

Table 1. Some of the recent works related to this study

Author name	Year	Contribution	Sector	Reference
Kumar et. al.	2021	Recognized and analyzed the implementation challenges of IIoT	SME	(Kumar et al. 2021)
BostjancicRakas et al.	2021	Showed IIoT technology's overview and addressed implementation challenges	Electric power energy sector	(BostjancicRakas et al. 2021)
Malhotra et al.	2022	Analyzed and categorized the implementation challenges of IIoT	Manufacturing sector	(Malhotra et al. 2022)
Knezevic and Kasunic	2020	Showed the overview of vulnerabilities, problems and their mitigation techniques of IoT device	Food industry	(Knezevic and Kasunic 2020)
Bhatt and Bindal	2021	Benefits, limitations and challenges of IIoT 4.0	Development of smart hardware	(Bhatt et al. 2021)
Khalil et al.	2020	Categorized challenges regarding design and implementation of DL-IIoT	-	(Khalil et al. 2021)
Wójcicki et al.	2022	Identified the challenges, opportunities and threads for the implementation of Industry 4.0, IIoT an IoT	-	(Wójcicki et al.2022)
Malhotra et al.	2021	Showed the challenges while implanting the IIoT in India	Indian enterprises	(Malhotra et al. 2021)
Bajramovic et al.	2019	Described security challenges and the practices in IIoT	-	(Bajramovic et al. 2019)
Kumar et al.	2019	Identified challenges and benefits for implementing IIoT	Manufacturing and engineering industry	(Kumar et al. 2019)
Chowdhury et al.	2019	Addressed major challenges for adopting IIoT	-	(Chowdhury et al. 2019)

3. Methods

Assessing the implementation challenges of IIoT is a problem based on multi-criteria decision-making. This research is performed in the Bangladeshi electronics manufacturing industry to investigate the implementation challenges of IIoT. The challenges were identified based on the previous research and with the help of industry experts. All of the industrial experts who gave the feedback for this research had proper knowledge about industrial IoT. BMW method was used to evaluate the challenges. The flow chart of this research is shown in Figure 1.

Best Worst Method

In the literature, there are a lot of available MCDM tools. BWM is one of the best MCDM tools. Compared to the other MCDM tools like the analytical hierarchy process (AHP), there are some advantages to using BWM. The obtained results have more consistency and require fewer pairwise comparison matrices for obtaining better output. It helps the researcher to find the impact that has better reliability and takes less time (Moktadir et al. 2018).

The flow chart of BWM is shown in Figure 2. This figure shows the step-by-step procedure of activities and also provides an overview of this research. Figure 3 shows the steps of the BWM method which is used in this research.

