

# Evaluating Industry 4.0 Technologies for Supply Chain Optimization: A Best-Worst Method Approach

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## ABSTRACT

The emergence of Industry 4.0 has brought transformative changes to supply chain management, introducing advanced technologies that challenge and reshape traditional operational practices. These innovations are designed to enhance supply chain efficiency, agility, and resilience, offering organizations the opportunity to overcome existing challenges and stay competitive. This study seeks to evaluate the adoption levels of the key Industry 4.0 practices in Moroccan supply chains, using the Best Worst Method (BWM) to systematically rank them based on their levels of implementation and their strategic importance to improving supply chain performance. Data was gathered from 15 expert respondents with diverse expertise in supply chain management and Industry 4.0 technologies. The analysis identifies the most widely adopted practices, such as IoT and big data analytics, alongside those with lower levels of integration, such as additive manufacturing and autonomous robots. The findings offer critical insights for organizations transitioning toward digitalized supply chains. By contributing to the academic discourse on the prioritization and implementation of Industry 4.0 practices, this research offers a valuable resource for scholars and decision-makers working to navigate the complexities of digital transformation in supply chains.

**Keywords:** *best worst method, digitalization, industry 4.0, supply chain, technology*

## 1. INTRODUCTION

The industrial sector has been profoundly transformed by successive technological revolutions. While the first three industrial revolutions introduced mechanization, electrification, and automation, the fourth industrial revolution (Industry 4.0) represents a paradigm shift, characterized by the convergence of digital technologies with traditional manufacturing processes (Oztemel & Gursev, 2020). Industry 4.0 integrates advanced

technologies that redefine operational models, impacting not only production systems but also organizational structures and workforce dynamics (Dahmani, 2024). Consequently, firms must adapt to these technological advancements, as they have become essential components of modern business strategies (Tay *et al.*, 2018).

One of the most significantly affected domains is supply chain management (SCM), which has become increasingly complex due to the necessity for real-time monitoring, predictive analytics, and adaptive decision-making. The integration of Industry 4.0 technologies within supply chains enhances operational efficiency, resilience, and competitive advantage (D. A. Ghadge *et al.*, 2020). As a result, these technologies are now regarded as critical enablers of supply chain agility in highly dynamic and competitive environments.

Despite the potential benefits of Industry 4.0, its adoption remains a challenge in emerging economies, such as Morocco, where digital transformation is still in its nascent stages. In Morocco, factors such as limited infrastructure, digital skill gaps, and financial constraints create barriers to the widespread adoption of Industry 4.0 technologies. However, these challenges also present unique opportunities for growth. By embracing Industry 4.0, companies in Morocco can leverage advanced technologies to enhance supply chain efficiency, improve resilience, and compete on a global scale. This study aims to provide insights into these opportunities and challenges, offering a roadmap for the successful adoption of Industry 4.0 technologies within Morocco's supply chain sector.

In response to this need, the present study pursues two primary objectives: (i) to provide a comprehensive review of Industry 4.0 and its foundational technologies, and (ii) to evaluate and prioritize Industry 4.0 technologies using the Best Worst Method (BWM). To achieve these objectives, the paper is structured as follows: Section 2 presents a detailed review of the literature on Industry 4.0 and its associated technologies. Section 3 outlines the research methodology, elaborating on the application of the BWM approach for technology ranking. Section 4 discusses the findings, highlighting the relative significance of different technologies for supply chain management. Finally, Section

5 concludes the study by summarizing key insights and contributions.

## 2. LITERATURE REVIEW

### 2.1 *The Fourth Industrial Revolution (Industry 4.0)*

Over the past few years, companies have been affected by various revolutions in order to improve their manufacturing process. These revolutions is about transforming traditional practices into innovative methods and techniques driven by modern technology (Raja Santhi & Muthuswamy, 2023) . Companies have undergone a sequence of industrial revolutions from Industry 1.0 to Industry 4.0, leading spectacular changes. In the late 18th century, the world experienced a big transition marking a shift from agrarian economies to industrial production. At that time, water and steam powered machines were introduced to help labors in their tasks leading to an increased efficiency (Mathur *et al.*, 2022; Musarat *et al.*, 2023). This made companies move from concentrating only on individual interests to embracing collective interests. Despite this, the first industrial revolution was criticized for several reasons including working conditions, environmental degradation and social disruption, etc. After the 1800s, the second industrial revolution emerged as a technological revolution marked the transition from steam power to electricity (Mathur *et al.*, 2022). Moreover, this era was also distinguished by Henry Ford's invention of a new approach, the "Assembly line". This method is designed to reduce costs and production time by breaking down the work into small tasks. Following this period, a new phase appeared using computer technology. It's in this era where companies used computers, electronics and automation to enhance and streamline their processes which reduced the importance of human power (Teker & Koc, 2019). As in every era, Industry 3.0 has a set of limitations such as the overcrowding of urban areas, pollution and labor exploitation.

