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Evaluating the difficulties and potential responses to implement Industry 4.0 in Bangladesh's steel sector

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Abstract

With the promise of great benefits for industry and new possibilities for a wide range of applications, Industry 4.0 is quickly rising to prominence as one of the most important and widely discussed topics in academia and in practice. In this study, we look at the steel production business and identify the current state of affairs as well as the barriers to implementing Industry 4.0 there. Initially, the current state of Industry 4.0 was uncovered by visiting and surveying four prominent steel companies in Bangladesh. Less than fifty percent of Industry 4.0 components are now implemented in these plants. To determine the reasons for this unfavorable situation, research was conducted to identify the obstacles impeding the implementation of Industry 4.0. On the basis of the preferences of 9 experts (4 from industry and 5 from academia), 9 of the 12 proposed challenges have been selected as significant obstacles. The ranking of these nine difficulties was then assessed utilizing the popular best–worst method (BWM), a multi-criteria decision-making approach. It was determined that "high capital investment" was the most significant barrier, while "lack of government support" was the least significant. In addition, a sensitivity analysis was conducted, which improved the ranking's quality. Then, several viable techniques for overcoming these challenges are discussed.

Keywords: Industry 4.0, Steel sector, Smart production, Best–worst method, Sensitivity analysis

Introduction

The notion of Industry 4.0 has generated significant attention among both industry professionals and the academic research community, becoming a widely used term inside research institutes and universities. While the subject matter has been a longstanding focus of academic research within universities, the term "Industry 4.0" has recently emerged and gained significant traction, encompassing both academic discourse and its application within the industrial economy [1]. Hence, in the current competitive business landscape, numerous corporate entities are placing considerable emphasis on the integration of intelligent technology inside their production systems. This strategic move aims to enhance operational efficiency, mitigate risks, promote environmental

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sustainability, and deliver superior-quality products. Hence, the concept of Industry 4.0 has garnered significant traction within the corporate and organizational landscape owing to its advantageous implications for industrial operations and ecological preservation. The advent of Industry 4.0 has significantly influenced the operational and policy frameworks of manufacturing enterprises.

Digital transformation is a term used to describe the ways in which Industry 4.0 is influencing the field of company management and how it is altering and replacing traditional business paradigms [2]. Adopting Industry 4.0 has become an element of competitive advantage for companies and nations alike, despite its mixed effects, disruption of incumbents, and enormous and robust possibilities for new entrants [3]. Business models, organizational and managerial elements, the whole supply chain, and product and process development are all impacted by digital transformation, or digitalization, which poses substantial problems for firms [4]. It has recently been shown that innovation procedures grounded in the "open innovation" principle ought to reflect digital change [5]. The manufacturing step of the value chain is where Industry 4.0 was developed, bringing together physical and digital production technology [6]. The fundamental advances in information and communication technology share many similarities with the physical ideas at the heart of manufacturing. Smart computing, virtual and augmented reality, robotics, sensors, AI, and business analytics are becoming commonplace. The outcome of these mergers is a manufacturing process that is both digitalized and linked [7].

On one side, Industry 4.0 could lead to greater profitability and effectiveness and better quality for businesses that manufacture goods. On the other hand, it could expose them to more competition, which can be disruptive, and make change management more difficult [8]. In addition, there is a dearth of research on the possibilities and threats that businesses face while trying to adopt Industry 4.0. There is evidence that industrial manufacturers are hesitant to embrace Industry 4.0 due to their lack of clarity on the potential and problems it presents [9–13]. Manufacturers in the industrial sector appear to be hesitant to adopt Industry 4.0 due to the lack of clarity surrounding the benefits and drawbacks of the technology [14]. The idea of digital maturity was introduced in recent literature to explain the continuous shift in business models towards the adoption of digital technologies. An organization's digital transformation may be seen through the lens of maturity, which is defined as the degree to which a planned change has been completed or perfected [15]. It is possible to think of maturity models as a tool for tracking development towards a predetermined goal state [16, 17]. In their extensive literature study, Tarhan et al. demonstrated that maturity models, with their defined stages of maturity, constitute an ideal logical progression [18].

Manufacturing companies can make use of automation tools made possible by the rapid development of information technology (IT) and the Internet of Things (IoT) in the manufacturing sector [19]. This advancement may provide manufacturers with huge possibilities for their production to be efficient with the use of intelligent technology employing IT and IoT; however, Bangladesh's steel industries are not simply able to incorporate these technologies into manufacturing systems owing to significant constraints. As a result, it is necessary to assess the current scenario and investigate the barriers that these industrial businesses encounter while trying to incorporate Industry 4.0. Multiple scholars have carried out several studies on Industry 4.0 projects but none of them have so far discovered and analyzed the difficulties that companies face in trying to adopt Industry 4.0 in the steel industry. It really has justified and encouraged the necessity for this study.

In this regard, Waibel et al. (2016) analyzed how smart manufacturing systems affect Industry 4.0 [20], while Stock and Seliger [21] identified sustainable production possibilities in Industry 4.0. In their study, Faller and Feldmúller [22] studied the Industry 4.0 learning factor for small and medium-sized regional firms. A complete review of Industry 4.0 was done by Lu [1]. Recent research indicates that there has been a lack of focus on determining the current stage of the Industry 4.0 process and the barriers that impede its complete implementation. For example, the study conducted by Govender et al. [23] focused on examining the technological advances and investments utilized by steel businesses, with the aim of utilizing these existing resources to achieve a smart enterprise and effectively address present and future steel needs. Radoslaw and associates [24] conducted a study to examine the energy efficiency trends in firms, with a particular emphasis on enhancing the energy efficiency of production processes. The objective of the study was to provide recommendations for investment strategy in the Polish steel sector during the Industry 4.0 era. Bożena et al. [25] conducted a study aimed at developing a comprehensive framework for research and development and innovation (R&D&I) activities within the steel industry. Additionally, they conducted a thorough examination of R&D&I expenditures specifically within the metal production sector in Poland. This research was conducted at a period of increasing interest in the idea of Industry 4.0, which occurred in the last decade. Based on the aforementioned studies, it is evident that several investigations have been conducted pertaining to investment policies, R&D programs, and energy efficiency. However, there appears to be a relative dearth of research about the obstacles associated with implementing Industry 4.0 in steel plants, as well as potential strategies to tackle these issues. In order to address this research gap, this paper provides a methodology to identify the existing position in Bangladesh steel industries and to examine the obstacles of adopting Industry 4.0 as well as their possible solutions.

This research first reveals the present stage of Industry 4.0 application through an industry survey, and then it analyzes and ranks the obstacles to adopting Industry 4.0 using a novel multi-criteria decision-making (MCDM) algorithm called the "best–worst method" (BWM). The need for raw materials and steelmaking technology in Bangladesh is growing as the country serves as an important hub in the region. The availability and proliferation of building materials, especially steel-linked businesses, are crucial to the growth of a progressive national economy [26]. Steel is an essential element for building infrastructure and many other applications. Surprisingly, the country has a long and storied history of steel manufacture and building. Producing durable steel products including rebar, angel, beam, and channel, Bangladesh's steel sector has made a significant contribution to the country's overall infrastructure development. In the last decade, the demand for long steel has increased by 7.5 million tons or 2.5 million tons per year. Steel consumption is anticipated to rise to 45 kg per capita, a consumption of just 25 kg, per capita in 2012, of 73 kg, within 2022, per capita. So the steel sector should expand at least 16% annually when GDP is projected to rise by 8% [27]. The Bangladeshi steel industry therefore emerges and needs sustainable production techniques such as intelligent production to enable it to make calculated decisions in possible to lessen its influence on the environment and to boost its productivity to fulfill the national ambition. Therefore, this study contributes to the existing body of knowledge by aiming to do the following:

i) Assess the current state of Industry 4.0 as it is implemented in practice.
ii) Survey the steel industry to identify the obstacles to Industry 4.0 implementation;
iii) Assess and rank those obstacles utilizing a novel best–worst method based on multi-criteria decision-making.
iv) Determine potential strategies for overcoming the aforementioned obstacles.

In order to facilitate the attainment of these objectives, an analysis of the relevant literature is being conducted to ascertain potential challenges that may hinder the implementation of Industry 4.0 within the steel industry. The authors convened a meeting with a cohort of industry managers and specialists hailing from prominent steel businesses in Bangladesh, with the objective of discerning the prevailing challenges.

