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What Prevents Sustainable Last-Mile Delivery in Industry 4.0? An Analysis and Decision Framework

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Abstract: Industry 4.0 (I4.0) has revolutionized every sector in the last decade. A huge demand has been created in the supply chain for doorstep delivery services. However, many barriers are hindering the progression of I4.0 implementation to last-mile delivery (LMD) operations. In this study, these hindrances need investigation for improving customer satisfaction levels in LMD. The present research is focused on analyzing barriers to adopting I4.0 technologies for sustainable smart supply chains with a special focus on LMD operations. The published literature is critically investigated to determine the crucial factors which are acting as barriers to I4.0 implementation in LMD. The interpretive structure modeling (ISM) approach is adopted to evaluate different levels with their hierarchal order for analyzing the I4.0 barriers to digitalized logistic networks. Delivery capacity emerged as the major barrier to LMD operational networks due to insufficient technological and hardware support for I4.0 cyber-physical systems in logistics. Infrastructure for I4.0 emerged as the most basic requirement for the smart logistics management criteria for efficient LMD. The need to adopt I4.0 technologies for developing inventory hubs and warehouse management has evolved recently. There is scope for customized and specific case studies for the supply chain to achieve a higher level of sustainability. A conceptual framework for a smart and sustainable supply chain is presented and future directions for sustainable LMD are discussed.

Keywords: Industry 4.0 (I4.0); logistics management; last-mile delivery (LMD); barriers; sustainability; interpretive structure modeling (ISM)

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1. Introduction

The logistics sector is growing at a high rate in global economies, leading to the digitalization of all supply chain processes. Logistics management keeps control of the complete process, from the collection of raw materials for manufacturing units to the last-mile delivery of finished and packed products to the customers. Logistics companies have grown globally and created a major difference at the global competition level. All industrial firms are focusing on increasing their efficiency level at every stage, such as procurement, inventory management, production planning, supply of materials and products, etc. In 2021, the size of the international logistics market reached USD 4.92 trillion, and researchers and industry experts are projecting that the market will rise at a compound annual growth rate of 4.7 percent between 2022 and 2027, which will surpass USD 6.55 trillion [1]. In the present scenario, logistics firms interact with many manufacturers, suppliers, transporters, warehouses, retailers, and delivery services in the supply chain, making logistics management a complex system. This creates a need for optimized technical solutions to meet business and sustainability goals [2].

Many developing nations are becoming manufacturing hubs for global production and supply. In particular, India and China have emerged as global leaders among the developing nations working in the manufacturing and logistics sector. China has dominated the supply chains, with a logistics market size of USD 2.11 trillion in the year 2021 [3]. Many businesses have aimed to increase their digital capabilities, lock in longer-term capacity, and move toward omnichannel integration. In 2021 manufacturing activities and start-up agreements in China increased by more than USD 7 billion, providing an ideal start after the COVID-19 pandemic scenario. China's logistics sector has already digitalized a lot and is quickly progressing towards full automation and I4.0 adoption [4]. The nation has played a significant role in the supply chains of businesses all over the world for many years. Similarly, in the case of India, the logistics industry has been expanding quickly, and by 2025, it is anticipated to reach a value of 380 billion US dollars [5]. The government has started emphasizing localized manufacturing through schemes such as "Make in India" and "Digital India". The emergence of many direct-to-customer service enterprises and the continuous growth of online shopping firms based on e-commerce models promise a better future for the service industry in India [6]. The proportionate size of the manufacturing sector in an economy depends upon the level of technological development. Manufacturing in India, which makes up 16% of the Gross Domestic Product (GDP), has stayed mostly unchanged and has shown a lot less growth compared to other developed nations. India suffers from certain significant technological gaps, and as a result, most estimations place India at the lower level of industrialization. Competitive nations such as Germany and China have also stepped up their efforts in the manufacturing sector to lead the world in technology reforms by having ground-breaking research and development programs such as Industry 4.0 and resource-efficient manufacturing at very early stages.

The Indian supply chain system has already become more efficient since the implementation of digitalized financial transactions such as the Unified Payments Interface (UPI). It has shown a 18–20% decrease in mobility turnaround for providing cash. Digitalization and planned warehouse management have reduced heavy vehicle traffic quite significantly [6,7]. Logistics efficiency has shown improvement through the geotagging of warehouses and the promotion of the "IoT" in warehousing. India's private organizations and the government have shown intentions to develop the logistics sector and implement automation technologies until 2025 [8]. India's logistics estimation graph until 2025 is presented in Figure 1 based on available data sources.

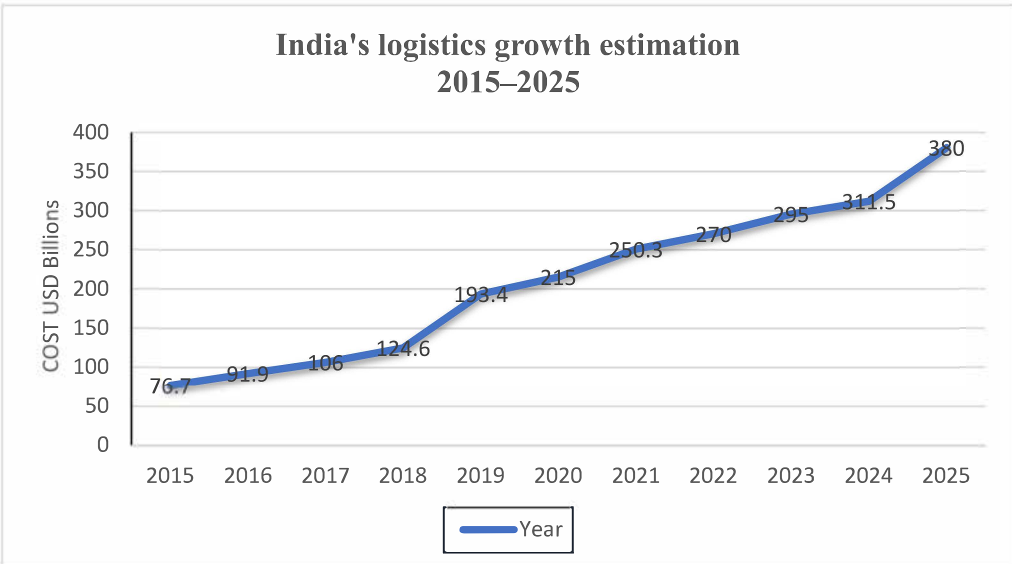

Figure 1. Logistics expenditure estimation for India between 2015–2025 [1,3,9].