Based on this, the fourth industrial revolution was triggered in Germany in the first instance. It is about modernizing industries through the use of digitalization and emerging technologies (Alaloul *et al.*, 2020; Awan *et al.*, 2021). In general, companies' transition to Industry 4.0 is to boost manufacturing output (Wankhede & Vinodh, 2021a). The fourth industrial revolution focuses on transforming machine-dominated manufacturing to digital and smart manufacturing (Awan *et al.*, 2021; Oztemel & Gursev, 2020). At an exponential pace, Industry 4.0 is advancing rapidly as a transformation process that consists in creating connectivity with exploiting some new digital technologies such as artificial intelligence and cyber-physical systems (Teker & Koc, 2019). In fact, the fourth revolution aims to minimize human resources in companies through the use of advanced and precise technologies that have of course a low margin of error, which will improve product quality and make production processes more efficient and flexible (De Oliveira *et al.*, 2023).

### 2.2 *Industry 4.0 Technologies*

According to Yang & Gu (2021), there are several technologies linked to Industry 4.0 that are playing an important role in making manufacturing processes smart and more efficient such as the internet of things, big data analytics, cloud computing, cybersecurity, simulation,

augmented reality, additive manufacturing, autonomous robots and system integration.

- Internet of things (IoT): It introduces the vision of global infrastructure on networked physical objects which enables easy communication and sharing of information with other systems and devices. Its primary function is to enhance connectivity and communication. Studies that have explored IoT include Abdel-Basset *et al.*, (2018); Bahrin *et al.*, (2016); Baran & Korkusuz Polat, (2022); Dahmani, (2024); Fatorachian & Kazemi, (2021); Ghadge *et al.*, (2020); Jamwal *et al.*, (2021); Madakam *et al.*, (2015); Vaidya *et al.*, (2018); L. Xu *et al.*, (2014) and Yang & Gu, (2021).
- Big data analytics: It involves collecting data in real time while using analytical tools and computer algorithms to discover information from text, audio and video. Its main function is data analysis. Several researchers have identified this technology, including Acharjya, (2016); Jeble *et al.*, (2018); Elgendy & Elragal, (2014); Vaidya *et al.*, (2018); Fatorachian & Kazemi, (2021); Yang & Gu, (2021); Baran & Korkusuz Polat, (2022); Tay *et al.*, (2018); Jamwal *et al.*, (2021); Bahrin *et al.*, (2016) and Duan & Da Xu, (2021).
- Cloud computing: It refers to the provision of IT services via the Internet, such as storage, databases, networks, software, etc. It represents a new system approach that provides users with a vast storage space. It has been mentioned by Baran & Korkusuz Polat, (2022); Vaidya *et al.*, (2018); Yang & Gu, (2021); Tay *et al.*, (2018); Jamwal *et al.*, (2021); Fatorachian & Kazemi, (2021); Bahrin *et al.*, (2016) and Wankhede & Vinodh, (2021).
- Cybersecurity: It is used to protect, detect and respond to attacks. This technology is very important because today's companies operate online, making them increasingly exposed to the risk of digital attacks. It has been addressed by Tay *et al.*, (2018); Jamwal *et al.*, (2021); Alcácer & Cruz-Machado, (2019); Vaidya *et al.*, (2018); Saeed *et al.*, (2023) and Bahrin *et al.*, (2016).
- Simulation: It involves representing and testing processes virtually, systems and products before they are implemented in the real world. Its core function is simulation and virtual reality. This technology has been highlighted by Vaidya *et al.*, (2018); de Paula Ferreira *et al.*, (2020) and Bahrin *et al.*, (2016).
- Augmented reality: It superimposes digital content, such as images, videos and sounds, on a real environment in real time. Its main function is visualization. It has been mentioned by Tay *et al.*, (2018); de Paula Ferreira *et al.*, (2020); Vaidya *et al.*, (2018); Du *et al.*, (2022) and Bahrin *et al.*, (2016).
- Additive manufacturing: It offers the possibility of producing customized products at low cost, in a short time, with less waste and energy. Its function is customized production and prototyping. It has been mentioned by Tay *et al.*, (2018); Jamwal *et al.*, (2021); Vaidya *et al.*, (2018); Alcácer & Cruz-Machado, (2019); Wankhede & Vinodh, (2021); Bahrin *et al.*, (2016) and Ghadge *et al.*, (2020).