The subsequent section delineates the organizational structure of the paper's reminder. Section 2 of the paper delves into an examination of the conceptual underpinnings of Industry 4.0, the technological components employed within this paradigm, as well as the obstacles encountered when attempting to implement Industry 4.0. Section 3 of the paper provides an in-depth analysis of the study's methodology, encompassing the research design employed as well as the utilization of the best–worst strategy. In Section 4, a comprehensive examination of the findings and a thorough study of the sensitivity are presented. Section 5 presents a comprehensive analysis of potential solutions to the identified difficulties. Section 6 of the paper provides an in-depth analysis of the study's findings, including the derived conclusions, implications for industry and practical applications, identified limits, and suggestions for potential avenues of further research.

Theoretical background

Industry 4.0

The topic of Industry 4.0 is currently being extensively discussed across several industries. The aforementioned matter also has an impact on the iron and steel sectors. The phrase "Industry 4.0" was coined in 2011 as part of the German High Tech 2020 Strategy. The concept of "Industry 4.0" pertains to the forthcoming fourth industrial revolution that arises from future automated manufacturing endeavors [28]. The phrase "Industry 4.0" is widely used in European nations, particularly in Germany's industrial industry [29]. Industrial automation, cyber-physical systems, artificial intelligence, and the Internet of Services are the foundation of the concept known as "Industry 4.0." Four dimensions can explain the fundamental features of Industry 4.0: (1) vertical integration and intelligent production system throughout the whole value chain, (2) horizontal integration through modern trends across the overall value connections, (3) acceleration through advanced technologies. And (4) through-engineering across the full product's life cycle [14]. Vertical integration throughout the whole value chain and intelligent production manufacturing operation refers to the digitization and smart integration of the production facility through a cyber-physical production process, which may produce a flexible and dynamically strong production system by taking into account quick market changes and inventory levels. Vertical integration connects resources and goods in this system [30]. The smart sensor technology is employed to monitor the entire network in this case. Industry 4.0 envisions integrated networks of cyber-physical and business systems that add unparalleled process automation, adaptability, and operating excellence into manufacturing processes when it comes to horizontal integration. This technology generates optimal networks with high levels of flexibility and integrated transparency. Horizontal integration produces a dynamic manufacturing system that spans the full process chain, from procurement to delivery. The third crucial attribute is clever technology-assisted acceleration. Smart technology has a huge influence on industrial production processes [16]. The implementation of intelligent technology has the potential to enhance the efficiency of the manufacturing process through the reduction of production time and cost reduction. The integration of automation into the manufacturing process is a crucial requirement of Industry 4.0. The implementation of advanced technologies, such as sophisticated robots, artificial intelligence, and monitoring devices, has the potential to enhance the level of autonomy in the production process. The ultimate attribute of Industry 4.0 is referred to as comprehensive engineering over the entirety of the product's life cycle. This characteristic involves the intelligent amalgamation and digitization throughout the full life chain of the product, commencing from the procurement of raw materials and extending to the ultimate disposal stage [29]. The availability of data throughout the product's life cycle has the potential to foster the creation of more flexible production methods.

Technologies employed in Industry 4.0

Industry 4.0 illustrates the global technological revolution. Big data analytics (BDA), robots, simulation, the industrial internet of things, cyber-security, cloud computing, additive manufacturing, augmented reality, and machine learning are needed to integrate into Industry 4.0 [31]. Numerous businesses are embracing such production system technologies in preparation for Industry 4.0 adoption. BDA tools aid in the analysis of actual data to improve productivity and minimize uncertainty in the decision-making process [30]. The industrial production, pharmaceutical, chemical, and automobiles are just some of the many that benefit from this tool's ability to streamline and green their supply chains.

The autonomous robot is regarded as a crucial instrument in the context of Industry 4.0. The utilization of autonomous robots can provide businesses with advantages in scenarios where human employees face limitations or constraints in executing activities with enhanced precision [30]. About 14% of all operational industrial robots are added each year, and automation is constantly giving rise to new robot varieties that are more versatile and effective. Manufacturers of the future will likely employ both robots and humans to meet consumer demand, so they must adapt to this new reality [28].

Machines, people, and goods simulate a real-world manufacturing system [28]. It is used in technology simulation to optimize design, safety engineering to secure systems, and scientific modeling to visualize operational systems [32]. These days, 2D and 3D simulations are routinely used in the industrial sector to evaluate many different factors, including the length of a process's cycle, the comfort and ease of a design, and the efficiency [33]. The use of simulation in Industry 4.0 has the potential to lessen the occurrence of breakdowns in production as well as waste and extraneous materials.

IoT plays a major role in Industry 4.0 manufacturing. Due to the fact that all aspects of the internet are utilized in order to facilitate the manufacturing process, IoT has been dubbed the "industrial internet" [28]. IoT integrates virtual data for operational purposes to help manufacturing activities improve [34]. IoT software intelligently plans and controls machines.

The implementation of Industry 4.0 is impeded by a substantial obstacle in the form of cybersecurity. In the context of operating a business within the framework of Industry 4.0, the indispensability of connectivity and the adoption of a standardized communication protocol are evident. There is a pressing need for the development of safer, more sophisticated, and reliable frameworks that can effectively safeguard industrial manufacturing systems from the potential cyber security hazards posed to both machines and operators [30]. One of the most important steps toward "Industry 4.0" is connecting the physical environment to the digital data required for production optimization, planning, and quality control [35]. Cyber-physical systems aid in the union of digital and physical infrastructures. In the manufacturing sector, cyber-physical system-based smart vehicles are utilized for warehouse management, and data mining aids in route prediction [30].

Today's businesses rely largely on real-time data storage and analysis. Cloud computing was utilized in the fourth industrial revolution, or Industry 4.0, to store the enormous volumes of data being gathered in real time for use in the manufacturing process [36]. Connecting and sharing communication devices amongst businesses might be useful in a manufacturing facility. Connecting businesses worldwide through cloud computing makes digital production a reality [28].

Additive manufacturing technologies are employed to enhance efficiency and reduce the expenses associated with the production system. Industry 4.0 promotes the convergence of intelligent technologies and production systems. Additive manufacturing is considered a viable solution to meet the significant needs posed by the fourth industrial revolution [37]. With this method, factories can optimize the production of a small number of unique products. Manufacturing additives can also cut down on shipping times and inventory needs [28]. Additive manufacturing aids in meeting fluctuating consumer demands by permitting rapid iteration of product design. Several manufacturers today use additive manufacturing systems to swiftly meet rising client demand.

Augmented reality is a communication system that provides technological aid to various sectors through various channels of communication. Augmented reality enables businesses to obtain real-time feedback from customers, which can then be used to enhance working conditions and examine a variety of decisions [28]. For maintenance and repair tasks, augmented reality is particularly useful because it informs workers of procedures and provides guidance while they perform them.

The vast amounts of structured and unstructured data that a firm might at any given time acquire is known as big data. Machine learning is a developing computer-based technique that can extract meaningful information and the optimal choice from big data [38]. In production, machine learning monitors defects, detects flaws, and predicts future demands [39]. Many writers have demonstrated machine learning techniques for diverse uses. Qu et al. [40] compared vibration sensors and acoustic emissions to diagnose gearbox faults, whereas As a means of defect severity classification and origin localization, Zhou et al. [23] created a multilayer neural network architecture. Thus, machine learning is essential for defect analysis and process enhancement in manufacturing businesses.

Methods

Research design

Implementing Industry 4.0 in an existing company enterprise is a complex and multi-faceted subject. It is not possible to represent it with a single variable. In order to evaluate the challenges associated with the implementation of Industry 4.0, a comprehensive analysis employing a multi-criteria decision framework is necessary. The primary objectives of this study were to enhance comprehension of the present state and obstacles hindering the implementation of Industry 4.0 within Bangladesh's steel sector, employing an industrial survey methodology. A combination of literature study and insights from industry managers and academicians has led to the identification of numerous challenges associated with the implementation of Industry 4.0. The survey was attended by managers responsible for overseeing supply chains, operations, and information technology (IT). The novel BWM methodology was employed to evaluate the identified issues. The subsequent content provides an overview of the distinctive BWM-based Multiple Criteria Decision Making (MCDM) approach that has been developed. Following the identification and grading of the difficulties, a sensitivity analysis was conducted to assess the potential bias in the results. It is unwise to claim that a Multiple Criteria Decision Making (MCDM) situation is totally satisfactory without accomplishing sensitivity analysis [41].