Logistics management is required by organizations to provide significant growth in market value. Logistics management comprises many small attributes and all processes are driven by the motive of customer satisfaction. Customer experience by and large depends on the last step of the supply chain, which is last-mile delivery (LMD). It is the bottleneck for many logistics service providers and organizations. It is well known that the most complex part of the whole delivery process is LMD, and technology can provide an impeccable solution to handle the implementation issues [10,11]. The diffusion of I4.0 technologies in logistics management leads to Logistics 4.0. Logistics 4.0 refers to the employment of advanced robots, the Internet of Things (IoT), and big data analytics in managing supply chains to distribute goods and services. This networked system of supply operates with a digital core combined with several data sources, forming a lattice that enables the communication between typically distinct supply chain nodes [12,13]. The typical design plan, material source, production, and delivery present a sequence of a linear supply chain. The IoT has transformed each step of the production process and there is a need to create a Logistics 4.0 that copes with manufacturing units [14]. Businesses will have a wonderful opportunity to embrace just-in-time solutions and various cost-saving techniques in the supply chain in the new Logistics 4.0 era. It is anticipated that data analytics, robotics, and artificial intelligence will completely revolutionize the sector in the upcoming years [15,16].

According to experts, transportation and warehousing facility improvement through technological solutions are the focus areas in the logistics sector [17]. The timely completion of customer orders remains an essential need for the success of any logistics firm [18,19]. Inefficient last-mile deliveries result in stock accumulation and financial loss to any service provider. Industries need to concentrate on finding sustainable and technological solutions for these issues [20]. There is a need to focus on and develop strategies for the development of innovative I4.0 solutions that make logistics management systems more efficient and effective [21]. This study reveals the effective enablers for I4.0 adoption in the logistics sector with the proposed conceptual model to improve supply chain efficiency and performance. It also clarifies the role of the latest I4.0 technologies in the logistics sector for LMD. The I4.0 technology set provides insights to managers for technological advancements, complex systems, and innovative solutions. This paper presents barriers to complex supply chains while adopting I4.0 technological solutions for LMD. The study also provides a conceptual model for the efficient application of I4.0 in the e-commerce sector for successful LMD operations under complexity and constants. E-commerce businesses could incorporate machine learning and AI-based solutions for driver allocation, route navigation, and other services.

2. Literature Review

I4.0 has emerged as a network of technologies creating a difference in present industrial processes and supply chain networks. It has revolutionized the present industrial setup and provided a more connected and controlled environment at the manufacturing stage [22]. The I4.0 technologies in the field of supply chain and logistics can create self-responsive and self-governing networks. I4.0 utilizes a combination of advanced technologies such as AI, ML, big data, etc., in logistics management [23]. The diffusion of I4.0 technologies into logistics provides a new automated supply chain design for maintaining the database and monitoring operations at real-time product flow over the manufacturing cycle and delivery conditions. It keeps a real-time record of all operations in the journey of the product with proper quality standards and transparency.

Every innovation which occurs in the commercial world needs to be profitable, secure, and sustainable. Developing countries such as China and India are trying to establish their place in sustainable technology development by adopting certain strategic policies at different levels. It is difficult for the industrial sector, especially in developing nations such as India, to adopt green logistical techniques [24,25]. Therefore, environmental concerns are also very important aspects of any new technology implementation at the grassroots level. Supply chains face several challenges while implementing a completely new disruptive and creative industrial setup until the changes are mature and established. There are certain barriers during the implementation of new technology, especially when it is a fully pledged technological revolution [26]. It is always welcomed to focus on sustainability and eco-friendly government norms from the initial stage while creating the plan and strategy [27,28]. The need for the deployment of hi-tech infrastructure for the adoption of green and sustainable I4.0 practices is required to be addressed [29]. Misalignments between accepted technology and organizational elements may result in the poor performance of the supply chain networks during the adoption of I4.0 [30]. Some of the major barriers are investigated from the published literature and expert discussion concerning I4.0 implementation in the logistics sector for LMD, and the role and utility of these factors for achieving sustainable solutions are studied in the I4.0 context for LMD. The following Table 1 illustrate barriers to I4.0 in logistics management.

Table 1. Barriers to I4.0 in logistics management.

Synod	Barriers and Sources	Description	Role in Sustainability and Utility in LMD
1	Environmental Concerns [27,31,32]	Environmental concerns consider pollution or the consequences of vehicle emissions into the air on the road or in the water, which act as a pollutant during logistics operations.	1. Any environmental issues with logistics involve energy conversions leading to an increase in carbon footprints. 2. Construction of new roads, rail lines, airports, or ports causes numerous traffic jams in the cities, which cause LMD delays and pollution.
2	Infrastructure [33–35]	A need for numerous hardware installations and software updates creates infrastructure challenges to I4.0. A high-tech (Information and Technology) IT-based infrastructure is required to implement I4.0 technologies in last-mile delivery to create communication.	1. Developments in industrial software systems and the transformation of knowledge from the IT sector to the service sector help to make sustainable and efficient LMD operations. 2. In contrast to earlier revolutions, this one covers a more revolutionary development, the end-to-end digitalization of the logistics industry.
3	Acceptability of Green practices [36–38]	Green practices in logistics management are described as green purchasing, green production, green materials management, green distribution, and reverse logistics. Green logistics refers to new developments in the purchase and delivery of products at the doorstep with the help of green technology innovations (GTIs).	1. In the long run, the many functions in logistics can be automated and digitally recorded, leading to less expenditure on data auditing and maintenance with effective operations. 2. Incorporating environmental consciousness into supply chain management with the help of GTIs can lead to the use of biodegradable packaging and products. It can create challenges in terms of availability and cost.
4	Electronic Data Interchange (EDI) [39–41]	EDI is the process of sending business documents between companies in a standardized format. A common electronic format that substitutes paper-based documents such as purchase orders or invoices is the most basic definition of EDI.	1. The ability of digital logistics networks to collaborate and interact with I4.0 systems is its most significant feature. Typically, it generates an atmosphere that fosters cooperation and a sense of community among manufacturers, shippers, and consumers. 2. EDI message standards serve as the basis for all EDI transactions. For data quality, adequate governance procedures are essential. 3. The selection of useful technologies from I4.0 and their integration are a big challenge for present supply chain managers considering environmental issues.