- Autonomous robots: Nowadays robots have begun interacting with each other, working safely harmoniously with operators and providing them with assistance. They are becoming more autonomous, flexible, and cooperative. The literature covering this technology includes Jamwal *et al.*, (2021) ;Vaidya *et al.*, (2018); Bahrin *et al.*, (2016);Krueger *et al.*, (2019) and Ghadge *et al.*, (2020) .
- System integration: System integration has two approaches: horizontal and vertical. Horizontal integration refers to the inter-company integration via information systems, resulting in close collaboration between companies. While vertical integration is intra-company. It's about sharing and exchanging information and elaborating between the different levels of the company hierarchy. The main function of system integration is interconnectivity and flexibility. It has been addressed by Vaidya *et al.*, (2018) ;Alcácer & Cruz-Machado, (2019) ; Bahrin *et al.*, (2016) and Lasi *et al.*, (2014).

### 2.3 Supply Chain Management in the Era of Industry 4.0

As an essential aspect of business operations, supply chain management is a science that involves the management of activities and processes transforming raw materials into final products. According to Nakov *et al.*, (2014), supply chain management is described as a strategic approach to manage the company's activities in a systematic manner. The ultimate goal of supply chain management is to produce the right product, in the right quantity, at the right time and in the right place with the lower cost (Wu *et al.*, 2016). In the last decades, the management of the supply chain has undergone a significant transformation, with the focus shifting from traditional supply chains to the concept of a smart supply chain. This transition can be explained by the complexity and unpredictability of the supply chain, leading to imbalances between supply and demand. And to do so, companies nowadays are investing more in integrating advanced technologies like Internet of Things, big data Analytics, etc. According to the literature, to define the smart supply chain, six characteristics are required:

- Instrumented supply chain: It's a critical aspect for generating data where visibility is guaranteed thanks to the use of sensors, GPSs, systems and other devices (K. L. Lee *et al.*, 2023).
- Interconnected supply chain: All the supply chain's components are connected including stakeholders, customers, suppliers, IT systems, assets, etc. (Wu *et al.*, 2016).
- Intelligent supply chain: it's a supply chain that makes good decisions in order to improve overall performance and optimize processes with the use of advanced technologies like artificial intelligence, automation and predictive analytics (K. L. Lee *et al.*, 2023).
- Automated supply chain: Transitioning to a smart supply chain necessities the automation of processes. The goal is to minimize errors, streamline operations and enhance efficiency (Wu *et al.*, 2016).
- Innovative supply chain: It's a supply chain that actively applies and adopts new technologies and strategies to meet the market requirements (Mandal *et al.*, 2013) .

- Integrated supply chain: It refers to establish a coordinated and unified system where collaboration involves all over the supply chain (Wu *et al.*, 2016).

Given the complexity of adopting multiple interconnected technologies, various methodologies have been employed to assess and prioritize Industry 4.0 technologies in the context of supply chain management. One such methodology is the Best Worst Method (BWM), which has gained prominence for its ability to handle multi-criteria decision-making (MCDM) problems. Debnath *et al.* (2023) have conducted a study to investigate the critical success factors and impact of Industry 4.0 technologies like cloud computing, the Internet of Things, and big data analytics on supply chain sustainability in the context of pharmaceutical industries. They have used a Bayesian BWM to prioritize these factors. This method is noted for its ability to generate more reliable expert opinions and reduce the information gap that often arises in multi-criteria decision-making problems (Debnath *et al.*, 2023). Abdullah *et al.* (2024) have focused on assessing the adoption of Industry 4.0 practices in Indian companies. They have also used BWM to rank the most critical factors for successful Industry 4.0 implementation by identifying and weighing the best and worst criteria. The study highlights the importance of BWM in structuring complex decision-making processes in the context of technological adoption, offering valuable insights for organizations seeking to improve their Industry 4.0 maturity (Abdullah *et al.*, 2024). Wankhede and Vinodh (2021) have focused on the identification and ranking of key challenges to Industry 4.0 adoption using the BWM. They have evaluated barriers such as high costs, lack of skilled workforce, and inadequate infrastructure, emphasizing their impact on successful implementation in industries (Wankhede & Vinodh, 2021b). Moreover, Patil *et al.* (2023) have explored how big data and Industry 4.0 technologies can be leveraged to enhance supply chain sustainability in the context of the circular economy. The study identifies 17 readiness factors essential for adopting Industry 4.0 in sustainable supply chain management and uses a fuzzy BWM to prioritize these factors based on their influence, to improve the readiness for Industry 4.0 in sustainable supply chains (Patil *et al.*, 2023).