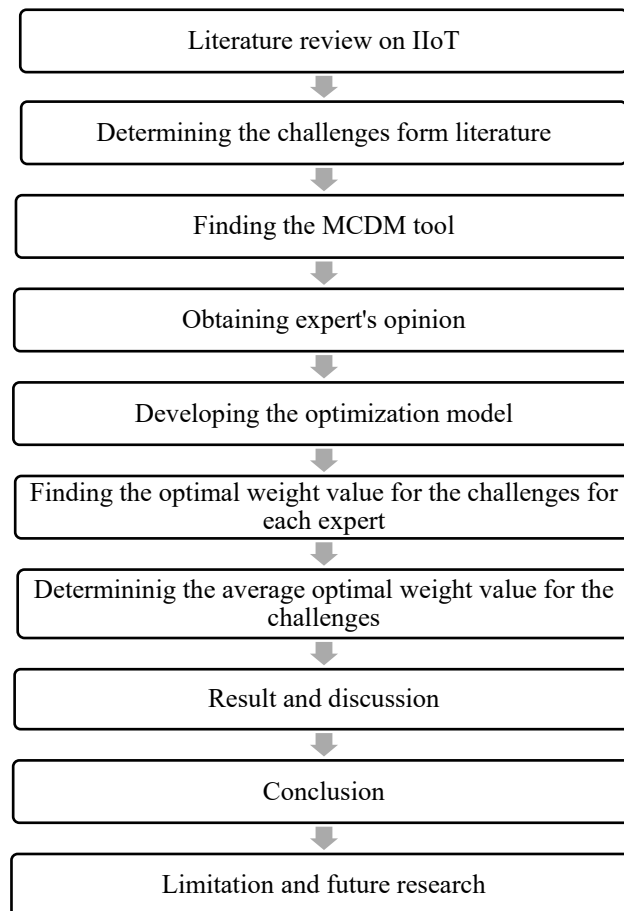


Figure 2. Flow chart of this research

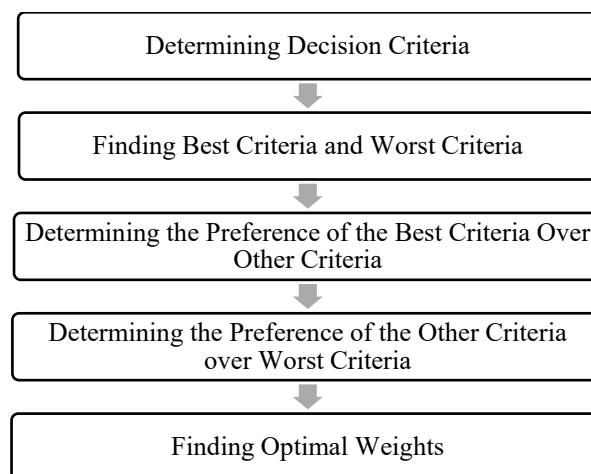


Figure 3. Flow chart of BWM

The steps for applying BWM are given bellow.

Step 1: Determining Decision Criteria

A number of decision-making criteria is determined for this study.

Step 2: Finding Best Criteria (which has most importance) and Worst Criteria (which has least importance)

In this step, the most important criteria among the determined criteria are identified and the least important criteria are also identified.

Step 3: Determining the Preference of the Best Criteria Over Other Criteria

The preference of the best criteria over the other criteria is determined. For this purpose, the rating is given from 1 to 9. The rating score 1 means that the best criteria have equal preference compared to the other criteria. The rating score 9 means that the best criteria have strong preference with compare to the other criteria. BO (Best to Others) vector can be formed as follow:

$$BO = (a_{B1}, a_{B2}, a_{B3}, \dots, a_{Bn})$$

Where, a_{Bj} indicates the preference for the best criteria over other criteria.

Here, $a_{Bj} \geq 1$,

$$a_{BB} = 1,$$

and $j = 1, 2, 3, \dots, n$

Step 4: Determining the Preference of the Other Criteria over Worst Criteria

The preference of other criteria over the worst criteria is determined by giving the rating score between 1 to 9. OW (Other to Worst) vector can be formed as follows:

$$OW = (a_{1W}, a_{2W}, a_{3W}, \dots, a_{nW})$$

Where, a_{jW} indicates the preference for other criteria over worst criteria.

Here, $a_{jW} \geq 1$,

$$a_{WW} = 1,$$

and $j = 1, 2, 3, \dots, n$

Step 5: Finding Optimal Weights

The optimization model is used for obtaining the optimal weights. For each pair of W_B/W_j and W_j/W_W , the best situation is when $W_B/W_j = a_{Bj}$ and $W_j/W_W = a_{jW}$. For getting the best result, it should be minimized for the maximum among the set for $\{|W_b - a_{Bj}W_j|, |W_j - a_{jW}W_w|\}$. This formulation of the problem is shown as follow:

$$\min \max_j \{|W_b - a_{Bj}W_j|, |W_j - a_{jW}W_w|\}$$

Subject to,

$$\sum_j^n W_j = 1 \tag{1}$$

$$W_j \geq 0 \text{ for } j = 1, 2, 3, \dots, n$$

Linear programming (LP) problem can be formed by using the equation (1). The problem can be shown as