Table 1. *Cont.*

Synod	Barriers and Sources	Description	Role in Sustainability and Utility in LMD
5	Cost effectiveness [42–44]	I4.0 is primarily associated with investments in fixed assets; both tangible and intangible, these investments are substantial in the logistics sector, as well involving a huge cost initially and cost saving in the long run.	1. Poor decision making and planning in the logistics sector can contribute to expenditures, delivery delays, and damaged goods. Therefore, improving operational effectiveness and scaling back on logistics expenses are essential. 2. Investment in installing technology hardware sensors, such as RFID (Radio Frequency Identification) systems, RTSL (Real-Time Locating Systems), IoT devices, and big data storage, has a significant impact on sustainable logistics networks.
6	Transparency [8,45,46]	The logistics industry, powered by cutting-edge technology, may boost visibility and transparency as a result of digitization throughout the supply chain management. Building a smart system helps increase visibility for enterprises and creates fear of data privacy.	1. Digitization leads to improved supply chain transparency. It helps us to have transparent tracking of the product history with a proper record. It helps in quick response and a better consumer experience with personal data access. 2. It also turns out to be a critical prerequisite, making intra-operational logistics visible, secure, and far more effective than at their earlier levels. 3. Transparency can lead to data scams and privacy matters, so maintaining a safely secured visibility is a difficult task in a smart supply chain.
7	Delivery capacity [47–49]	By precisely projecting delivery timings for each stage of the flow, from preparation and staging through time on site and time back to the delivery pickup point. It can also affect the managment of bulk orders where preferential business is made.	1. Managing demand, warehouse storage, vehicle availability, and manpower during the product delivery cycle within the capacity of the firm is a challenging task. 2. Delivery capacity forecasting tries to determine the availability of products and persons in a time frame at each stage of the delivery cycle. It eliminates the need for time buffers and gives you more delivery capacity without adding staff.
8	Traffic management [37,50,51]	Traffic management is a necessary problem with unexpected vehicles on delivery routes causing delays in LMD. Traffic jams create a lot of noise and air pollution leading to environmental problems.	1. An increasing number of vehicles has created a lot of traffic in cities, leading to long waiting hours in the case of traffic jams. 2. I4.0 technologies, which were initially utilized for in-house industrial purposes, can be consciously applied to enhance city logistics for improving the overall supply chain.

Table 1. *Cont.*

Synod	Barriers and Sources	Description	Role in Sustainability and Utility in LMD
9	Real-Time tracking system (RTLS) [52–54]	Any system that precisely pinpoints the position of a person or an object is referred to as an RTLS. An RTLS is a goal that may be achieved with several asset management and location systems, not a particular system or technology.	1. It requires a lot of infrastructure and electronic devices to monitor the product in real time, even at the last location. 2. With applications such as staff tracking and high-value asset tracking, an RTLS is employed in a variety of sectors. Implementation of an RTLS requires a lot of communication and sensor support, irrespective of the geographies.
10	Vehicle fitness [37,55,56]	It covers the vehicle concerns of availability and health for the last-mile delivery services. A combination of physical and computerized test equipment should be used throughout the examination of vehicle conditions.	1. Poorly maintained and serviced old vehicles cause environmental and life threats to drivers and the local population in the city. 2. The adoption of an efficient vehicle inspection program is advised, complying with the norms or standards of vehicle exhaust emissions for the purpose of improving air quality and road safety.
11	Dynamic Routing [57–59]	Dynamic routing is a networking technique that provides the optimal data routing plan for logistics services. Unlike static routing, dynamic routing allows routers to make decisions based on rapid changes in the logical network topology.	1. Using a set of orders as a starting point, dynamic route optimization in logistics allows for route modifications in response to traffic or weather conditions. 2. Dynamic route planning has scalability and adaptability as its key benefits. The present business needs to be upgraded to utilize the dynamic platform for routing in the I4.0 era.
12	Government Eco-Friendly norms [4,33,60]	The government is making eco-friendly policies for freight carriers to lower emissions and support "cleaner" transportation. It also provides certain subsidies for implementing green practices in smart supply chains.	1. The government comes up with certain eco-friendly schemes and initiatives to ensure environmental balance for sustainable development. They maintain the real-time data by their respective pollution control boards at local and national levels. 2. It is always a challenge to follow strict government policies and norms without compromising on profit margins in the business.

There are crucial factors that significantly influence logistics costs, such as delayed arrivals at ports, which raises the cost of transportation. International trade is governed by complicated regulations (document processing, compliance inspections) and delivery suspensions that are followed by higher warehousing costs [61]. In actuality, the environmental impact of logistics, which moves items within supply chains, goes well beyond the frequently criticized greenhouse gas emissions from freight and passenger travel. The combustion of fossil fuels and the gaseous and particulate emissions from the powertrain are the main sources of vehicular emissions [38]. Warehouses are a danger to community safety, especially if they are filled with hazardous materials [62]. Terminals such as ports, airports, and train stations all contribute to noise pollution, as moving cars and cranes disturb the peace. To better control the environmental effect, I4.0 is an appropriate technology set for mitigating certain ecological issues as per the expert's suggestion [57].

Digitalization is hailed as a tool for achieving clean industry production and supply chain networks [27,63]. Government policies are driven towards a paperless working process with the complete digitalization of databases. Government agencies provide a considerable portion of the energy benefits of the adoption of both novel and proven green technologies. Additive manufacturing in I4.0 is frequently mentioned as eco-friendly GTIs. Its 3D printing technique has been a great revolution in the aviation and transport industry. These industries are manufacturing lightweight engines and body frames, to lower 25% of the existing weight. This results in a reduction in both energy costs and CO_2 emissions [23,64]. On top of that, energy optimization tactics are increasingly using the IoT and AI, particularly for industrial robots and drones [65,66]. A real-time analytic tool for energy performance data management is utilized for achieving environmental goals. According to the energy intelligence report, smart factories are reducing energy consumption by 15% [67].

