC.2017.7996801

Koch, V., Kuge, S., Geissbauer, R., Schrauf, S., 2014. Industry 4.0 - Opportunities and challenges of the industrial internet. Strateg. Former. Booz Company, PwC 13, 1–51. doi:10.1016/j.futures.2014.12.002

Kolberg, D., Zühlke, D., 2015. Lean Automation enabled by Industry 4.0 Technologies, in: IFAC-PapersOnLine. pp. 1870–1875. doi:10.1016/j.ifacol.2015.06.359

Kolomaznik, K., Adamek, M., Andel, I., Uhlirova, M., 2008. Leather waste-Potential threat to human health, and a new technology of its treatment. J. Hazard. Mater. 160, 514–520. doi:10.1016/j.jhazmat.2008.03.070

Laka, J., Gonzalez, M., 2015. Industry 4.0. Dyna. doi:10.6036/7392

Lasi, H., Fettke, P., Kemper, H.G., Feld, T., Hoffmann, M., 2014. Industry 4.0. Bus. Inf. Syst. Eng. 6, 239–242. doi:10.1007/s12599-014-0334-4

Lavalle, S., Lesser, E., Shockley, R., Hopkins, M.S., Kruschwitz, N., 2011. Big Data, Analytics and the Path From Insights to Value. MIT Sloan Manag. Rev. 52, 21–32. doi:10.0000/PMID57750728

Leary, M., Kron, T., Keller, C., Franich, R., Lonski, P., Subic, A., Brandt, M., 2015. Additive manufacture of custom radiation dosimetry phantoms: An automated method compatible with commercial polymer 3D printers. Mater. Des. 86, 487–499. doi:10.1016/j.matdes.2015.07.052

Lee, I., Lee, K., 2015. The Internet of Things (IoT): Applications, investments, and challenges for enterprises. Bus. Horiz. 58, 431–440. doi:10.1016/j.bushor.2015.03.008

Lee, J., Bagheri, B., Kao, H.A., 2015. A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. Manuf. Lett. 3, 18–23. doi:10.1016/j.mfglet.2014.12.001

Lee, J., Kao, H.A., Yang, S., 2014. Service innovation and smart analytics for Industry 4.0 and big data environment, in: Procedia CIRP. pp. 3–8. doi:10.1016/j.procir.2014.02.001

Lofrano, G., Meriç, S., Zengin, G.E., Orhon, D., 2013. Chemical and biological treatment technologies for leather tannery chemicals and wastewaters: A review. Sci. Total Environ. doi:10.1016/j.scitotenv.2013.05.004

Lom, M., Pribyl, O., Svitek, M., 2016. Industry 4.0 as a part of smart cities. 2016 Smart Cities Symp. Prague 1–6. doi:10.1109/SCSP.2016.7501015

Lu, Y., 2017. Industry 4.0: A survey on technologies, applications and open research issues. J. Ind. Inf. Integr. doi:10.1016/j.jii.2017.04.005

Man, J.C. De, Strandhagen, J.O., 2017. An Industry 4.0 Research Agenda for Sustainable Business Models, in: Procedia CIRP. pp. 721–726. doi:10.1016/j.procir.2017.03.315

Marley, a a J., 2008. The Best-Worst Method for the Study of Preferences : Theory and Application. Int. J. Psychol. 43, 168–347. doi:10.1080/00207594.2008.10108484

Maurice, J., 2001. Tannery pollution threatens health of half-million Bangladesh residents. TT -. Bull. World Health Organ. 79, 78–79. doi:10.1590/S0042-96862001000100018

Mengistie, E., Smets, I., Van Gerven, T., 2016. Ultrasound assisted chrome tanning: Towards a clean leather production technology. Ultrason. Sonochem. 32, 204–212. doi:10.1016/j.ultsonch.2016.03.002

Minerva, R., Biru, A., Rotondi, D., 2015. Towards a definition of the Internet of Things (IoT). IEEE Internet Things 86. doi:10.5120/19787-1571