There is an abundance of MCDM resources out there. The "Best Worst" MCDM tool, created by Professor Rezaei in 2015, is one of the most useful resources [42]. In comparison to methods such as the analytical hierarchy approach, this method is superior when trying to resolve an issue involving multiple criteria for reaching a decision (AHP). Compared to other methods and resources, this one has certain distinct benefits. By producing more reliable results than previous MCDM techniques and by requiring fewer pairwise comparison matrices to produce a better outcome, this method aids researchers and decision-makers in achieving more accurate results in a short time [43]. All of the aforementioned merits play a significant role in this study's decision to choose this particular MCDM platform.

The BWM literature has a strong foundation. This methodology has been applied by numerous researchers in a variety of fields. For instance, Abouhashem Abadi et al. [44] used BWM to study the development plan for medical tourism. BWM was utilized by Badri Ahmadi et al. [45] to assess the social sustainability of supply chains, while Guo and Zhao [36] used fuzzy-based BWM to solve the MCDM issue. Rezaei et al. [43] used the BWM to choose suppliers while merging traditional and environmental criteria. BWM was utilized by Torabi et al. [46] to create a framework for risk assessment. The selection of biomass technology [47], a study of how outside factors affect oil and gas distribution networks for sustainable development [48], the assessment of the advantages of eco-industrial parks [49], and other uses of BWM are a few others. The entire BWM process can be summed up as follows: [42]

Establishing the criteria for making decisions

A collection of criteria for choosing decisions (C1, C2, C3, C4……….Cn) that are required to guide decisions toward the study's purpose are established in this step.

Identifying the best criteria and the worst criteria

Without employing a comparison matrix, the selected decision-makers score the criteria from most important to least important. Instead of assigning a monetary value to the decision-making criterion, decision-makers might simply rank the criteria from most essential to least important.

Using a 1–9 point rating system, determining which criterion is superior to the others

The decision-makers determine the best-to-others vector. The rating scale displays which criterion is more significant. On the rating scale, 1 signifies the best criterion is equal to the other. The best criterion is substantially better than the other criterion at 9. This is the final best-to-others (BO) vector of criteria:

$$\mathrm{A_B} = (\mathrm{a_{B1}}, \mathrm{a_{B2}}, \mathrm{a_{B3}}, \mathrm{a_{B4}}, \ldots\ldots\ldots a_{Bn})$$

where $\mathrm{a_{Bj}}$ represents the preference of best criterion over criterion *j*. Hence, $a_{BB}=1$.

Preference of all other criteria over the worst using just a 1–9 point rating scale

The next phase is for decision makers to establish the others-to-worst vector that emerged from the previous steps. Therefore, the following notation can be used to depict the resulting others-to-worst vector:

$$\mathrm{A}_W = (\mathrm{a_{1W}}, \mathrm{a_{2W}}, \mathrm{a_{3W}}, \mathrm{a_4}, \ldots\ldots\ldots a_{nW})$$

where $\mathrm{a_{jW}}$ indicates the preference of the j criteria over the worst criteria and $\mathrm{a_{WW}}=1$.

Computed the optimal weights (w_1, w_2, w_3……………., w_n)

If the prerequisites are to be met, then the ideal weights of the criteria are for each pair of $\mathrm{w_B}/\mathrm{w_j}$ and $\mathrm{w_j}/\mathrm{w_W}$ the best possible solution is where $\mathrm{w_B}/\mathrm{w_j}=\mathrm{a_{Bj}}$ and $\mathrm{w_j}/\mathrm{w_W}=\mathrm{a_{jW.}}$ Hence, to obtain the best possible solution, the maximum should be minimized among the set of {$|w_B$- a_{Bj} |, $|w_j$- a_{jW} $w_W|$}, and the problem can be expressed as follows:

$$\min, \max_{\mathrm{j}}\left\{\left|W_B - a_{Bj}W_j\right|, \left|W_j - a_{jW}w_W\right|\right\}$$

subject to

$$\sum wj = 1 \tag{1}$$

$$w_j \geq 0 \text{ for all } j$$

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

$$\min, \xi^{L}$$

Subject to

$$\left|W_B - a_{Bj}W_j\right| \le \xi^{L} \text{ for all } j$$

$$\left|W_j - a_{jW}W_W\right| \le \xi^{L} \text{ for all } j \tag{2}$$

$$\sum wj = 1$$

$$w_j \ge 0 \text{ for all } j$$

By solving the aforementioned linear programming issue, the optimal weights (w1, w2, w3, w4,, wn) and ξ^{L} can be derived. ξ^{L} represents the uniformity of the comparison matrices. The system is more consistent, and hence comparisons are more reliable if is closer to zero, and vice versa.

By solving the aforementioned LP problem, we may determine the ideal weights ($\mathbf{w_1}$, $\mathbf{w_2}$, $\mathbf{w_3}$**................,** $\mathbf{w_n}$) and L. The symbol ξ^{L} denotes that the comparison matrices are stable. If the value of L is near 0, the system is consistent and the comparisons may be trusted, and vice versa.

By employing this methodology, individuals can expeditiously and precisely assess the comparative significance of each issue and ascertain the ones that warrant prioritization. Therefore, it will facilitate our ability to surmount these challenges through diligent effort within a condensed temporal context.

Results and discussion

Industry visit/survey

First, information regarding the existing state of Industry 4.0 installations has been gathered through visits to four prominent Bangladeshi steel companies. All four steel mills were welcoming, allowing us to tour their facilities and gather all the information we needed from knowledgeable workers. Information about these four sectors, including products, data providers, etc., can be found in Table 1 below.

The current status of Industry 4.0 in Bangladesh's steel industry was a primary motivation for this research. In order to achieve this goal, information relevant to all aspects of Industry 4.0 was gathered from the aforementioned sectors. In order to acquire this information, the authors made sure of a few key things across the board. The information about each element was collected based on some key features of that element that are shown in Table 2.

Investigating the challenges of implementation of Industry 4.0

From the aforementioned data on current Industry 4.0 installations, it is evident that all of these plants have less than fifty percent of the anticipated Industry 4.0 installations. The authors have studied the causes of this using a questionnaire. The industrial specialists were presented with a total of 12 problems, as illustrated in Table 3. These

Table 1 Information about four renowned steel industries for the survey

Name of company	Description of company	Industrial managers (respondents)	Areas of expertise	Types of products
Company A	It is one of the biggest companies in Bangladesh that makes steel. In 2020, it was able to make 7.60 million tonnes per year. It has shipped 25000 tonnes of billet to China. Its annual revenue is BDT13.27 billion in 2019 which has been decreased to BDT9.41 billion in 2020 due to COVID-19 pandemic effect. [50]	Quality control engineer	Production and control	Billet, Deformed bar, Plain Bar
Company B	It is one of the prestigious and biggest steel making companies in Bangladesh. It was founded in 1952. The company generates $800 million revenue. In 2016, sales of MS products went over one million M. ton for the first time in the history of BSRM Group [51]	Assistant Manager, Quality Control and Management	Quality control and management	Xtreme 500 W, Deformed bar, Plain Bar, Billet etc
Company C	This is South-East Asia's largest multi-diversified steel producing unit. In 2015, it erected the country's first and only Electric Arc Furnace (EAF). Each year, 1.4 million metric tons of high-quality graded hot-rolled steel (TMT) rebar can be made at re-rolling mill [52]	Manager-Supply Chain Management	Supply Chain Management	TMT 500 W and 550 W, Double coated corrugated iron sheet
Company D	Since its beginning in 1984, it has been focused on producing reinforced steel and deformed bars on automated rolling mills employing cutting-edge European POMINI technology. Their cutting-edge plant can generate a whopping 8 lac metric tons of product each year [53]	Assistant Engineer-Rolling workshop	Rolling and rod making	PREMIUM B500DWR 80G, B500CWR

Table 2 Average current installation of elements of Industry 4.0 in four industries