Environmental supply chain management involves the processes of purchasing, procurement, replacement, reduction, recycling, and reuse. It assures that the logistics network capability is environmentally responsible and builds a cascade of sustainable practices throughout the supply chain. It supports businesses in streamlining their supply chain and cultivating more enduring, cooperative connections with important suppliers to collaborate on environmental challenges. The process of tracking and monitoring supply chain environmental performance is an added advantage of a smart supply chain [68]. There are not many empty places on the map of international economic interactions anymore. This can lead to not only extremely complicated logistical linkages, but also occasionally extensive transit routes that must be completed as soon as feasible. Infrastructure is also not well-developed in all regions, creating a barrier to I4.0 implementation for rural areas [33]. Based on good (Information and Technology) IT infrastructure, the best green practices can be adopted for quick and on-time LMD [69].

Technology integration helps to provide visibility and control across the entire supply chain, enabled by data-driven, real-time decisions, managing from inventory status and manufacturing service interruptions to the supply constraints of logistics [53,64]. EDI is a widely used integration program for technical advancement in the service sector for standardization and digitalization. EDI has become a prominent technology feature for many producers, merchants, suppliers, transporters, and exporters for carrying out the movement of orders [40,70]. It is much easier, quicker, more precise, and environmentally friendly than manually processing paper invoices or purchase orders for maintaining daily, weekly, monthly, and annual reports. The frequency at which assets are tracked is a core part of an RTLS and depending on the application, these data may be used in several ways. RTLS applications merely need timestamps when an object travels through a certain region; other databases require more detailed information and product specifications. It provides visibility and regular data updates [23]. An ideal real-time location system is able to precisely identify and manage assets, products, or people. It also assists businesses in making informed decisions based on the location data received [54].

Vehicle performance capabilities and services become more transparent with high monitoring and control of movement. The deployment of the right vehicle inspection system can reduce air pollution and vehicle emissions, enhancing roadworthiness [63]. There are still a lot of outdated vehicles commuting on the roads, causing harm to the air quality index. According to several studies, even a small number of poorly maintained automobiles may significantly worsen ambient air quality issues, which in turn causes difficulties with urban air quality. Even brand-new cars with cutting-edge technologies start to degrade after a short time in operation and must be properly maintained to keep operating at the correct emissions levels. New technology vehicles that adhere to strict emissions and safety norms need to be applied for transport purposes. The deployment of a successful vehicle inspection system can reduce air pollution and, as a result, reduce vehicle emissions and enhance roadworthiness [71]. Building a sustainable inspection and certification system is the primary goal to lower emissions and increase safety. According to each nation's governing legislation, car owners are expected to examine and maintain their vehicles. The deployment of a successful vehicle inspection system can reduce air pollution and, as a result, reduce vehicle emissions and enhance transport worthiness [72].

The dynamic routing table is needed to be maintained and updated by the routing protocol by installed routers. Numerous protocols and techniques are used in dynamic routing for providing an optimized path for LMD. The widely used protocols are the open shortest path first and routing information protocols. All enterprises consider the cost of routing while designing a path for delivery services. Dynamic routing automates the constraints table and offers the optimum pathways for data transfer considering the least expenses [58].

GTIs and IoT technologies are being used to create eco-friendly, long-lasting, biodegradable products for the future. GTIs include any technological advancements that aid in the creation of important goods, services, or procedures that lessen the adverse effects of pollutants on the environment [73]. Sensors are often employed in IoT environmental monitoring applications to support ecological safety, atmospheric conditions, soil fertility, and air quality. GTIs deal with providing solutions to issues such as carbon pricing, the use of biopesticides, the quality of biopharmaceuticals, green building materials, and bio-based membrane filters. These solutions are crucial for the green recovery of global economies. Eco-friendly technologies, green chemistry, and organic materials management are promoted to separate pollutants and recycle waste. The product engineering of advanced materials and the recycling of electronic waste needs to be performed to achieve sustainable development goals with the help of I4.0 technological amendments.

3. Methodology

3.1. Interpretive Structural Methodology (ISM)

The well-known ISM allows for the visualization of connections between certain elements and factors that constitute an industrial or research problem [74]. Researchers have begun using this method more frequently to illustrate how different aspects of the problem are interconnected. J. Warfield introduced the ISM as a hierarchal modelling technique for the first time in 1973 [75]. It controls the intricate relationships between the confirmed variables involved in a complex scenario. The ISM is frequently used to provide a crucial understanding of difficult situations and to provide a method for resolving a problem. It has been utilized by several high-level organizations and researchers globally [35,76].

3.2. Study of I4.0 Barriers in the Logistics Sector Using ISM

Using an interpretive approach such as ISM from a group of chosen items, the variables may be evaluated to discover connections between them. The sequential process for implementing the ISM in the adoption of I4.0 in the supply chain is shown in Figure 2. To find the appropriate factors and elements, the ISM is found to be a suitable technique [35,75,76]. This study was conducted utilizing a rigorous, professional method.

Figure 2 illustrates the steps for research methodology and the ISM for supply chain adoption of I4.0. A literature research study was conducted during phase one to determine the crucial barriers to I4.0 implementation for LMD operations. Then, the discovered factors and constraints pool of 20 barriers was discussed in a brainstorming session with experts in the second phase. In the third phase, a group of professionals were put together, comprising supply chain managers, entrepreneurs, and directors/professors from technical universities and industries, particularly engineering and management departments. The entrepreneurial propensity characteristics discovered in the literature were used to build a question on each variable, which was then debated with experts in the subject area. The group size might affect group decisions and judgments, so the obtained variables are supported by at least five experts' viewpoints for validity [77,78]. After the expert's advice and suggestions, 12 important barriers were finalized by the authors in the fourth phase. Their role in I4.0 was described, and the formulation of the structural self-interaction matrix (SSIM) was done in the fifth phase of expert discussion. It is based on the contextual interconnections between the elements, which was then followed by the creation of a reachability matrix (RM). Its canonicalization and level partitioning were done using the ISM hierarchal approach. A model was developed with the help of dependent and independent factor classification using MICMAC analysis in the final phase.