Moktadir, M.A., Ahmed, S., Tuj Zohra, F., Sultana, R., 2017. Productivity Improvement by Work Study Technique: A Case on Leather Products Industry of Bangladesh. Ind. Eng. Manag. doi:10.4172/2169-0316.1000207

Moktadir, M.A., Rahman, T., Rahman, M.H., Ali, S.M., Paul, S.K., 2018. Drivers to sustainable manufacturing practices and circular economy: a perspective of leather industries in Bangladesh. J. Clean. Prod. doi:10.1016/j.jclepro.2017.11.063

Mourtzis, D., Doukas, M., Bernidaki, D., 2014. Simulation in manufacturing: Review and challenges, in: Procedia CIRP. pp. 213–229. doi:10.1016/j.procir.2014.10.032

Mangla, S.K., Kumar, P., Barua, M.K., 2015. Risk analysis in green supply chain using fuzzy AHP approach: A case study. Resour. Conserv. Recycl. 104, 375–390. doi:10.1016/j.resconrec.2015.01.001

Pereira, T., Barreto, L., Amaral, A., 2017. Network and information security challenges within Industry 4.0 paradigm. Procedia Manuf. 13, 1253–1260. doi:https://doi.org/10.1016/j.promfg.2017.09.047

Prakash, C., Barua, M.K., 2015. Integration of AHP-TOPSIS method for prioritizing the solutions of reverse logistics adoption to overcome its barriers under fuzzy environment. J. Manuf. Syst. 37, 599–615. doi:10.1016/j.jmsy.2015.03.001

Qian, Z.-H., Wang, Y.-J., 2012. IoT technology and application. Tien Tzu Hsueh Pao/Acta Electron. Sin. 40, 1023–1029. doi:10.3969/j.issn.0372-2112.2012.05.026

Qin, J., Liu, Y., Grosvenor, R., 2016. A Categorical Framework of Manufacturing for Industry 4.0 and beyond, in: Procedia CIRP. pp. 173–178. doi:10.1016/j.procir.2016.08.005

Qu, Y., He, D., Yoon, J., Van Hecke, B., Bechhoefer, E., Zhu, J., Hecke, B. Van, Bechhoefer, E., Van Hecke, B., Bechhoefer, E., Zhu, J., 2014. Gearbox tooth cut fault diagnostics using acoustic emission and vibration sensors--a comparative study. Sensors (Basel). 14, 1372–1393. doi:10.3390/s140101372

Raghava Rao, J., Chandrababu, N.K., Muralidharan, C., Nair, B.U., Rao, P.G., Ramasami, T., 2003. Recouping the wastewater: A way forward for cleaner leather processing. J. Clean. Prod. 11, 591–599. doi:10.1016/S0959-6526(02)00095-1

Rajput, A.S.D., 2009. Enzymes and biotechnology for cleaner leather processing. Curr. Sci.

Reinhard, G., Jesper, V., Stefan, S., 2016. Industry 4.0: Building the digital enterprise. 2016 Glob. Ind. 4.0 Surv. 1–39. doi:10.1080/01969722.2015.1007734

Rezaei, J., 2015a. Best-worst multi-criteria decision-making method. Omega 53, 49–57. doi:10.1016/j.omega.2014.11.009

Rezaei, J., 2015b. Best-worst multi-criteria decision-making method: Some properties and a linear model. Omega (United Kingdom) 64, 1–5. doi:10.1016/j.omega.2015.12.001

Rezaei, J., Kothadiya, O., Tavasszy, L., Kroesen, M., 2018. Quality assessment of airline baggage handling systems using SERVQUAL and BWM. Tour. Manag. 66, 85–93. doi:10.1016/j.tourman.2017.11.009