## 3. METHODOLOGY

To assess and prioritize Industry 4.0 technologies in supply chain management, this study employs the Best Worst Method (BWM), a widely recognized multi-criteria decision-making (MCDM) approach introduced by Rezaei (2015). The selection of BWM is justified by its ability to enhance the consistency, reliability, and efficiency of expert evaluations while minimizing cognitive burden. Unlike traditional MCDM methods such as the Analytic Hierarchy Process (AHP), which require extensive pairwise comparisons that can introduce inconsistency, BWM optimizes the decision-making process by focusing only on the most and least important criteria. This structured approach reduces subjectivity and enhances decision accuracy, making it particularly suited for complex, technology-driven environments like Industry 4.0 (Rezaei, 2016).

In the context of Industry 4.0 adoption, where numerous interdependent technologies must be evaluated

based on their impact on supply chain performance, a method that ensures precision and robustness is essential. BWM is particularly advantageous because it provides a more stable ranking of criteria, even when the number of comparisons is limited, making it well-suited for studies with a focused expert panel (Khan *et al.*, 2022). Compared to AHP, studies have shown that BWM yields higher consistency ratios, making it a more reliable tool for decision-making in supply chain management. Given the dynamic and uncertain nature of modern supply chains, employing BWM enables a structured and rational evaluation process, ensuring that the most impactful technologies are identified and prioritized effectively for optimizing supply chain operations. By leveraging BWM, this study offers a systematic and analytically rigorous approach to understanding Industry 4.0 adoption in emerging economies (Kurniawanti *et al.*, 2024).

### 3.1 Supply Chain Management in the Era of Industry 4.0

To provide a clearer understanding of the BWM process, Figure 1 presents its flowchart, followed by a detailed explanation of each step.

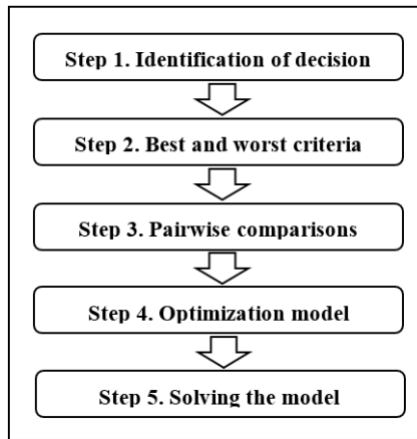


Figure 1 Flowchart for the best-worst method.

#### Step 1. Identification of decision criteria

The first step is to identify the criteria to be assessed and ranked. Considering that  $C = \{C_1, C_2, \dots, C_n\}$  represent the set of criteria/practices. In the context of Industry 4.0 practices for supply chain management, we have selected the following criteria, which are identified as the most widely used in existing literature, as discussed in the literature review section: Internet of Things ( $C_1$ ), Big Data Analytics ( $C_2$ ), Cloud computing ( $C_3$ ), Cybersecurity ( $C_4$ ), Simulation ( $C_5$ ), Augmented Reality ( $C_6$ ), Additive manufacturing ( $C_7$ ), Autonomous Robots ( $C_8$ ) and System integration ( $C_9$ ).

#### Step 2. Best and worst criteria selection

In this step, we asked the participants, “Which of the Industry 4.0 practices is the most important for supply chain management?” and “Which of the Industry 4.0 practices is the least important for supply chain management?”. Then, each participant selects one criterion as the “best”  $C_b$  and one as the “worst”  $C_w$  based on their judgment. For instance, if “Cybersecurity” ( $C_4$ ) is chosen as the best and “Cloud computing” ( $C_3$ ) as the worst, these will serve as reference points for the comparisons.

#### Step 3. Pairwise comparisons

The best practice over all other practices: each Industry 4.0 practice is compared to the best criterion. The

participants assign a value  $a_{b,i}$  on a scale from 1 to 9: 1 = equal importance; 3 = Moderately more important; 5 = Strongly more important; 7 = Very strongly more important; 9 = Extremely more important; 2, 4, 6, 8 = Intermediate values.