$$\min \xi^L$$

Subject to,

$$|W_b - a_{Bj}W_j| \leq \xi^L, \text{ for all } j$$

$$|W_j - a_{jW}W_w| \leq \xi^L, \text{ for all } j \tag{2}$$

$$\sum_j^n W_j = 1$$

$$W_j \geq 0 \text{ for } j = 1, 2, 3, \dots, n$$

ξ^{L*} represents the consistency of the comparison matrices. When the value of ξ^{L*} is close to zero, the system has more consistency and reliable comparison. The value of optimal weights ($W^*1, W^*2, W^*3, \dots, W^*n$) and ξ^L can be determined by solving this LP problem.

Application of BWM in Real World Problem Solving

1. Determining Decision Criteria

The implementation challenges of industrial IoT were determined. The challenges were obtained from literature review and industrial expert's feedback. This study was conducted on Bangladeshi electronics product manufacturing industries. The challenges for implementing industrial IoT are shown in table 2 which were collected from different research paper. The experts who gave their opinion have proper knowledge about industrial IoT. Data was collected from six industrial expert from different company. Details information of the expert's profile is shown in table 3.

Table 2. Implementation Challenges of Industrial IoT

Challenge No.	Challenges	Reference	Details
IIC1	IoT governance issue	(Janssen et al. 2019)	Often, data processing, use, and ownership are performed in several phases. But which party controls the system and the responsibilities of each party are often unclear.
IIC2	Estimating ROI	(Janssen et al. 2019; Tomic 2017)	For the manufacturers, investment is needed in both IoT and its integration with the existing system. Redesign of existing production facilities is needed on a large scale. For this, estimating Return on Investment (ROI) is unclear and difficult.
IIC3	Cyber-Security	(Rehman et al. 2018; Tomic 2017; Xu, He, and Li 2019)	Machines and equipment of an IIoT system are connected, controlled, and monitored wirelessly. Lack of ensuring enough data protection is one of the major obstacles for implementing the IIoT system.
IIC4	Cultural Resistance	(Janssen et al. 2019; Tomic 2017)	When the personnel of a manufacturing company do not get the education or training about the implementation process of IIoT, there may have difficulties while persuading the people to implement this new technology.
IIC5	Infrastructural Problem	(Choi, Song, and Yi 2018; Tomic 2017)	Internal infrastructure of a firm can be an obstacle for implementing a new technology. When there is a lack of flexibility or agility in internal structure, it is almost impossible to introduce a new technology.
IIC6	IIoT Integration	(Kumar and Iyer 2019; Moktadir et al. 2018)	Integration of information technology (IT) and operational technology (OT) is the critical challenge for implementing Industrial IoT. This integration ensures the smooth data communication in which there does not have any vulnerability and loss.
IIC7	Unstable Internet Connectivity	(Choi et al. 2018; kumar et al. 2019)	Discontinuity internet connectivity interrupts real time communication. Providing a continuous internet connectivity among the devices is one of the core challenges for implementing Industrial IoT in manufacturing.
IIC8	Lack of skills and knowledge	(Janssen et al. 2019; Xu et al. 2019)	The deficiency of enough knowledge and skills of employees and staff is another major obstacle for implementing this technology.

Table 3. Profile of the Experts Who Gave Their Opinion for This Study

Expert No	Designation	Years of experiences	Experience areas
Expert 1	Operative director	9	Research & Innovation (R&I)
Expert 2	Deputy General Manager	12	Production
Expert 3	Additional Director	5	Production
Expert 4	Sr. Engineer	5	Manufacturing
Expert 5	Regular Engineer	8	firmware & communication engineer
Expert 6	Manager	7	Production

- Finding the Best Criteria (which has the most importance) and Worst Criteria (which has the least importance)

Each of the experts gave their opinion for choosing the most important criteria and the least important criteria among the criteria set. The information about the best criteria and the least criteria which are given by the experts is shown in Table 4.