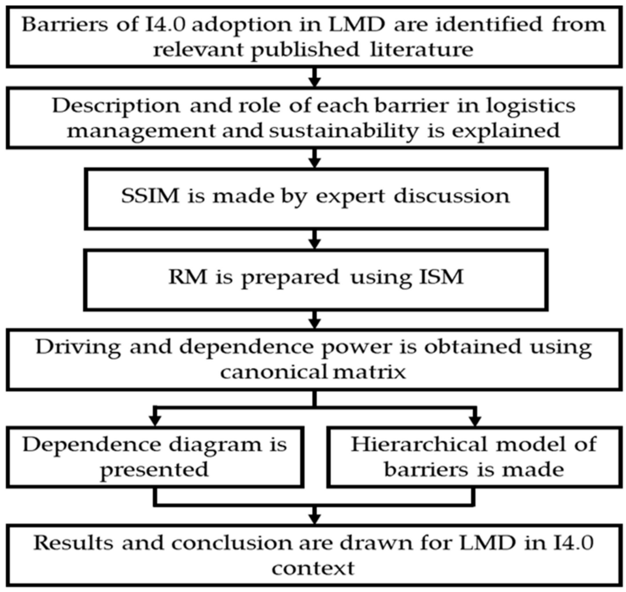

Figure 2. Steps for research methodology and the ISM for supply chain adoption of I4.0.

3.3. Structural Self-Interaction Matrix (SSIM)

By creating an SSIM through element-to-element mapping, employing the following relations, it is possible to identify the links between the sustainability barriers of I4.0 for the application of I4.0 in distribution networks:

V: Factor j is dependent on factor i.
A: Factor i is dependent on factor j.
X: Factors i and j function together to accomplish goals.
O: Factor i and j have no relation.

Table 2 presents the SSIM for the implementation of I4.0 in the supply chain using the above relationship and rules.

Table 2. SSIM for implementation of I4.0 in logistics network.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	X	A	O	A	V	A	O	A	A	A	A	A
2		X	V	V	V	V	V	V	V	O	V	O
3			X	V	V	X	V	V	V	V	V	X
4				X	V	V	V	V	V	V	V	A
5					X	V	V	A	A	A	A	O
6						X	V	V	V	V	V	A
7							X	A	A	A	A	O
8								X	A	A	V	A
9									X	A	V	A
10										X	V	A
11											X	O
12												X

1. Environmental concerns
2. Infrastructure
3. Acceptability of green practices
4. Electronic data interchange
5. Cost effectiveness
6. Transparency
7. Delivery capacity
8. Traffic management
9. Real-Time tracking
10. Vehicle fitness
11. Dynamic Routing
12. Government eco-friendly norms

It is very evident from the above relational SSIM that Environmental concerns are dependent on Cost effectiveness and the rest of the factors rely on it or have no relation. Similarly, Infrastructure is the driving factor for the other variables, except for Vehicle fitness. A similar interpretation can be considered for the other factors/barriers from the above-presented VAXO. This methodology was applied, and the results are presented in the next section.

4. Result and Discussion

4.1. Formulation of RM

The formulation of the SSIM is followed by the development of the RM. The RM is generated to obtain the transitivity of the formulated SSIM from the literature and experts' opinions. This helps to analyze the relationships amongst the various barriers responsible for the hindrance of I4.0 implementation for logistics management. Table 3. presents the developed RM implementation of I4.0 in the supply chain. The RM is the conversion of the formulated SSIM into binary form by substituting V, A, X and O with zeros and ones under the following ISM guidelines:

If (i, j) in the SSIM is V, then, (i, j) in the RM becomes 1 and the (j, i) becomes 0.
If (i, j) in the SSIM is A, then, (i, j) in the RM becomes 0 and the (j, i) becomes 1.
If (i, j) in the SSIM is X, then, both (i, j) and (j, i) in the RM become 1.
If (i, j) in the SSIM is O, then, both (i, j) and (j, i) in the RM become 0.

Table 3. The developed RM implementation of I4.0 in the supply chain.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	1	0	1	0	1	1	1	1	1	1	1	0
2	1	1	1	1	1	1	1	1	1	1	1	1
3	1	0	1	1	1	1	1	1	1	1	1	1
4	1	0	1	1	1	1	1	1	1	1	1	1
5	1	0	1	0	1	1	1	1	1	1	1	0
6	1	0	1	1	1	1	1	1	1	1	1	1
7	0	0	0	0	0	0	1	0	0	0	0	0
8	1	0	1	1	1	1	1	1	1	1	1	1
9	1	0	1	1	1	1	1	1	1	1	1	1
10	1	0	1	1	1	1	1	1	1	1	1	1
11	1	0	1	1	1	1	1	1	1	1	1	1
12	1	0	1	1	1	1	1	1	1	1	1	1

4.2. Canonical Matrix Formulation

The canonical form of the matrix represents an object as a mathematical expression to extract important information through inspection. The RM is then converted into canonical form. It helps to provide insights into the system's internal variance and structure by reducing data transformations and maintenance efforts. Table 4 shows the cluster levels across the rows and columns. The sum of the ones along the row gives the driving power (DRP) and, across the column, the dependency power (DEP).

Table 4. Cluster levels across rows and columns.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**DRP**
1	1	0	1	0	1	1	1	1	1	1	1	0	9
2	1	1	1	1	1	1	1	1	1	1	1	1	12
3	1	0	1	1	1	1	1	1	1	1	1	1	11
4	1	0	1	1	1	1	1	1	1	1	1	1	11
5	1	0	1	0	1	1	1	1	1	1	1	0	9
6	1	0	1	1	1	1	1	1	1	1	1	1	11
7	0	0	0	0	0	0	1	0	0	0	0	0	1
8	1	0	1	1	1	1	1	1	1	1	1	1	11
9	1	0	1	1	1	1	1	1	1	1	1	1	11
10	1	0	1	1	1	1	1	1	1	1	1	1	11
11	1	0	1	1	1	1	1	1	1	1	1	1	11
12	1	0	1	1	1	1	1	1	1	1	1	1	11
DEP	11	1	11	9	11	11	12	11	11	11	11	9	

4.3. Level Portioning Using RM

The elements are then divided into various levels after being clustered over the rows and columns. Each component of the RM has a set of reachability (R_i) and antecedent (A_i) aspects associated with it. Reachability sets form a collection of factors that can be reached from the element (E_i). Antecedent sets are the group of items that allow access to an element (E_i). The RM allows for the development of R_i and A_i. The variables that aid in the formation of the reachability set for a given variable are contained in the reachability set as well as the variable itself. The variable itself plus the other factors that aid in accomplishing it make up the antecedent set. This set's intersection is then verified for all variables and their intersection is determined. The variables that achieve the levels are then eliminated from the remaining variables. The iteration is carried out until the levels of each variable are obtained. These levels determine the importance of each barrier for LMD operations and help to decide the priority order. The level 1, 2, 3, and 4 iterations are shown in Tables 5–8. The RM helps to determine the impact of the barriers on the LMD operations and which operations are more crucial for improving the diffusion of I4.0 in logistics. Table 5 displays the initial I4.0 supply chain deployment iterations (level 1). At level 1, delivery capacity (7) is identified. It is the most crucial factor for improving the efficiency in I4.0, leading to LMD efficiency, and it is acting as a major barrier.