This represents how much more important the best criterion  $C_b$  is compared to each criterion  $C_i$ . For instance,  $a_{b,i} = 1$  if  $C_b$  is equally important as  $C_i$ . And  $a_{b,i} = 9$  if  $C_b$  is extremely more important than  $C_i$ . We can express the best to others vector as:

$$A_B = (a_{b,1}, a_{b,2} \dots, a_{b,n}) \quad (1)$$

where  $a_{b,i}$  signifies the importance of the best criterion  $B$  over the criterion  $i$ .

Others-to-worst comparisons: similarly, we asked the participants to compare each criterion to the worst criterion. The participants assign a value  $a_{i,w}$ , representing how much more important  $C_i$  is compared to the worst criterion  $C_w$ . For instance,  $a_{i,w} = 1$  if  $C_i$  is equally important as  $C_w$ . And  $a_{i,w} = 9$  if  $C_i$  is extremely more important than  $C_w$ . We can express others to worst vector as:

$$A_w = (a_{1,w}, a_{2,w} \dots, a_{n,w}) \quad (2)$$

where  $a_{i,w}$  signifies the importance of the criterion  $i$  over the worst criterion  $W$ .

#### Step 4. Optimization model

The objective of the optimization problem is to determine the weights  $w_1, w_2, \dots, w_n$  of the criteria such that the maximum absolute deviation between the pairwise comparisons and the derived weights is minimized. The following optimization model is formulated (Liang *et al.*, 2020):

$$\begin{aligned} \text{Min} \{ \max_i (|w_b - a_{b,i}w_i|, |w_i - a_{i,w}w_w|) \} \\ \text{s.t. } \sum_i w_i = 1 \\ w_i \geq 0, \text{ for all } i \end{aligned} \quad (3)$$

With:

- $w_b$  = Weight of the best criterion;
- $w_w$  = Weight of the worst criterion;
- $w_i$  = Weight of criterion  $i$ ;
- $a_{b,i}$  = Preference of the best criterion over criterion  $i$ ;
- $a_{i,w}$  = Preference of criterion  $i$  over the worst criterion.

The goal is to find a set of weights  $w_i$  that minimizes the worst inconsistency between the preference values  $a_{b,i}$  and  $a_{i,w}$ . The first term  $|w_b - a_{b,i}w_i|$  ensures that the weight of the best criterion is correctly related to the weights of others. The second term  $|w_i - a_{i,w}w_w|$  ensures that each criterion’s weight is consistent with its relative importance compared to the worst criterion.

Also, to solve Equation (3) a linear optimization model is needed, and it can be expressed as follow:

$$\begin{aligned} \min^{\delta^L} \\ \text{s.t.} \\ |w_b - a_{b,i}w_i| \leq \delta^L, \text{ for all } i \\ |w_i - a_{i,w}w_w| \leq \delta^L, \text{ for all } i \\ \sum_i w_i = 1 \\ w_i \geq 0, \text{ for all } i \end{aligned} \quad (4)$$

Here,  $\delta^L$  is the maximum deviation between the pairwise comparison values and the ratio of the weights, and the goal is to minimize this deviation.

This model determines the optimal weight distribution of criteria while ensuring the highest level of consistency in

the decision-maker's pairwise comparisons. The objective function seeks to minimize the maximum deviation  $\delta^L$  from the ideal consistency in the comparisons between the best and other criteria, as well as between the other criteria and the worst criterion.

The first constraint ensures that the weight of the best criterion  $w_b$  aligns with the decision-maker's relative preferences over all other criteria  $a_{b,i}w_i$ . Any inconsistency in these pairwise comparisons is bounded by  $\delta^L$ . The second constraint ensures that each criterion's weight  $w_i$  is consistent with its assigned preference compared to the worst criterion  $a_{i,w}w_w$ , with deviations also limited by  $\delta^L$ . The third constraint maintains a probability-like interpretation by ensuring that all weights sum to 1. The fourth constraint guarantees that all weights are non-negative, making them meaningful in real-world decision-making contexts.

**Step 5. Solving the model**

The optimization problem is solved using linear programming version of BWM Excel solver (Ait Hammou *et al.*, 2023). The output provides the optimal weights  $w_1, w_2, \dots, w_n$ , indicating the relative importance of each criterion. A lower value of  $\delta^L$  indicates a more consistent set of judgments from the participant.