Table 4. Best and Worst Criteria Given by the Expert 1-6

Challenges	Best criteria by experts	Worst criteria by experts
IoT governance issue (IIC1)		6
Estimating ROI (IIC2)	1, 2, 4	
Cyber-Security (IIC3)	5	
Cultural Resistance (IIC4)		1, 2, 5
Infrastructural Problem (IIC5)	3, 6	
IIoT Integration (IIC6)		
Unstable Internet Connectivity (IIC7)		
Lack of skills and knowledge (IIC8)		3, 4

- Determining the Preference of the Best Criteria Over Other Criteria

The expert indicated the best challenge preference over other challenges by using rating points from 1 to 9. The preference of the best challenge over other challenges given by expert 1 is shown in table 5.

Table 5. The preference of Best Challenge Over Other Challenge Given by Expert 1

Other challenge	IIC1	IIC2	IIC3	IIC4	IIC5	IIC6	IIC7	IIC8
Best challenge (IIC2)	4	1	3	9	5	6	5	7

- Determining the Preference of the Other Criteria over Worst Criteria

The expert indicated other challenges over the worst challenges by using rating points from 1 to 9. The preference of other challenges over the worst challenges given by Expert 1 is shown in Table 6.

Table 6: The Preference of Other Challenge Over Worst Challenge Given by Expert 1

Other challenges	Worst challenge (IIC4)
IIC1	7
IIC2	9
IIC3	6
IIC4	1
IIC5	5
IIC6	4
IIC7	6
IIC8	2

5. Finding Optimal Weights

The optimal weights are determined by using the optimization model and constraints which are mentioned above. For Expert 1, the model is shown below:

$$\begin{aligned} & \min \xi^L \\ & \text{Subject to,} \\ & |W_{IIC2} - 4W_{IIC1}| \leq \xi^L; |W_{IIC2} - 1W_{IIC2}| \leq \xi^L; |W_{IIC2} - 3W_{IIC3}| \leq \xi^L; |W_{IIC2} - 9W_{IIC4}| \leq \xi^L; \\ & |W_{IIC2} - 5W_{IIC5}| \leq \xi^L; |W_{IIC2} - 6W_{IIC6}| \leq \xi^L; |W_{IIC2} - 5W_{IIC7}| \leq \xi^L; |W_{IIC2} - 7W_{IIC8}| \leq \xi^L; \\ & |W_{IIC1} - 7W_{IIC4}| \leq \xi^L; |W_{IIC2} - 9W_{IIC4}| \leq \xi^L; |W_{IIC3} - 6W_{IIC4}| \leq \xi^L; |W_{IIC4} - 1W_{IIC4}| \leq \xi^L; \\ & |W_{IIC5} - 5W_{IIC4}| \leq \xi^L; |W_{IIC6} - 4W_{IIC4}| \leq \xi^L; |W_{IIC7} - 6W_{IIC4}| \leq \xi^L; |W_{IIC8} - 2W_{IIC4}| \leq \xi^L \\ & W_{IIC1} + W_{IIC2} + W_{IIC3} + W_{IIC4} + W_{IIC5} + W_{IIC6} + W_{IIC7} + W_{IIC8} = 1 \\ & W_{IIC1}, W_{IIC2}, W_{IIC3}, W_{IIC4}, W_{IIC5}, W_{IIC6}, W_{IIC7}, W_{IIC8} \geq 0 \end{aligned}$$

The optimal weight of the challenges according to expert 1's response is shown in Figure 4.