Rezaei, J., Nispeling, T., Sarkis, J., Tavasszy, L., 2016. A supplier selection life cycle approach integrating traditional and environmental criteria using the best worst method. J. Clean. Prod. 135, 577–588. doi:10.1016/j.jclepro.2016.06.125

Roblek, V., Meško, M., Krapež, A., 2016. A Complex View of Industry 4.0. SAGE Open 6, 215824401665398. doi:10.1177/2158244016653987

Rodič, B., 2017. Industry 4.0 and the New Simulation Modelling Paradigm. Organizacija 50. doi:10.1515/orga-2017-0017

Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., Harnisch, M., 2015a. Industry 4.0. Bost. Consult. Gr. 20.

Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., Harnisch, M., 2015b. Industry 4.0. The Future of Productivity and Growth in Manufacturing. Bost. Consult. 1–5.

Ruiz, N., Giret, A., Botti, V., Feria, V., 2014. An intelligent simulation environment for manufacturing systems. Comput. Ind. Eng. 76, 148–168. doi:10.1016/j.cie.2014.06.013

Russom, P., 2011. Big data analytics. TDWI Best Pract. Rep. 1–35. doi:10.1109/ICCICT.2012.6398180

Sanders, A., Elangeswaran, C., Wulfsberg, J., 2016. Industry 4.0 implies lean manufacturing: Research activities in industry 4.0 function as enablers for lean manufacturing. J. Ind. Eng. Manag. 9, 811–833. doi:10.3926/jiem.1940

Santos, K., Loures, E., Piechnicki, F., Canciglieri, O., 2017. Opportunities Assessment of Product Development Process in Industry 4.0. Procedia Manuf. 11, 1358–1365. doi:10.1016/j.promfg.2017.07.265

Schumacher, A., Erol, S., Sihn, W., 2016. A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises, in: Procedia CIRP. pp. 161–166. doi:10.1016/j.procir.2016.07.040

Sridhar, S., Hahn, A., Govindarasu, M., 2012. Cyber-physical system security for the electric power grid. Proc. IEEE 100, 210–224. doi:10.1109/JPROC.2011.2165269

Stock, T., Seliger, G., 2016. Opportunities of Sustainable Manufacturing in Industry 4.0, in: Procedia CIRP. pp. 536–541. doi:10.1016/j.procir.2016.01.129

Thanikaivelan, P., Rao, J.R., Nair, B.U., Ramasami, T., 2005. Recent trends in leather making: Processes, problems, and pathways. Crit. Rev. Environ. Sci. Technol. doi:10.1080/10643380590521436

Thomas-Seale, L.E.J., Kirkman-Brown, J.C., Attallah, M.M., Espino, D.M., Shepherd, D.E.T., 2018. The barriers to the progression of additive manufacture: Perspectives from UK industry. Int. J. Prod. Econ. 198, 104–118. doi:https://doi.org/10.1016/j.ijpe.2018.02.003

Tjahjono, B., Esplugues, C., Ares, E., Pelaez, G., 2017. What does Industry 4.0 mean to Supply Chain? Procedia Manuf. 13, 1175–1182. doi:10.1016/j.promfg.2017.09.191

Torabi, S.A., Giahi, R., Sahebjamnia, N., 2016. An enhanced risk assessment framework for business continuity management systems. Saf. Sci. 89, 201–218. doi:10.1016/j.ssci.2016.06.015

Trstenjak, M., Cosic, P., 2017. Process Planning in Industry 4.0 Environment. Procedia Manuf. 11, 1744–1750. doi:10.1016/j.promfg.2017.07.303

Tupa, J., Simota, J., Steiner, F., 2017. Aspects of Risk Management Implementation for Industry 4.0. Procedia Manuf. 11, 1223–1230. doi:10.1016/j.promfg.2017.07.248

van de Kaa, G., Kamp, L., Rezaei, J., 2017. Selection of biomass thermochemical conversion technology in the Netherlands: A best worst method approach. J. Clean. Prod. 166, 32–39. doi:10.1016/j.jclepro.2017.07.052