Key elements of Industry 4.0	A	B	C	D	Average
Robotics ➢ **Robotic arm application** ➢ **Robots in steel melting and processing** ➢ **Robots in material handling**	70%	60%	65%	65%	65.00%
Cyber-physical system **(CPS)** ➢ **Combination and coordination between physical and computational elements** ➢ **Computer-based algorithms** ➢ **Digital and smart embedded system**	75%	80%	70%	70%	73.75%
Cloud technologies ➢ **Remote database** ➢ **Online servers** ➢ **Storage, backup, and data retrieval**	85%	60%	60%	70%	68.75%
Simulation ➢ **Modelling and evaluation tool** ➢ **Designs of complex systems** ➢ **Reliable estimates of system's performance**	75%	50%	65%	60%	62.50%
Big data analysis and artificial intelligence **(AI)** ➢ **Ability to analyze large amounts of data** ➢ **Automatic learning systems** ➢ **Intelligent computer systems**	20%	30%	15%	20%	21.25%
Industrial Internet of things (IIoT) ➢ **High-speed internet** ➢ **Building a trusted cyber-physical communication** [7] ➢ **Enables all data online instantly**	25%	50%	45%	30%	37.50%
Cyber security ➢ **cyber-attacks, system vulnerabilities** ➢ **cyber threats, risks, and countermeasures** ➢ **Transfer data from and to unauthorized devices**	40%	50%	45%	40%	43.75%
Sensors and actuators ➢ **Different parameter sensors** ➢ **Automatic feedback system** ➢ **Fast actuator action**	80%	80%	85%	80%	81.25%
Augmented Reality (AR) ➢ **Supporting technicians in their real working environment** ➢ **Visualize step-by-step procedures of the task** ➢ **Real-time remote assistance systems**	0%	0%	0%	0%	0.00%
Radio frequency identification **(RFID)** ➢ **Product** tracking **with RFID** ➢ **Asset** manageme**nt** and **Tracking** ➢ **Personnel** tracki**ng**	15%	10%	15%	10%	12.50%
Horizontal and vertical integration ➢ **Integration among different departments within** the **industry** ➢ **Coordination with other companies/competitors**	5%	25%	35%	20%	21.25%
Additive manufacturing **(3D** printing) ➢ **Complex design solutions by 3D printing**	0%	0%	0%	0%	0.00%

respondents were asked for their input on the refinement of the tasks by providing a "yes" (affirmative), somehow yes, or "no" response (negative). A predetermined threshold is decided upon, and any challenge that exceeds or reaches this threshold after analysis is retained; otherwise, it is discarded. Concurrently, an adequate literature review was conducted to identify the obstacles. After conducting a thorough analysis, a total of nine obstacles were identified as significant obstacles to the adoption of Industry 4.0.

Table 3 Proposed challenges to implement Industry 4.0

SL No	Proposed challenges	Obviously yes	Somehow yes	No
01	Poor IT infrastructure	B, C	A	D
02	High capital investment	A, B, D	C	
03	Security risk of data	B, C	A, D	
04	Risk of job loss	B, C, D	A	
05	Insufficient strategy toward Industry 4.0	A, B, C, D		
06	Lack of knowledge about Industry 4.0	A, B, C, D		
07	Difficulty in reconfiguring of production pattern	A, B, D	C	
08	Lack of skilled management team	A, B, D		C
09	Imbalanced connectivity among manufacturer	A	C, D	B
10	Environmental side-effects		A	B, C, D
11	Lack of government support	B, D	A, C	
12	Unwillingness of company owners	A	C	B, D

According to the experts' preferences, 9 of the 12 difficulties were chosen for examination using the best–worst technique, and three challenges were excluded, including imbalanced connectivity among manufacturers, environmental side effects, and unwillingness of firm owners. Table 4 lists the selected nine problems, along with their descriptions and literary background.

Application of best–worst method to rank the above challenges

Currently, there are nine difficulties that have been identified. The utilization of the best–worst method (BWM) was a crucial aspect of this research, as it facilitated the ranking of various issues, enabling a comprehensive assessment of their relative significance. In order to address this requirement, we collected input data for BWM by consulting specialists from both business and academia, thereby ensuring the research's high quality. Initially, data was collected from a panel of four specialists in the field of steel mill operations. Subsequently, data was collected from scholars. The academic specialists were selected from prominent universities in Bangladesh and are presently focused on the fourth industrial revolution and its implementation. All the experts possess the academic rank of assistant professor or above. Additional information regarding them can be found in Table 5.

In the following section, the application of best worst method has been shown.

Selecting the best and worst challenge

In this step, all nine experts (four from industry and five from academics) selected the best and worst challenges that are listed in Table 6.

Determination of the best criterion over the other criteria using 1–9 point

In this stage, decision-makers assess the best-to-others vector produced. If one criterion is given a higher score than the others, it means that it is more important. According to the rating scale, the best criterion is on par with the other criterion. With respect to the rating scale 9 displayed in Table 7, the best criterion is clearly favored above the other criterion.

Table 4 Finally selected nine challenges

Serial	Challenges	Reference	Brief descriptions of challenge
CHL-1	Poor IT infrastructure	Varghese and Tandur, 2014 [54]; Zhou et al. 2016 [55]	Inadequate data and technology infrastructure hinders industrial firms' efforts to adopt Industry 4.0
CHL-2	High capital investment	Zhou et al. 2016 [55]; Koch et al. 2014 [56]	Industry 4.0 implementation process needs a huge initial capital investment
CHL-3	Security risk of data	Gölzer et al. 2015 [57]; Constantine, 2014; Zhou et al. 2016 [58]	Inadequate data protection measures in place during Industry 4.0 rollout for steel producers due to lack of security systems
CHL-4	Risk of Job loss	Zhou et al. 2016 [55]; Waibel et al. 2017 [20]; Zezulka et al. 2016 [59]	Industry 4.0 implementation process requires a huge replacement of human with autonomous robot and automation which may leave some workers jobless
CHL-5	Insufficient strategy towards Industry 4.0	Deloitte, 2015 [14]; Zhou et al. 2016 [55]	The manufacturing sector is slow to adopt Industry 4.0 due to a lack of a solid and dynamic strategic plan for doing so
CHL-6	Lack of knowledge about Industry 4.0	M. A. Islam et al. 2018 [60]	Many working people including managers still do not have knowledge about Industry 4.0
CHL-7	Lack of government support	M. A. Islam et al. 2018 [60]	Lack of governmental policy to implement Industry 4.0 throughout the country
CHL-8	Lack of skilled management team	Hecklau et al. 2016 [61]; Deloitte, 2015 [14]	Inability to field a management team with the necessary expertise to develop and carry out the implementation of Industry 4.0's newly conceived and pioneering production and business models
CHL-9	Difficulty in reconfiguration of production pattern	Lee et al. 2015 [19]; Lu, 2017; Qin et al., 2016 [62]; Sanders et al. 2016 [63]	Industrial firms lack the experience and resources to adopt Industry 4.0, hindering the transformation

Table 5 Details of experts from top universities of Bangladesh

Name	Department	University	Area of expertise
Expert-1 (E1)	Mechanical Engineering (ME)	Chittagong University of Engineering and Technology (CUET)	Industry 4.0, Automation
Expert-2 (E2)	Industrial and Production Engineering (IPE)	Bangladesh University of Engineering and Technology (BUET)	Industrial automation and robotics
Expert-3 (E3)	Industrial and Production Engineering (IPE)	Rajshahi University of Engineering and Technology (RUET)	Supply chain management
Expert-4 (E4)	Industrial and Management Engineering (IEM)	Khulna University of Engineering and Technology (KUET)	Operation research management
Expert-5 (E5)	Mechatronics and Industrial Engineering (MIE)	Chittagong University of Engineering and Technology (CUET)	Operations Management and supply chain

Determination of the preference of all the other criteria over the worst criterion using 1–9 point rating scale

Decision-makers evaluate the resulting others to the worst vector in this step. The rating

Table 6 Best and worst challenge according to nine experts

Serial	Challenges	Best challenge	Worst challenge
CHL-1	Poor IT infrastructure	E3	
CHL-2	High Capital investment	A, C, D	E2
CHL-3	Security risk of Data		A, E1, E4
CHL-4	Risk of Job loss	B	D, E3
CHL-5	Insufficient strategy toward Industry 4.0	E2	C
CHL-6	Lack of knowledge about Industry 4.0	E4	B
CHL-7	Lack of govt. support		E5
CHL-8	Lack of skilled management team	E1	
CHL-9	Difficulty in reconfiguration of production pattern	E5	

Table 7 Selecting the best to others vector

Best to others	CHL-1	CHL-2	CHL-3	CHL-4	CHL-5	CHL-6	CHL-7	CHL-8	CHL-9
A	7	1	5	6	4	5	7	3	3
B	5	4	4	1	6	8	3	7	4
C	2	1	2	5	3	6	7	2	6
D	4	1	6	9	2	3	7	8	5
E1	3	2	3	6	3	4	5	1	3
E2	7	9	8	2	1	3	4	5	6
E3	1	4	2	6	4	5	5	4	4
E4	3	8	1	7	1	1	7	2	3
E5	3	3	9	7	2	6	9	4	1

Table 8 Selecting others to worst vector

Others to the worst	CHL-1	CHL-2	CHL-3	CHL-4	CHL-5	CHL-6	CHL-7	CHL-8	CHL-9
A	2	7	1	2	4	6	4	6	5
B	3	4	6	8	3	1	5	4	5
C	6	7	5	5	1	5	6	3	4
D	6	9	4	1	8	7	3	2	5
E1	4	4	1	2	2	4	2	7	5
E2	3	1	2	8	9	7	6	5	4
E3	8	6	4	1	5	4	3	2	4
E4	3	9	1	5	6	8	3	8	6
E5	6	4	2	3	8	3	1	2	9

scale indicates which criterion is preferred over the others. The best criterion is equally preferable to the other criterion, according to the rating scale 1. The best criterion is significantly preferred above the other criterion, according to the rating scale 9. Table 8 shows the other worst vectors according to all experts.