Table 6 displays the second iteration (level 2) of I4.0 adoption in the logistics network. Environmental concerns (1), Acceptability of green practices (3), Cost effectiveness (5), Transparency (6), Traffic management (8), Real-time tracking (9), Vehicle fitness (10), and Dynamic routing (11) are derived at level 2. These factors are also very crucial and have equal importance for creating challenges for the sustainable deployment of I4.0 in LMD operations. These barriers need to be addressed for significant growth in LMD efficiency.

Table 7 displays the third iteration (level 3) for implementing I4.0 in the logistics network. Government Policy (12) and EDI (4) are generated at level 3. It should go without saying that any industry undergoing such a significant technological transition needs government policy assistance, as well as EDI, to manage operations and data.

Table 5. First iteration for implementation of I4.0 in the logistics network.

Barrier	Reachability	Antecedent	Intersection	Level
1	1, 3, 5, 6, 7, 8, 9, 10, 11	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 3, 5, 6, 8, 9, 10, 11	
2	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	2	2	
3	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	
4	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	2, 3, 4, 6, 8, 9, 10, 11, 12	3, 4, 6, 8, 9, 10, 11, 12	
5	1, 3, 5, 6, 7, 8, 9, 10, 11	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 3, 5, 6, 8, 9, 10, 11	
6	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	
7	7	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	7	1
8	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	
9	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	
10	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	
11	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	
12	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	2, 3, 4, 6, 8, 9, 10, 11, 12	3, 4, 6, 8, 9, 10, 11, 12	

Table 6. The second iteration (level 2) for implementation of I4.0 in the logistics network.

Barriers	Reachability	Antecedent	Intersection	Level
1	1, 3, 5, 6, 8, 9, 10, 11	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 3, 5, 6, 8, 9, 10, 11	2
2	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	2	2	
3	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	2
4	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	2, 3, 4, 6, 8, 9, 10, 11, 12	3, 4, 6, 8, 9, 10, 11, 12	
5	1, 3, 5, 6, 8, 9, 10, 11	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 3, 5, 6, 8, 9, 10, 11	2
6	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	2
8	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	2
9	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	2
10	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	2
11	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	2
12	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	2, 3, 4, 6, 8, 9, 10, 11, 12	3, 4, 6, 8, 9, 10, 11, 12	

Table 7. The third iteration (level 3) for implementation of I4.0 in the logistics network.

Barriers	Reachability	Antecedent	Intersection	Level
2	2, 4, 12,	2,	2,	
4	4, 12,	2, 3, 4, 6, 8, 9, 10, 11, 12,	4, 12,	3
12	4, 12,	2, 3, 4, 6, 8, 9, 10, 11, 12,	4, 12,	3

Table 8. The fourth iteration (level 4) for implementation of I4.0 in the logistics network.

Barrier	Reachability	Antecedent	Intersection	Level
2	2	2	2	4

Table 8 displays the fourth iteration (level 4) of I4.0 adoption in the supply chain for the logistics network. At level 4, Infrastructure (2) is derived. Infrastructure is the first and foremost requirement for any industry which wants to have I4.0 implementation for any process. It is the first barrier for any firm to start its journey toward efficient and sustainable LMD solutions.

Table 9 displays the levels of each variable for the implementation of I4.0 in the logistics network. It presents the levels found after iterations of the ISM from the RM and canonical matrix for barriers to I4.0 implementation.

Table 9. Variables with respective levels of I4.0 in the logistics network.

Variables	Level
7	1
1, 3, 5, 6, 8, 9, 10	2
4, 12	3
2	4

4.4. Review of Barriers Obtained

In LMD, barriers are investigated and analyzed using the ISM for I4.0. It is very evident from the above analysis that managing Delivery capacity is the most difficult task in a smart supply chain, followed by Environmental concerns, Acceptability of green practices, Cost effectiveness, Transparency, Traffic management, Real-time tracking, Vehicle fitness, and Dynamic routing. As with new technology adoption, the process takes some time to get going and has a low maturity level; therefore, it is likely that delivery capacity declines and becomes a problem for sustainability and LMD efficiency. Green practices are required to be followed with proper emphasis on environmental and social concerns. Government policy and EDI can offer a common mandate and methodology for I4.0 adoption that is lagging. Infrastructure continues to be the primary and fundamental requirement for this technological transformation since advanced IT systems and IoT-based services networks are required for speedy and effective LMD.

4.5. Levels of Barriers

The ISM provides the priority order that is required to be considered for I4.0 adoption for sustainable LMD. These 12 obstacles may be researched and addressed by the priority framework for enhancing the logistics network in I4.0, taking into account their levels of accomplishment. These levels were discovered by a regressive assessment of the literature, expert analysis, and ISM analysis. The most crucial level for LMD in the I4.0 context is level 1 (Delivery capacity), and the most basic requirement is depicted by level 4 (Infrastructure). The ISM digraph developed after level portioning is shown in Figure 3.

4.6. MICMAC Analysis

MICMAC analysis is carried out with the help of a canonical matrix, where the DRP and DEP are allocated to their respective quadrants [76,78]. A graph is plotted with the DRP, and the DEP is obtained from the results of the matrix. It is divided into four quadrants with elements that have autonomous, dependent, linked, and independent natures. An evaluation of necessary changes and theoretical inconsistencies is performed. The DRP and the DEP of the variables for I4.0 barriers for sustainable LMD are analyzed by the driving and dependence diagram, as shown in Figure 4.