**3.2 Data Collection and Analysis**

In this study, data collection began by targeting potential respondents selected through purposive sampling, focusing on individuals with relevant expertise in supply chain management. The initial sample of 35 participants was carefully chosen to ensure diversity and relevance to the study's objectives. Participants were selected from diverse sectors in Morocco, particularly in manufacturing and supply chain industries, where the adoption of Industry 4.0 technologies is most relevant. The selection criteria were based on industry type, company size, and experience with

Industry 4.0 technologies, ensuring that the sample represented both large and small enterprises across different stages of technology adoption. To mitigate potential biases in the selection process, we employed random sampling within each predefined subgroup (e.g., industry types, company sizes, and roles). This approach ensured that no single group or type of participant was overrepresented, promoting a balanced and diverse sample. Additionally, participants were selected from a range of roles, including management, operations, and technical teams, which helped capture a wide variety of perspectives on the adoption process and the challenges of integrating Industry 4.0 technologies into supply chain management.

Prior to survey distribution, a pilot test was conducted with three experts to assess the clarity of the questions and ensure compliance with research ethics. These pilot responses were excluded from the final analysis. The finalized survey was then distributed to the 35 selected participants via ResearchGate. Data was gathered between September and November 2024, resulting in 20 total responses. However, five responses were eliminated due to straight lining, leaving 15 valid responses for analysis. The sampling process, including random sampling within subgroups and the inclusion of participants from diverse roles, helped mitigate bias and ensured that the results were representative of the target population.

As noted by Hebaz *et al.* (2022), data saturation in most MCDM studies is typically achieved with 4 to 10 respondents, supporting the reliability of our study's findings. According to Liang *et al.* (2020), the consistency ratio threshold for a set of nine criteria should be below 0.10 to ensure that the results are reliable and the comparisons are sufficiently consistent, which is valid in our study as presented in Table 1 above, where  $\delta^L = 0.0716$  (Liang *et al.*, 2020).

**Table 1.** Optimal weights and average consistency ratio.

Resp.	Cloud Computing	Big Data Analytics	System Integration	Autonomous Robots	Cybersecurity	IoT	Simulation	Augmented Reality	Additive Manufacturing	$\delta$
1	0,122	0,242	0,084	0,010	0,209	0,217	0,048	0,037	0,022	0,091
2	0,128	0,265	0,078	0,019	0,197	0,207	0,047	0,031	0,038	0,055
3	0,115	0,276	0,075	0,017	0,206	0,223	0,050	0,032	0,026	0,084
4	0,109	0,249	0,079	0,019	0,207	0,202	0,045	0,032	0,038	0,072
5	0,103	0,274	0,089	0,011	0,195	0,207	0,053	0,049	0,025	0,064
6	0,104	0,270	0,079	0,014	0,193	0,203	0,056	0,038	0,027	0,075
7	0,113	0,246	0,085	0,015	0,192	0,201	0,048	0,045	0,037	0,059
8	0,111	0,254	0,088	0,018	0,209	0,223	0,053	0,030	0,033	0,076
9	0,126	0,249	0,082	0,018	0,193	0,203	0,046	0,037	0,024	0,058
10	0,116	0,241	0,077	0,014	0,205	0,213	0,043	0,046	0,028	0,095
11	0,106	0,260	0,077	0,014	0,191	0,219	0,049	0,031	0,036	0,068
12	0,112	0,253	0,083	0,015	0,206	0,219	0,044	0,040	0,026	0,058
13	0,127	0,269	0,078	0,018	0,191	0,227	0,049	0,036	0,032	0,086
14	0,101	0,268	0,073	0,018	0,201	0,214	0,058	0,031	0,021	0,060
15	0,100	0,273	0,079	0,014	0,206	0,228	0,056	0,038	0,021	0,067
Mean	0,113	0,259	0,080	0,016	0,200	0,214	0,050	0,037	0,029	
Rank	4	1	5	9	3	2	6	7	8	

**4. RESULTS AND DISCUSSION**

Based on the results obtained, "Big data analytics" has the highest criterion weight of 0.259. This shows the significant weight that this technology has within industry

4.0. Big data analytics stands out among technologies, this is explained by the various benefits that can this technology has on the supply chain including enhanced product quality, cost efficiency and improved decision-making capabilities (I. Lee & Mangalaraj, 2022). Previous studies also show that big data analytics has a major impact on firm performance

(Sivarajah *et al.*, 2024). Nowadays, the supply chain operates on a global scale, generating vast amounts of data from all the processes which require data to be collected, controlled and analyzed. In fact, the ability to have a set of data enables better management of supply chain operations, coping with fluctuations in demand and optimizing stocks (Fosso Wamba & Akter, 2015). Within the scope of the study, the big data analytics is seen as the main key that enables the supply chain to adapt quickly to the current market (Tamym *et al.*, 2020). According to a report made by Solutions OCP in 2023 (Mamdouh, Akkouch, & Moulim, 2023), big data is increasingly being used in supply chains across several sectors in Morocco and Africa to improve productivity, save costs and make better decisions.