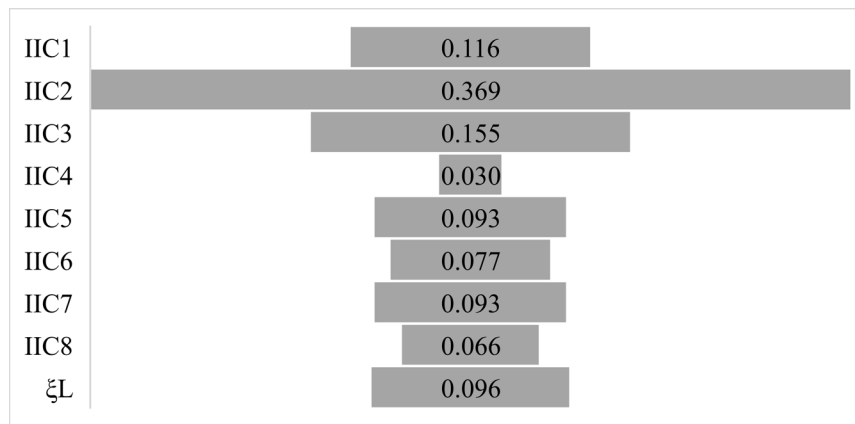


Figure 4. Optimal Weight Value of the Challenges Given by Expert 1

Based on all the expert's opinions, the average value of the optimal weight of the implementation challenges of industrial IoT is shown in Table 7. The value of ξ^L , which is closer to zero, indicates the reliability and consistency of the output result. The lower standard deviation value indicates the homogeneity of the expert's opinions.

Table 7. Optimal Average Weight Value of the Challenges

Challenges	Average Weight	Standard deviation
IIC1 (IoT governance issue)	0.13195769	0.055778
IIC2 (Estimating ROI)	0.253366314	0.099427
IIC3 (Cyber-Security)	0.15172466	0.066084
IIC4 (Cultural Resistance)	0.061894187	0.035314
IIC5 (Infrastructural Problem)	0.165647212	0.102052
IIC6 (IIoT Integration)	0.087300638	0.015946
IIC7 (Unstable Internet Connectivity)	0.074546534	0.021302
IIC8 (Lack of skills and knowledge)	0.073562767	0.041051

ξ^L (Average Consistency)	0.128223198
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4.Results and Discussion

This research's output determined the optimal average weight value for the defined challenges. Analyzing the output values, the ranking of the challenges was determined. The optimal average weight value of the challenges is shown in figure 5.

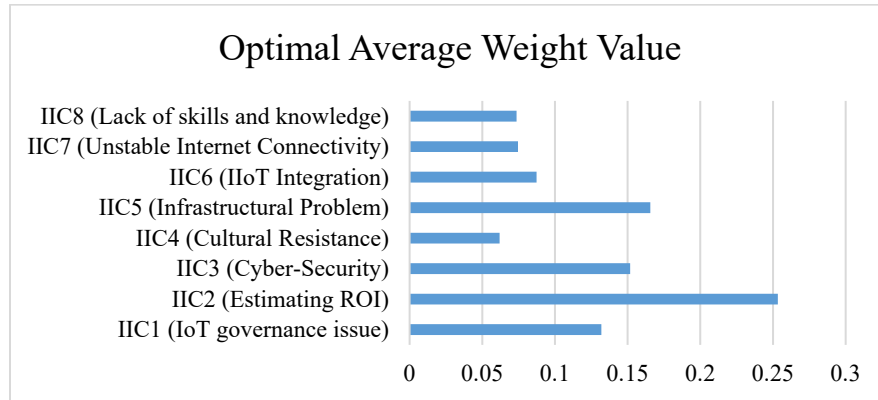


Figure 5. The average optimal weight value of the challenges

A ranking of the challenges which are obtained from the output of this study is:

IIC2 > IIC5 > IIC3 > IIC1 > IIC6 > IIC7 > IIC8 > IIC4

From the average optimal weight values of the challenges, it is clear that "IIC2 (Estimating ROI)" has the highest weight among the other challenges. It is determined as the most critical challenge for the electronics manufacturing company to estimate the return of overall cost for implementing industrial IoT. A company needs to analyze whether the company has the financial capability to implement the industrial IoT technology and when the investment cost will be gained. The average optimal weight value for this IIC2 challenge is 0.11619515. The decision maker of the electronics company should consider the "Estimating ROI" challenge and eliminate this problem first by calculating and analyzing investment cost, the investment cost's return time, and the profitability while using the industrial IoT technology. The second most important challenge is IIC5 which is the "Infrastructural Problem." The company's decision maker should focus on the IIC5 challenge when the IIC2 challenge is overcome. For implementing new technology like industrial IoT, internal flexibility makes the implementation easier. The decision maker should analyze and solve this issue while implementing industrial IoT. The average weight of the IIC5 challenge is 0.165647212. The third most important challenge is IIC3, which is the "Cyber-Security" challenge.