Computation of the optimal weights (w_1, w_2, w_3, w_4,….. w_n)

The optimal weights (w_1, w_2, w_3, w_4,….. w_n) and ξ^L can be obtained by solving the linear programming (LP) problem through BMW solver as stated in chapter 4. The notation ξ^L

indicates the consistency of the comparison matrices. If the value of ξ^L is closer to zero, it indicates the system is more consistence and hence reliable comparison, and vice versa. Table 9 indicates the calculated value of ξ^L for nine calculations. Here the average value of ξ^L is 0.0781 which is close to zero, it identifies the system as being more consistent, making comparisons between systems more accurate. All the optimal weights of nine experts have been listed in Table 10.

Discussion of obtained results

The primary objective of this research was to assess the challenges that are inherent in the implementation of Industry 4.0 within the steel sector of Bangladesh. The ultimate ranking is evident in the aforementioned table. We compiled this list with the assistance of nine experts from the academic and business communities. Following an extensive examination, it was ascertained that challenge-2 (high capital investment) posed the greatest and most formidable obstacle, carrying a weight of 0.1533. It demonstrates that integrating all of the many aspects of Industry 4.0 will require a significant financial investment, which the steel businesses are unwilling to make. Because of this, business owners view it as a significant barrier to their success. Subsequently, challenge-5, which pertains to an insufficient strategy for Industry 4.0, obtained a weight of 0.1391, placing it as the second most significant challenge. The analysis indicates that the strategic planning of steel makers for Industry 4.0 is significantly insufficient. Consequently, the formulation of a meticulously planned approach to attain this transformative change is imperative. Subsequently, challenge-1 (poor IT infrastructure), challenge-4 (lack of skilled management team), and challenge-9 (difficulty in reconfiguring production pattern) were ranked as the third, fourth, and fifth most significant challenges, respectively, with comparable weights of 0.1197, 0.1190, and 0.1176. This suggests that the three obstacles mentioned hold equal significance in the execution of Industry 4.0. It is accurate to assert that our organizations currently possess insufficient information and technological infrastructure to effectively apply the comprehensive suite of Industry 4.0 technologies. Furthermore, the absence of proficient management staff is a substantial obstacle. The presence of competent and diligent professionals who possess a high level of intelligence regarding Industry 4.0 is of utmost importance. In addition to the aforementioned point, it is necessary to consider the reconfiguration of the manufacturing pattern. The steel facilities exhibit a methodical production pattern. Consequently, individuals encounter significant challenges in reconfiguring established patterns and implementing novel frameworks.

Subsequently, the sixth problem denoted as challenge-6 (lack of knowledge about Industry 4.0), and is assigned a weight of 0.1067. Undoubtedly, a deficiency of information poses a significant barrier to the successful adoption of Industry 4.0.

Subsequently, challenge-4 (risk of job loss) obtained a weight of 0.964, positioning it in the seventh rank, as depicted in Fig. 1. The implementation phase of Industry 4.0, characterized by heightened automation in production, presents a notable obstacle in

Table 9 Value of ξ^L for nine different data analyses

Expert	A	B	C	D	E1	E2	E3	E4	E5	Average
Value of ξ^L	0.0774	0.0875	0.106	0.0545	0.0597	0.0827	0.0675	0.0695	0.0975	0.0781

Table 10 Final ranking of challenges with weights

Experts	CHL-1	CHL-2	CHL-3	CHL-4	CHL-5	CHL-6	CHL-7	CHL-8	CHL-9
A	0.061	0.299	0.035	0.071	0.106	0.085	0.061	0.141	0.141
B	0.081	0.101	0.101	0.324	0.068	0.030	0.135	0.058	0.101
C	0.173	0.217	0.173	0.069	0.030	0.058	0.049	0.173	0.058
D	0.096	0.315	0.064	0.027	0.192	0.128	0.055	0.048	0.077
E1	0.113	0.170	0.044	0.057	0.113	0.085	0.068	0.236	0.113
E2	0.055	0.027	0.048	0.192	0.315	0.128	0.096	0.077	0.064
E3	0.274	0.091	0.183	0.030	0.091	0.073	0.073	0.091	0.091
E4	0.104	0.039	0.035	0.045	0.157	0.313	0.045	0.157	0.104
E5	0.120	0.120	0.040	0.052	0.180	0.060	0.029	0.090	0.309
Total	1.077	1.379	0.723	0.867	1.252	0.96	0.611	1.071	1.058
Percentage Total	11.97%	**15.33%**	8.04%	9.64%	13.91%	10.67%	**6.79%**	11.90%	11.76%
Final Ranking	3	**1**	8	7	2	6	**9**	4	5

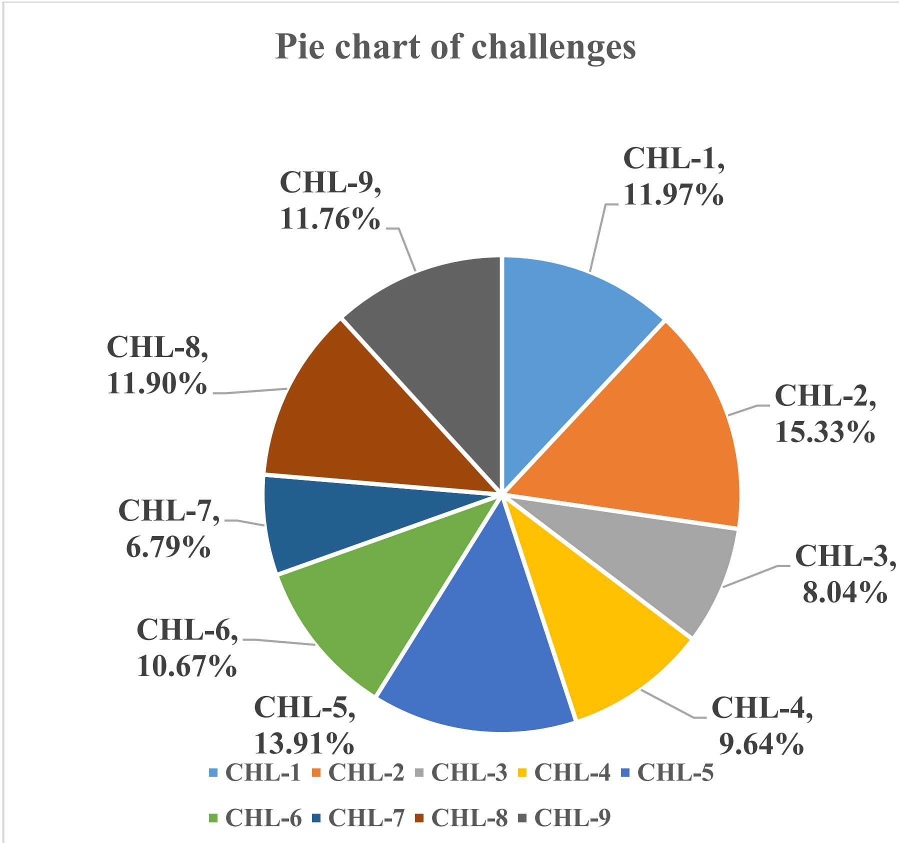

Fig. 1 Pie chart of weight of challenges

the form of potential job displacement for a substantial number of workers. Nevertheless, due to its seventh ranking, its influence on the implementation period is minimal. The occurrence of job losses can be mitigated by the acquisition of skills and training by individuals. On the contrary, these individuals provide significant value since they contribute to enhancing the manufacturing process and achieving the objectives of Industry 4.0 for organizations.