Varghese, A., Tandur, D., 2014. Wireless requirements and challenges in Industry 4.0, in: Proceedings of 2014 International Conference on Contemporary Computing and Informatics, IC3I 2014. pp. 634–638. doi:10.1109/IC3I.2014.7019732

Vaidya, S., Ambad, P., Bhosle, S., 2018. Industry 4.0 – A Glimpse. Procedia Manuf. 20, 233–238. doi:https://doi.org/10.1016/j.promfg.2018.02.034

Wagner, T., Herrmann, C., Thiede, S., 2017. Industry 4.0 Impacts on Lean Production Systems, in: Procedia CIRP. pp. 125–131. doi:10.1016/j.procir.2017.02.041

Waibel, M.W., Steenkamp, L.P., Moloko, N., Oosthuizen, G.A., 2017. Investigating the Effects of Smart Production Systems on Sustainability Elements. Procedia Manuf. 8, 731–737. doi:10.1016/j.promfg.2017.02.094

Wan Ahmad, W.N.K., Rezaei, J., Sadaghiani, S., Tavasszy, L.A., 2017. Evaluation of the external forces affecting the sustainability of oil and gas supply chain using Best Worst Method. J. Clean. Prod. 153, 242–252. doi:10.1016/j.jclepro.2017.03.166

Wang, S., Wan, J., Zhang, D., Li, D., Zhang, C., 2015. Towards smart factory for Industry 4.0: A self-organized multi-agent system with big data based feedback and coordination. Comput. Networks. doi:10.1016/j.comnet.2015.12.017

Weiss, A.R., Birnbaum, P.H., 1989. Technological Infrastructure and the Implementation of Technological Strategies. Manage. Sci. 35, 1014–1026. doi:10.1287/mnsc.35.8.1014

Weyer, S., Schmitt, M., Ohmer, M., Gorecky, D., 2015. Towards industry 4.0 - Standardization as the crucial challenge for highly modular, multi-vendor production systems, in: IFAC-PapersOnLine. pp. 579–584. doi:10.1016/j.ifacol.2015.06.143

Witkowski, K., 2017. Internet of Things, Big Data, Industry 4.0 - Innovative Solutions in Logistics and Supply Chains Management, in: Procedia Engineering. pp. 763–769. doi:10.1016/j.proeng.2017.03.197

Xu, W., Hao, L., An, Q., Zhou, L., 2010. Minimization of the environmental impact of leather processing: A benign and enzyme-based integrated leather processing technology, Advanced Materials Research. doi:10.4028/www.scientific.net/AMR.113-116.1614

Zezulka, F., Marcon, P., Vesely, I., Sajdl, O., 2016. Industry 4.0 – An Introduction in the phenomenon. IFAC-PapersOnLine 49, 8–12. doi:10.1016/j.ifacol.2016.12.002

Zhao, H., Guo, S., Zhao, H., 2017. Comprehensive benefit evaluation of eco-industrial parks by employing the best-worst method based on circular economy and sustainability. Environ. Dev. Sustain. 1–25. doi:10.1007/s10668-017-9936-6

Zhong, R.Y., Xu, X., Klotz, E., Newman, S.T., 2017. Intelligent Manufacturing in the Context of Industry 4.0: A Review. Engineering 3, 616–630. doi:https://doi.org/10.1016/J.ENG.2017.05.015

Zhou, K., Liu, T., Zhou, L., 2016. Industry 4.0: Towards future industrial opportunities and challenges, in: 2015 12th International Conference on Fuzzy Systems and Knowledge Discovery, FSKD 2015. pp. 2147–2152. doi:10.1109/FSKD.2015.7382284

Zhou, F., Gao, Y., Wen, C., 2017. A Novel Multimode Fault Classification Method Based on Deep Learning. Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics) 2017, 442–452. doi:10.1155/2017/3583610