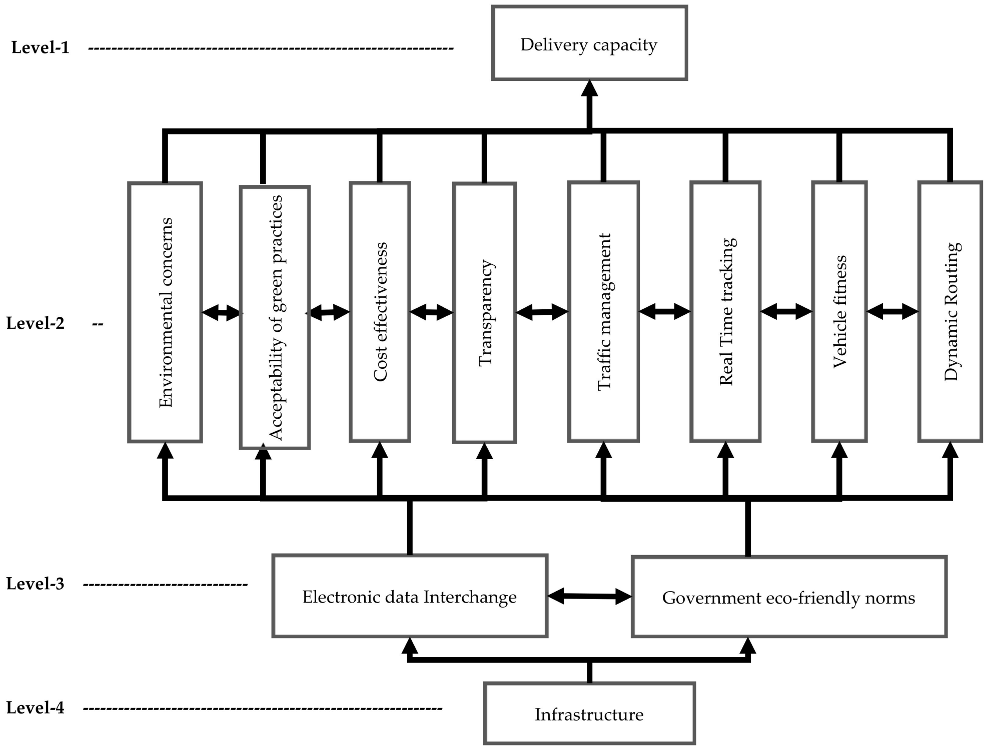

Figure 3. ISM diagraph based on the achieved levels.

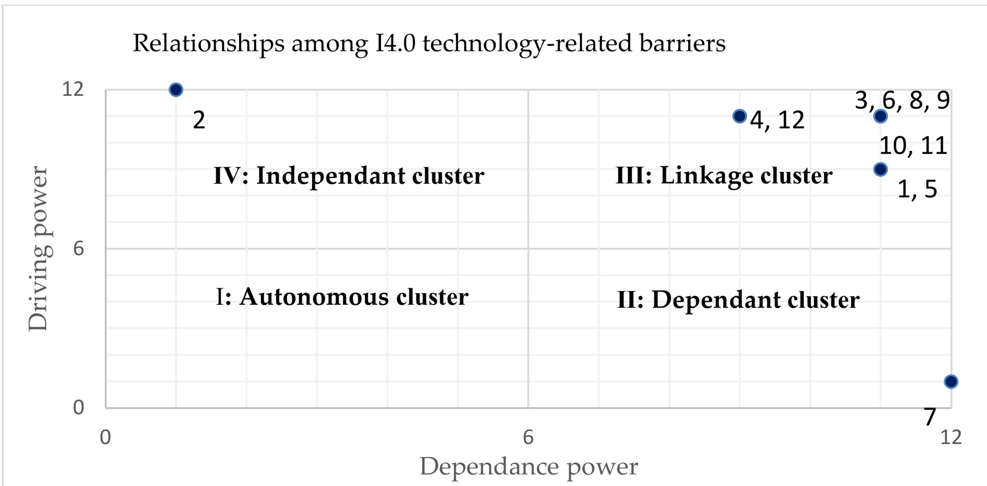

Figure 4. Driving and dependence diagram.

The autonomous cluster's variables are believed to have poor DRP and DEP. No autonomous variable was found to mesh in this cluster. Dependent clusters have factors that have little DRP but substantial dependency on other factors. Delivery capacity is found to be associated here, showing its clear dependency on many constraints. The linkage cluster's variables have high DRP and strong DEP. Eleven of the twelve factors lie in this region, showing their ability to integrate and drive the process. The fourth cluster of variables contains independent variables with a considerable driving force and little dependency. This cluster includes the infrastructure as an independent factor that is required to implement I4.0 in the supply chain and is not affected by logistic processes. It has its standalone importance and driving power that is irrespective of the firm's delivery model.

4.7. Proposed Framework

The proposed framework has integrated the set of all major technologies such as the IoT, AI, big data, robotics, image processing, machine learning, autonomous drones, mobile technologies, RFID, digital twin, and augmented and virtual reality for the supply chain. I4.0 puts sector integration technology at the forefront of its efforts to execute digital transformation. With the primary goal of achieving sustainability, the different distribution levels for LMD activities are detailed, along with the impediments that are influencing them. The outer ring indicates that Infrastructure is a fundamental requirement for I4.0 in logistics and that Delivery capacity will be the biggest roadblock to effective LMD in I4.0 adoption. The framework highlighting barriers of I4.0 technologies for LMD is presented in Figure 5.

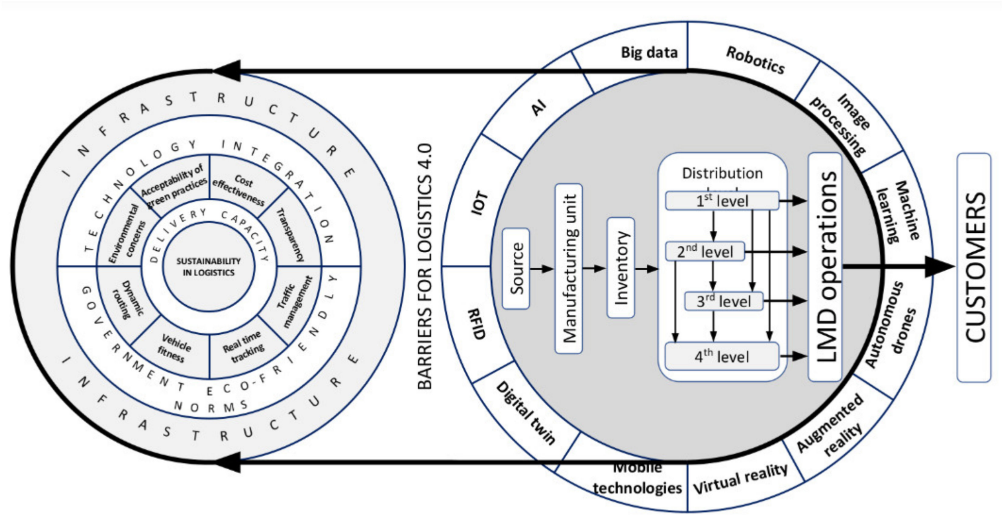

Figure 5. Framework highlighting barriers of I4.0 technologies for LMD.