Subsequently, challenge-3, which pertains to the risk of data security, was identified in the ninth place. The preservation of data security is of utmost importance due to the substantial volume of data generated inside cyber-physical systems (CPS) and the presence of confidential information within every organization. It is a well-acknowledged fact that in the contemporary era of advanced security systems, data may be securely kept and retrieved through the use of appropriate security measures. Consequently, these difficulties are considered peripheral by experts. Ultimately, challenge-7, which pertains to the absence of governmental support, was determined to be the least significant obstacle, carrying a weight of 0.679. This implies that obtaining governmental assistance for the implementation of Industry 4.0 is no longer a concern. Moreover, the government of Bangladesh is highly interested in the widespread adoption of Industry 4.0 across many industries. Consequently, scholars regard this obstacle as rather insignificant.

Based on the aforementioned findings, it is apparent that the primary obstacle to implementing Industry 4.0 is the large capital expenditure required. Bangladesh is classified as both a third-world and developing country. The finance for technological change is a crucial factor for both industry owners and governments. Under such circumstances, developed nations assume a crucial role in providing financial support for various Industry 4.0 implementation initiatives.

Comparison with other studies

A similar kind of research was performed by Moktadir et al. The leather sector of Bangladesh assesses that framework using best–worst method (BWM). The study revealed that the main obstacle to implementing Industry 4.0 in the Bangladeshi leather-based industry is the absence of technological infrastructure. On the other hand, the challenges related to environmental side-effects are less significant in hindering the implementation of Industry 4.0 [64]. Another study was performed by Wankhede et al. The study delineates thirty-six obstacles associated with the implementation of Industry 4.0 in the Indian automobile industry, classifying them into four distinct categories. The priority order consists of establishing a real-time connection between physical production and the digital factory, as well as implementing context-adaptive and autonomous systems [65]. Then research done by Mostafaeipour et al. reveals the obstacles hindering the progress of solar energy projects in Iran, with a specific emphasis on the Alborz Province. The impediments are categorized into technical, legal, economic, social, and expert support classifications. The report identifies economic reasons, such as volatile economic conditions and trade bans, as the main obstacles. The domestic demand for renewable energy projects is limited as a result of the substantial risks involved [66].

The aforementioned studies demonstrate the widespread utilization of the BWM approach in evaluating the obstacles faced in numerous domains, particularly in the implementation of Industry 4.0. The findings of this study also corroborate that pattern. Here, It was determined that "High Capital Investment" was the most significant barrier, while "Lack of Government Support" was the least significant.

Sensitivity analysis

It is necessary to analyze the biases in the acquired findings while using the multi-criteria decision-making (MCDM) technique. As a result, some researchers proposed performing a sensitivity study for the MCDM technique by adjusting the weights of the top-ranked criteria between 0.1 and 0.9 and seeing the effect on other criteria. The results of this sensitivity study give those responsible for making decisions the confidence that the findings reached are more reliable or not.

The weight of "high capital investment (CHL-2)" has been varied in this study from 0.1 to 0.9, and the influence on other selected difficulties for adopting Industry 4.0 has been investigated. When the weight of the "high capital investment (CHL-2)" problem is modified from 0.1 to 0.9, The relative importance of each challenge to implementing Industry 4.0 is summarized in Table 11. As a result, Table 12 displays the order in which the difficulties are ranked.

Concurrently, the magnitudes of other challenges are adjusted. The table presents a rating of the specified challenges for the implementation of Industry 4.0, based on

Table 11 Weights of the challenges sensitivity analysis

Selected challenges		Values of preference weights for the selected challenges of Industry 4.0								
	Normal (0.1533)	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
CHL-1	0.1197	0.1272	0.1131	0.0989	0.0848	0.0707	0.0565	0.0424	0.0283	0.0141
CHL-2	0.1533	0.1000	0.2000	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000
CHL-3	0.0804	0.0854	0.0759	0.0664	0.0569	0.0474	0.0380	0.0285	0.0190	0.0095
CHL-4	0.0964	0.1024	0.0910	0.0797	0.0683	0.0569	0.0455	0.0341	0.0228	0.0114
CHL-5	0.1391	0.1479	0.1315	0.1150	0.0986	0.0822	0.0657	0.0493	0.0329	0.0164
CHL-6	0.1067	0.1134	0.1008	0.0882	0.0756	0.0630	0.0504	0.0378	0.0252	0.0126
CHL-7	0.0679	0.0722	0.0642	0.0561	0.0481	0.0401	0.0321	0.0241	0.0160	0.0080
CHL-8	0.1190	0.1265	0.1125	0.0984	0.0843	0.0703	0.0562	0.0422	0.0281	0.0141
CHL-9	0.1176	0.1250	0.1111	0.0972	0.0833	0.0694	0.0555	0.0417	0.0278	0.0139
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 12 Ranking of the selected challenges through sensitivity analysis

Selected challenges		Ranking of challenges								
	Normal (0.1533)	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
CHL-1	3	2	3	3	3	3	3	3	3	3
CHL-2	1	7	1	1	1	1	1	1	1	1
CHL-3	8	8	8	8	8	8	7	8	8	8
CHL-4	7	6	7	7	7	7	7	7	7	7
CHL-5	2	1	2	2	2	2	2	2	2	2
CHL-6	6	5	6	6	6	6	4	6	6	6
CHL-7	9	9	9	9	9	9	8	9	9	9
CHL-8	4	3	4	4	4	4	3	4	4	4
CHL-9	5	4	5	5	5	5	3	5	5	5

sensitivity analysis. Table 11, Figs. 2 and 3 present the results of the sensitivity analysis, revealing that the issue labeled as "high capital investment (CHL-2)" consistently obtains the highest ranking. Conversely, the challenge denoted as "lack of government support (CHL-7)" consistently receives the lowest ranking. Figures 2 and 3 depict the alterations in weight and rankings that transpired throughout the sensitivity testing. Therefore, sensitivity analysis provides evidence to support the assertion that outcomes derived from the best–worst method (BWM) exhibit consistency, lack bias, and possess a higher degree of reliability.

Proposed solutions to the challenges

The primary objectives of this research encompassed the identification of impediments and barriers encountered during the implementation of Industry 4.0, along with the exploration of potential solutions to overcome these difficulties. The preceding steps involved the identification of difficulties and their respective relevance, specifically in terms of ranking. This process was carried out using data provided by a panel of nine experts from both business and academia. In the subsequent part, we will identify potential solutions to the aforementioned challenges by incorporating insights from industry

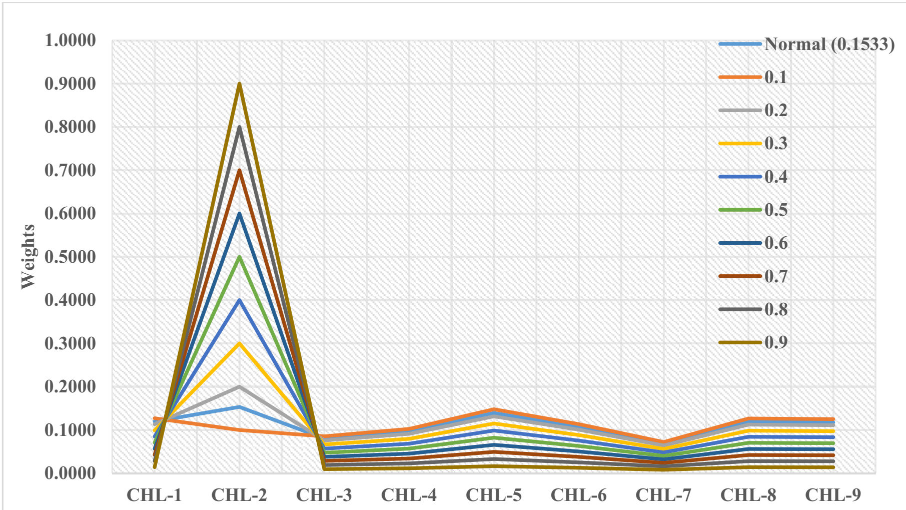

Fig. 2 During the sensitivity analysis, the weights of the challenges for implementing Industry 4.0

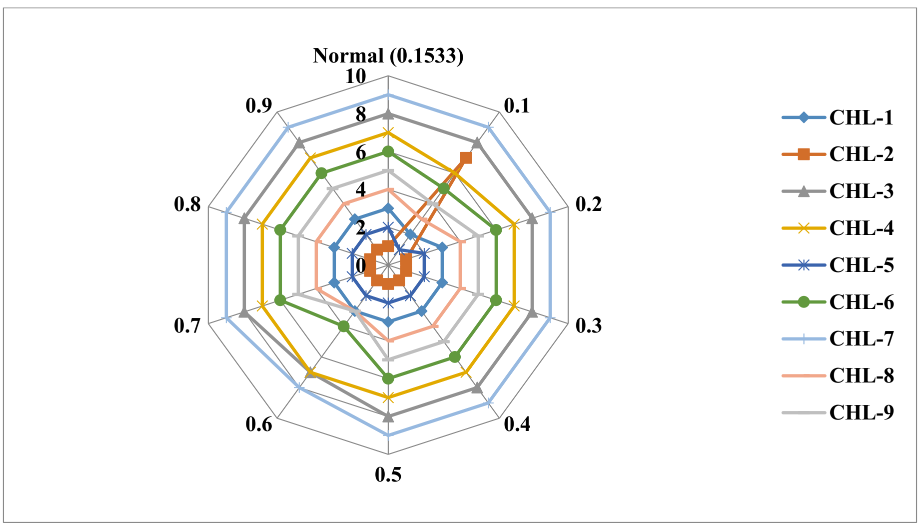

Fig. 3 Ranking of the challenges using sensitivity analysis

and academic experts. In addition to this, the author has extensively drawn upon previous research and potentially exhaustively utilized all accessible resources to succinctly outline the proposed answers.