The “Internet of things” ranks as the second most important technology for managing supply chains with a weight of 0,214. Beyond Data analytics, internet of things excels in processing and analyzing data, transforming raw data into actionable revelations which helps in making decisions and optimizing supply chain operations (Sallam *et al.*, 2023). The use of the internet of things is crucial to producing actionable information, leading to improvements in supply chain management. According to Jamwal *et al.*, (2021), IoT is one of the main enabling technologies for Industry 4.0, contributing to an excellent digital transformation of the supply chain. For Morocco, a developing country where digitalization is starting to take hold, the IoT is beneficial for creating connected systems that make supply chains less complex since the main use of IoT in supply chain management is to track objects in real time (Al-Ibrahim & Aksoy, 2024). This ranking matches the results of a study carried out in Kazakhstan by Dikhanbayeva *et al.*, (2021), where researchers confirmed that the most used technologies by companies are IoT and big data. After the internet of things, the findings show “Cybersecurity” as the third most commonly realized technology with a weight of 0,200. This position is based on the fact that all Industry 4.0 technologies require a high level of security and protection. Securing supply chains in Morocco against cyber threats is crucial to ensure continuity of processes and to strengthen supply chain resilience (Kenza *et al.*, 2024). Based on the results of the study, we are capturing the attention paid by Moroccan companies to cybersecurity in order to protect sensitive data and guarantee the integrity of their supply chain operations. From this analysis, we note that “Autonomous Robots” was selected as the technology least adopted by respondents with a weight of 0,016. This limited adoption can be largely explained by the higher implementation cost (Mohammed Anouar Elhazziti *et al.*, 2023). This result can also be explained by the fact that adopting Autonomous Robots requires a range of skills and competencies. Indeed, managing and implementing robots requires a good knowledge of robotics and software field. And like many emerging economies, Morocco suffers from a lack of professionals equipped with the necessary expertise in these fields and IT infrastructure (Gallab *et al.*, 2021).

To sum up the adoption of Industry 4.0 technologies in Morocco is influenced by a combination of factors such as cost and lack of advanced knowledge in the field of digitalization. The literature shows that Industry 4.0 has been successfully adopted in developed countries, but not to a large extent in emerging economies. This is generally due to adoption difficulties such as infrastructure, low investment

capacity and lack of policies that will help facilitate implementation (Alshahrani, 2023). Financial investment has been widely recognized in literature as a major challenge for emerging economies. For small and medium-sized enterprises in particular, financial constraints proved to have the highest relative importance because of the significant financial resources required to acquire new technologies (Luthra & Mangla, 2018). For companies operating in developing countries, the systems required for Industry 4.0 are unaffordable. Indeed, this change requires high implementation costs including the acquisition of technology and equipment, engineering services, equipment costs and a well-skilled workforce (Alshahrani, 2023). Moreover, Industry 4.0 requires an abundance of low-skilled labor, but this change cannot be accommodated, especially in today's developing countries with low-cost manufacturing industries (Siau *et al.*, 2019). In a study carried out by Dikhanbayeva *et al.*, (2021) in Kazakhstan, which is one of the developing countries, the researchers identified specific challenges facing companies in Kazakhstan, such as inadequate infrastructure, financial limitations, limited awareness and knowledge, which are blocking the effective adoption of advanced technologies. Speaking of infrastructure, which is a major barrier in emerging economies, Tripathi and Gupta (2021) analyzed India's current state for transforming supply chains into smart systems. From this analysis, they concluded that India as a developing country suffers from a lack of infrastructure and regulations. In addition, human awareness has been one of the factors blocking the implementation of these technologies. In fact, according to the study carried out by Dikhanbayeva *et al.*, (2021), respondents said that 70% of Industry 4.0 projects fail because of people. Employees are not helping to improve their ability to cope with these developments. In addition, there is a lack of qualifications and training for this technological change. Which means that companies have to bring in engineers or qualified profiles in this field from abroad or even set up training courses and pathways at universities in this field.