It has the average weight value of 0.15172466. Cyber security is one of the major challenges for the wireless communication system. In the industrial IoT system, equipment and machines are connected through the wireless communication system. The company should ensure enough data protection for implementing the industrial IoT. The fourth important challenge is the "IoT governance issue (IIC1)". The average weight of this challenge is 0.13195769. There are different phases for data processing, use, and ownership in the industrial IoT system. The different party performs the different phases. The responsibilities of the party remain unclear sometimes. For eliminating this issue, the responsibilities of the different party should be well defined. "IIoT Integration (IIC6)" is in the fifth position. For ensuring smooth data communication, it is necessary to integrate information technology and operational technology. The average weight value of IIC6 is 0.087300638. The sixth important challenge is "Unstable Internet Connectivity (IIC7)". The average weight value of this challenge is 0.074546534. For real time communication, continuous internet connectivity is needed. Otherwise, there will have an interruption in real time communication. So, there must have continuous internet connectivity for the industrial IoT system. The seventh important challenge is "Lack of skills and knowledge (IIC8)". The average weight value of this challenge is 0.073562767. Enough knowledge about industrial IoT and skilled manpower is required to successfully implement industrial IoT. The "Cultural Resistance (IIC4)" challenge is in the eighth position. The average weight value of this challenge is 0.061894187. Persuading the people

of the company is required to eliminate this challenge. The average value of ξ^L is 0.128223198, which is closer to zero. So, the output result is reliable and the standard deviation is also lower which indicates that there has the homogeneity of the expert's opinions.

5. Conclusion

The IIoT system is beneficial for providing the real time data, cost effectiveness, increment of productivity, etc. The system can be used in many sectors like production, healthcare, supply chain, retailer, etc. But for the implementation of IIoT, there are some challenges faced by the industry. In this study, the implementation challenges of the IIoT system were found. The study was conducted on the Bangladeshi electronics manufacturing industry. The challenges were found out from the literature review and industrial experts' help. The challenges were ranked by using the BWM. "Estimating ROI" was determined as the most important challenge with the highest optimal weight value among the other defined challenges while implementing the IIoT for the Bangladeshi electronics manufacturing industry. This study's outcome result indicates the importance of clarifying the investment cost and the return of the cost. The output result of this study will help the industrial manager to observe the importance of the challenges. The least optimal average weight value was for the challenge of cultural resistance. The theoretical benefit of this research is that the literature on the industrial automation sector is increased. The practical benefit is that this study may help the companies to provide the important guidelines when the company wants to implement IIoT. During the implementation of the IIoT, the industrial manager can get a list of challenges ranked by importance. This research will enable industrial managers and practitioners to assess and investigate the impact of the challenges defined for implementing the IIoT system.

This research is not free from limitations. This research is performed in the Bangladeshi electronics manufacturing industry. Eight most important challenges were considered for this research. The output result may vary when the research is performed in another industry or in another country. This limitation can be solved by performing this research in another industry.

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Biography

Subrata Talapatra, serving as a Professor in the department of Industrial Engineering and Management of Khulna University of Engineering & Technology. He obtained his B.Sc. in Mechanical Engineering from Rajshahi University of Engineering a Technology and M.Sc. in Industrial Engineering and Management from Khulna University of Engineering & Technology. He has also obtained his Ph.D. in Industrial Engineering and Management from Khulna University of Engineering & Technology. His areas of research are Statistical Quality Control, Ergonomics, Operation Research, and 3d-Drawing. He is also a member of Institution of Engineers (Bangladesh) and IEOM.

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