Solution to the CHL-1 (poor IT infrastructure)

Information technology (IT) development is very important for implementing Industry 4.0 in any sector. To improve the IT infrastructure following ways can be done:

i. Incorporating cloud computing into one's company

The term "cloud computing" is frequently used, and the concept is sound now that it has been implemented and thoroughly verified over time. Keeping your data on a server outside of one's physical area can help us optimize one's business by allowing us to store more data and send files at lightning speeds. There are a variety of cloud storage and computing solutions available, including a Microsoft Azure Cloud Partner, among others. Cloud solutions can aid in the modernization of a company's IT infrastructure.

ii. Improving the site's security

Maintaining the robust infrastructure of one's digital presence also necessitates site security. The correct plug-ins can help secure user information, site uptime, and data loss by making the site less vulnerable to malware or DDOS attacks. Because many sites will choose this option, adding SSL and HTTPS protection is required. Similarly, concealing admin data is crucial to keep unauthorized visitors out, as is regularly updating your plug-ins to avoid any security flaws. Updating your site's security is a great way to keep things running smoothly and safely.

iii. Taking into account the infrastructure's age

Additionally, this presents an opportune chance to evaluate the effectiveness of one's existing infrastructure. Although Windows XP and Vista are considered to be competent operating systems, they are not adequately equipped to handle the demands of modern processing power and advanced functionalities. Furthermore, they lack the necessary updates to meet current security standards. This analysis aims to assess the existing infrastructure and generate a comprehensive inventory of the most pressing upgrading requirements. Subsequently, a systematic approach will be employed to identify areas of deficiency and areas of accomplishment, establishing a comprehensive understanding of our strengths and weaknesses.

iv. Increasing the server's capabilities

If any company is lacking in network capability, adding more servers to the business operations will allow them to vastly improve in this area. Their business server is probably also old, even if they are not aware of it. Unlike towers, laptops, or even routers, this is something that is rarely noticed since it is rarely seen. Improving existing servers can assist in strengthening any network, allowing us to store more data and process it faster. It's also a good idea to expand or strengthen current IT infrastructure servers so that they won't experience any downtime if one goes down.

v. Making more storage space

It could potentially be a hardware issue that any organization is experiencing. Because IT security may be affected by a lack of storage space, boosting hard disk size and capabilities is a good idea. Including a variety of alternate storage solutions, such as flash drives for modest storage needs but mostly replacing computer drives, is also recommended. Returning to cloud computing, cloud storage companies can provide enhanced data storage options without requiring physical space or requiring hardware updates. This will prevent hard drivers from being overloaded.

vi. Creating system backups

It's recommended to make some big, sweeping backups for our systems using some of the hardware and software enhancements we've seen so far. This could entail mirroring the operating system on computers and partitioning drives to create full backups, or duplicating files on our hard drives and/or cloud storage, but the point is to always have a backup strategy. One never knows if an electricity outage will derail a months-long project or if downtime will result in data loss, but the point is that without backups, one may find themselves frightened with no answers, which is why one should back up his or her system.

vii. Educating whole team on safer IT practices

We now have enough information to determine where to begin, but the journey does not end there. From this point forward, one must be dedicated to educating their staff as well. Employees that are smarter are better employees, so if one can help pass on what they've learned, IT infrastructure can gradually develop. The simplest method to assist your staff with IT education is to teach them how to update their passwords to make them stronger. Anyone with administrative privileges should make this a top priority. Other suggestions include not sharing sensitive information and not utilizing work IT utilities for personal use.

Solution to the CHL-2 (high capital investment)

Considerable investments are being made in the initiatives related to Industry 4.0. The establishment of a transformational organization requires strategic and deliberate allocation of resources towards technical investments. In order to maintain their competitive advantage, organizations must prioritize innovation and strategic investment. Quantitative and qualitative analysis are essential components in evaluating substantial expenditures, encompassing the incorporation of Industry 4.0 technologies. The analysis takes into account both immediate and future expenses, benefits, and the overall financial viability of the enterprise.

Businesses win a unique chance to boost revenue and cut costs. Industry 4.0's improved connectivity and automation allow organizations to acquire and analyze data from partners, suppliers, collaborators, end-users, and end-customers to speed up and tailor processes to generate higher-quality, lower-cost output. Connectivity and automation can add value to products and services, allowing companies to create new market offerings.

To evaluate an investment, one must first grasp the organization's strategic position and competencies to identify gaps. Knowing strategic objectives helps align subsequent discussions and decisions about how to achieve them. Understanding that businesses have different opportunities and challenges to adopting I4.0 principles. The government can handle low-interest loans to fix this. Strong political and economic incentives, the right investment in skills and training, and enhanced tools that simplify execution will all speed up acceptance. JICA, ADP, and other foreign investments can solve this problem.

Solution to the CHL-3 (security risk of data)

Despite its lower level of security, the manufacturing sector is the second most targeted industry in terms of cyber-attacks. Similar to other networks, smart factories are susceptible to attacks through the exploitation of vulnerabilities, the introduction of malware, denial of service (DoS) attacks, device hacking, and various other methods. The expanded attack surface of the intelligent factory poses challenges for manufacturers in terms of detecting and defending against cyberattacks. The dangers associated with the Internet of Things (IoT) have witnessed a significant expansion, particularly in the context of the Industrial Internet of Things (IIoT), and can potentially lead to severe physical repercussions. The increasing deployment of networked systems necessitates the adoption of a dedicated approach to safeguarding intellectual property against cyberattacks. The concept of risk-based manufacturing security involves the alignment of defensive tactics with the criticality of business operations. It is imperative to ensure the correct real-time inventory of all operational technology (OT) assets.

i. As an integrated defense approach across all attack surfaces, combine the best of IT and OT.
ii. Locate and upgrade out-of-date infrastructure, unpatched security holes, and unprotected data stores.
iii. When deploying new connected systems, start with security in mind.
iv. Maintaining awareness of potential threats is made easier by continuous vulnerability assessments with risk-based prioritizations.
v. Confirm that technology vendors and linked device makers are committed to frequent security and software patching and audits.

Solution to the CHL-4 (risk of job loss)

The advent of intelligent machines and devices has brought out numerous advantages since advancements in technology have made the development and utilization of novel innovations increasingly cost-effective and easily attainable. Nevertheless, the implementation of automation has the potential to lead to job displacement. Based on a recent analysis by McKinsey, it is projected that a significant number of persons, predominantly lacking specialized skills, will experience job displacement due to the implementation of automation in the manufacturing sector during the past few decades. The impending Fourth Industrial Revolution is poised to exert a significant influence on nearly all facets of the labor market, with particular emphasis on the control and automation systems sector. The integration of robots, artificial intelligence (AI), smart systems, and automation across several industries presents significant opportunities, however, it is crucial to adequately prepare for the resulting changes in the labor market. It is imperative that all personnel undergo comprehensive training in order to effectively utilize emerging technologies. It is advisable for businesses to actively participate in staff training initiatives in order to facilitate the seamless integration of new systems and technology into the workplace when required, while also alleviating employees' concerns around potential changes. In order to maintain relevance and effectively respond to forthcoming advancements, it is imperative to engage in continuous learning.

Solution to the CHL-5 (insufficient strategy towards Industry 4.0)

The findings of this study describe seven essential recommendations that firms may use to establish an Industry 4.0 strategy and increase their chances of success in this new digital environment.