Despite these challenges, Industry 4.0 promises significant benefits in terms of efficiency and productivity in emerging economies. This era has brought about a change in the way supply chains operate. Industry 4.0 technologies have transformed modern supply chains by enabling data-driven decision-making, predictive insights and real-time monitoring. Firstly this technological transformation provides for supply chain managers efficiency, visibility and improved decision making through IoT-enabled real-time data collection which will help in reducing risks (Xu *et al.*, 2021). From interconnected devices, IoT-based analytics can collect data in real time, enabling companies to improve visibility and predictive maintenance (Ghadge *et al.*, 2020). By relying on autonomous robots, supply chain managers can streamline operations, minimize errors and reduce dependence on manual labor which can sometimes be inefficient (Alshahrani, 2023; Queiroz *et al.*, 2019). In addition, cybersecurity is a solution for managers looking to protect their companies' sensitive data from cyber threats and cyber-attacks (Saeed *et al.*, 2023). Storing and integrating scalable data is easy with cloud computing, enabling seamless collaboration and analysis-led decision-making (Wankhede & Vinodh, 2021). Another benefit of industry 4.0 for supply chain managers is ensuring

communication, collaboration and system integration among partners through cloud computing and interconnected platforms (Wankhede & Vinodh, 2021). In conclusion, Industry 4.0 technologies provide businesses with advanced analytical capabilities that will drive agility, cost reduction and smarter operational strategies. All these benefits illustrate the critical need for studying and advancing knowledge in this area. Indeed, the field of Industry 4.0 cuts across multiple domains such as supply chain management, social sciences, sustainability, economics, making it relevant to a broad academic audience.

Although the study makes valuable contributions, it has a few weaknesses. Firstly, the application of Best Worst Method tolerates a limited sample of respondents or experts in the field, which has the effect of limiting the scope of the study and even generalization to all sectors of the Moroccan economy becomes difficult. Secondly, digitalization is still in its infancy in Morocco. While our study represents a snapshot of the current state of the fourth industrial revolution in Morocco, some advanced technologies may be at different stages of adoption making it difficult to assess them. For example, IoT and big data analytics are better developed than autonomous robots or even additive manufacturing which affects the way they are evaluated. Thirdly, the importance of certain technologies may vary from sector to sector and which we have not been able to capture. Indeed, there are some technologies where we can feel a great deal of attention in certain sectors compared to other technologies. Another limitation is linked to the method. While BWM is useful for prioritizing technologies, it may not consider the external factors on which they depend, such as infrastructure or workforce knowledge. A logical extension of this study would be to study these technologies further on a large and diversified sample in order to evaluate them properly while extracting the barriers that are blocking their adoption.

## 5. CONCLUSION

In today's world, the integration of Industry 4.0 technologies into supply chain management is no longer optional, but an essential priority for supply chains aiming to succeed and survive in the modern economy. It's a major step for enhancing the efficiency and the resilience of the supply chain. This study assessed industry 4.0 technologies within supply chains using the Best Worst Method (BWM). The results showed "Big data analytics", "Internet of things" and "Cybersecurity" as the most appreciated technologies by experts. This is due to the numerous advantages they offer. As an emerging country, Morocco is beginning to position itself in this industrial era by adopting an industrial acceleration plan to align with market demands. However, integrating certain technologies may pose challenges which drives companies to avoid them such as "Autonomous robots". This finding can be explained either by the significant capital investment that these advanced technologies require or by the shortage of qualified professionals in the robotics sector. This study contributes to the growing literature on Industry 4.0 technologies and smart supply chain as well as evaluating these technologies using the BWM. It is groundwork that will drive policymakers to address this revolution. Based on the results, policymakers can consider the key Industry 4.0 technologies that drive

business performance, enabling informed decision-making and regulations, as well as incentives and investment strategies. For future researchers, a key focus could be on addressing different sectors and industries to make these results more universal. And as our country embarks on its journey toward digitization, we suggest researchers explain the challenges involved in implementing advanced technologies, explore long-term impacts of Industry 4.0 as well as regional and sector differences. Furthermore, future studies could tackle the issue of the workforce's adaptation to Industry 4.0. In conclusion, this research provides a basis for emerging economies to identify the challenges, technologies and strategies that will enable them to catch up with developed nations in terms of technological development and adoption.

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