1) Plan the scope of your firm and make sure your objectives are in line with the overall strategy. Clearly identify your objectives and prioritize your actions based on enhancing the efficiency of your operations, optimizing your value chain, and assessing the feasibility of developing new business models.
2) Create a work atmosphere that encourages an open mindset that values learning, change, and experimentation.
3) Define the skills that need to be developed, both internally and with the help of outside vendors.
4) Recruit and manage talent, with a focus on diverse teams and the ability to leverage data analysis into a competitive advantage.
5) To begin building the best network of partners, choose a group of providers with proven technology.
6) Develop an ecosystem mindset and hone your network management skills.
7) Begin with pilot initiatives, then validate your findings and systematize your learning procedures.

Solution to the CHL-6 (lack of knowledge about Industry 4.0)

Disruptive technologies, including robotics, the Internet of Things (IoT), and smart machinery, are poised to supplant a diverse array of occupations, primarily those characterized by repetitive tasks and physical labor. There exists a significant and urgent demand for those employed in the industrial sector, including both workers and managers, to actively pursue the acquisition of novel theoretical knowledge and practical skills. Based on a recent analysis by McKinsey [67], a significant number of persons, predominantly those lacking specialized skills, are projected to experience job displacement due to the use of automation in the manufacturing sector during the past few decades. Moreover, this will pave the way for novel horizons in the realm of cognitive abilities, technical proficiencies, intricate puzzle-solving, adeptness in resource allocation, aptitude in content and process management, and proficiency in social interactions, among several other facets. Remarkably, there is an ongoing exponential growth in computer power, which has the potential to automate a wide range of professions including attorneys, financial experts, surgeons, reporters, economists, financial planners, and academics, maybe at a faster pace than anticipated by the general population.

Solution to the CHL-7 (lack of government support)

Government support is crucial for the effective implementation of Industry 4.0. The government of Bangladesh asserts that the integration of Industry 4.0 is important for the sustained economic progress of the nation, with specific emphasis on the steel sector. In light of the prevailing circumstances in the realm of global competitiveness, the private sector is assuming a progressively prominent role in the process of industrialization within the nation. Consequently, the Ministry of Industry within the government has assumed the role of facilitator. In light of the challenges posed by the free-market economy and globalization, the government has recognized that private industrial enterprise management and ownership play a crucial role in achieving economic advancement. In addition to this, the government has introduced other constructive and timely measures, such as economic liberalization and trade policies, which have facilitated the profitable and unrestricted growth and operation of industrial enterprises by entrepreneurs.

Solution to the CHL-8 (lack of skilled management team)

To address the problems posed by an increasingly digital world, current employment and skills policies will need to be overhauled. The administration must play a role in ensuring that an increasingly digital world produces higher-quality jobs and that both businesses and employees have the resources to take advantage of new job possibilities that arise. Skills policy should focus on four critical areas to help people take advantage of these opportunities and support inclusive growth:

i. Part of the responsibility is to guarantee that all students receive fundamental ICT abilities, as well as solid reading, numeracy, and problem-solving skills, in order to effectively use ICT. Many of these skills are gained outside of traditional education and training institutions, such as in the workplace, underlining the need to recognize skills obtained outside of formal education and training.
ii. In order to change programs and courses offered and assist students toward positive results, education, and training organizations must better assess and anticipate evolving skill shortages.
iii. It is not enough for people to have the necessary skills for the digital economy; companies must also properly utilize these skills in order to take full advantage of increased production and competition. Learning, accounting, and problem-solving skills are used differently in different countries in a technologically advanced world.
iv. Because skill demands are constantly changing, workers must be trained to stay up with new skill requirements. This necessitates improved incentives for employees and businesses to re-skill and up-skill. It also entails utilizing new technology's capabilities to tailor new job duties to incumbent employees' skill sets. Simultaneously, the spread of "on-demand" jobs on digital platforms places a growing burden of blame on individuals to manage their own professional skills.

Solution to the CHL-9 (difficulty in reconfiguration of production pattern)

It's an important barrier of implementing Industry4.0. Every steel manufacturing facility possesses a pre-existing production pattern. However, the implementation of Industry 4.0 has the potential to reconfigure the existing pattern. In order to align with the principles of Industry 4.0, a manufacturing system must possess the capability to adaptively reconfigure itself in response to varying production demands, market trends, and system availability. The decision to engage in manufacturing reconfigurability is a crucial and expensive undertaking for any firm. Consequently, the significance of scoping techniques is growing. Given the strategic objectives of the company and the financial investment necessary to implement new system functionalities and technologies, adopting a scoping approach can aid in assessing the extent to which the new or upgraded production system will be adaptable.

Limitations

It is evident that every scientific endeavor possesses inherent constraints. This research is not attributed to them. Initially, it is important to note that our exploration has been limited to a few four plants, albeit these plants represent the largest ones. However, it is worth mentioning that Bangladesh is home to a substantial number of steel industries, with the count exceeding 50. However, as a result of the COVID-19 pandemic, our ability to visit several industries has been restricted. A further constraint pertains to the imperfect consistency of the data provided by all plants. Moreover, it would be prudent to collect data from supplementary scholarly authorities in order to enhance the rigor and credibility of this study. Ultimately, we used our utmost effort to enhance the general caliber of this endeavor.

Conclusions

In the contemporary era of digitalization, it is imperative for organizations to enhance their production and logistics systems in order to effectively incorporate emerging technology. Businesses have undergone a transformation to enhance their efficiency and cost-effectiveness. The design and implementation of production systems should prioritize customer-centricity and foster company agility. In order to attain these objectives, the implementation of Industry 4.0 is needed. The steel industry in Bangladesh is currently well-established and seeing significant growth. The sector, predominantly concentrated in the maritime city of Chittagong, has emerged as a significant contributor to the overall economic growth of the nation. The rise of the steel industry in Bangladesh is being propelled by the rapid expansion of the country's shipbuilding and real estate sectors, alongside significant expenditures in diverse infrastructure projects throughout the nation, as stated by experts. Therefore, the implementation of Industry 4.0 in this expansive area holds significant importance.

This research work mainly focused on all possible aspects of implementing Industry 4.0. There were four research inquiries in this study. The authors have successfully investigated all the inquiries and found some interesting outcomes. To observe the current condition of Industry 4.0 implementation in the steel sector, we have visited and surveyed the top 4 steel plants in Bangladesh. After proper survey and according to data given by experts from those four industries, we found 40.63% on average Industry 4.0 implementation in those plants. As the current installation is substantially poor, in the next step, the authors tried to find the challenges/barriers to implementing Industry 4.0. After proper studying previous literature on Industry 4.0 implementation, we proposed 12 challenges in front of experts. According to their preference, a total of nine challenges were finally selected for the next step. Then, the authors collected data from nine experts, four from those industries, and the rest five from top engineering universities of Bangladesh to apply the best–worst method (BWM) in order to rank those challenges. After a huge calculation, "high capital investment" was seen as the most significant barrier, while "lack of government support" was identified as the least significant. To verify the final ranking, sensitivity analysis was performed. And hopefully, sensitivity analysis validated our results. After that, some possible solutions to those nine challenges were suggested elaborately. It is hoped this research and hard work will significantly contribute to the steel sector and bring a revolutionary change in the steel manufacturing plants of Bangladesh.

Abbreviations

BWM	Best worst method
IoT	Internet of Things
IIoT	Industrial Internet of Things
IT	Information technology
BDA	Big data analytics
2D, 3D	Two dimensional, three dimensional
MCDM	Multi-criteria decision-making
AHP	Analytic hierarchy process
EAF	Electric arc furnace
TMT	Thermo-mechanically treated
AI	Artificial intelligence
AR	Augmented reality
RFID	Radio frequency identification
CPS	Cyber-physical system
LP	Linear programming
JICA	Japan International Cooperation Agency
ADB	Asian Development Bank
OT	Operational technology

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Authors' contributions
The first author (Md. Abdus Shabur) collected and analyzed the data from industry and academia. The second author (Dr. Kazi Afzalur Rahman) was the main supervisor of this research and was a major contributor in writing the manuscript. The third author (Md. Raihan Siddiki) helped to gather data from various industrial and academic experts and also helped in the "Methods" section. All authors have read and approved the final manuscript.

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Availability of data and materials
All data have been collected from industrial and academic experts (Human) upon request as mentioned in the article above. While collecting data, authors asked every expert about the publishing their given data in journal paper and all the experts gave their full consent about publication. Even they were very much interested in participating in this study. Moreover, there is no individual person's data in any form (including individual details, images or videos) in this study.

Declarations

Ethics approval and consent to participate
This study was approved by the Directorate of Research & Extension, Chittagong University of Engineering and Technology, Bangladesh.

Competing interests
The authors declare that they have no competing interests.

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