4.8. Discussion

The various barriers to I4.0 diffusion in logistics management need to be mitigated by adopting various methods and procedures. Delivery capacity comes out to be the most crucial factor, as in the case of dynamic customized production, large inventory maintenance is a difficult task. A lot of issues regarding delivery time and quality of service for high-demand products are needed to be studied and improved. Environmental concerns and the Acceptability of green practices should be taken care of in second order to achieve sustainable growth in the logistics sector. I4.0 has a significant role to play in transportation and green logistics. It incorporates facilities for warehouses, transport terminals, packaging, distribution, and material handling [63].

Traffic management with automation enables the road infrastructure to mitigate waiting time problems and increases road safety. This suggests that if traffic creation is to be avoided, transport ministers need a bigger say in choices about housing, regional development, and land use planning with a proper town development plan. The sustainability process for freight carriers helps to lower emissions and support "cleaner" transportation and supply chains. Vehicle fitness needs to be checked at regular intervals for smooth logistics operations and the air quality index. The success of the green initiative program depends on how well the national awareness campaign is planned and executed. This is a continuous technological upgradation process to achieve the goals of sustainability. The required emission levels and services need to be maintained properly with the movement toward green fuel utilization [79]. The study of barriers is very crucial for any industry which wants to establish I4.0 technology norms. Logistics 4.0 is a buzzword that the public is looking at very closely for its social and environmental effects. Concerns such as carbon footprints, eco-friendly packaging, and biofuel should be taken care of on both the customer's and supplier's sides. Shipping and logistics activities should adopt more eco-friendly transport facilities on a worldwide scale.

Dynamic routing and real-time tracking are difficult tasks without IoT-enabled systems. I4.0 provides a facility to monitor real-time vehicle and product history. It increases the transparency level in the supply chain and helps customers to get the right product in a quick time. I4.0 initially needs a lot of infrastructures to integrate technologies and upgrade the existing industry and service setup. EDI changes the original or "traditional" processes of database management and control for supply chain systems. It acts as a bridge between physical components and all information systems for tracking, monitoring, and executing logistics operations. Cyber-physical systems are classed as a collection of I4.0 technologies for big data collection, data storage warehousing, and analytics [80]. It requires a lot of IT infrastructure investment from industries and government organizations. This investment in digitalization and data management will be very useful in the long run for the business sector. Governments can also promote the I4.0 revolution by subsidizing certain green industry manufacturing units. This will lead the logistics industry toward a sustainable growth model.

5. Conclusions

I4.0 is the next-generation technological advancement that is making its new dimensional approach in every sector. Growth in the service sector depends majorly on customer satisfaction and governmental policies. To resolve the problems of I4.0 adoption in LMD operations, this study provides the major barriers to the adoption of the technology revolution for smart supply chains. The created model clearly explains the many levels at which obstacles exist, as well as their prevalence in the I4.0 supply chain. The study clearly shows that the principal barriers are categorized at four different levels, and these levels must be strategically considered for efficient LMD operations. This helps to determine the importance of each variable and its significance in the I4.0 logistics network. GTIs can enhance the economical, ecological, and technological targets of the e-commerce and retail sectors. Delivery capacity emerged as the major focus area for logistics firms in a digitalized environment to maintain sustainable growth. Multiple supplier database management can enhance the overall efficiency of the supply chain. It will help to utilize the all-dimensional capability of the I4.0 technology umbrella for logistics management. EDI will serve as the primary tool for data management systems in supply chains of the future, supported by I4.0 technologies such as the IoT, blockchain, and artificial intelligence. Environmental concerns, Acceptability of green practices, Cost effectiveness, Transparency, Traffic management, Real-time tracking, Vehicle fitness, and Dynamic routing are found to be major areas of concern for the strategic measures in Logistics 4.0. These factors influence the smart supply chain and logistics involved in the LMD process. I4.0 can provide sustainable and viable solutions for modern-day logistic problems from planning to the distribution of products.

Digitalization with tools such as EDI helps to monitor all activities in the logistics system. EDI helps to create cyber-physical systems integrating real-time problems with virtual and augmented reality. It helps to create a digital twin system with the help of high-tech IT infrastructure. In order to achieve sustainable development, transportation ministers must be more proactive, and proper planning should be done to create digitized green transport zones for the logistics industry. Infrastructure needs to be developed to provide smart LMD services. I4.0 needs well-established, matured cyber-physical and IoT-based infrastructure to create smart logistics networks. Key obstacles in the operational process of logistics for LMD services are determined using the ISM technique. This study is based on juridical and contractual uncertain obstacles with high driving power and low reliance power. This research also shows that organizational obstacles have the largest dependence and the lowest driving power for I4.0 technologies. The findings indicate that "technology infrastructure and digital solutions", "top management commitment", and "governmental standards" are the main determinants of the adoption of sustainable Logistics 4.0. The research's conclusions help decision makers to conceptualize and determine the roadmap for stainable Logistics 4.0's deployment and operationalization. The presented model will help to classify the priority order for resolving the present obstacles for I4.0 for logistics. The report includes recommendations for logistics experts on how to improve performance while pushing digital interventions in a sustainable supply chain.

6. Future Scope

This study has considered standard issues and barriers for LMD operations in the I4.0 scenario. The research may be specifically conducted for particular sectors such as FMCG, health, automotive, shipping and e-commerce to uncover the subtle changes in the demand for business transformation [81]. More aspects of the transition to digital technology can be studied regarding the technology maturity level. Human factors may be considered while conducting the study on the framework of sustainable Logistics 4.0 with social aspects. An empirical study can also be done to find out how sustainable Logistics 4.0 techniques affect a company's competitiveness and annual customer base. A real-world case study could help to establish the proposed sustainable Logistics 4.0 model. It can examine the consequences that organizations experience in terms of profitability and revenue growth. It will be interesting to see the environmental benefits after the execution of a completely digital supply chain for LMD services.

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References

1. Wood, L. *Global Logistics Market (2022 to 2027)—Industry Trends, Share, Size, Growth, Opportunity and Forecasts*; Business Wire: San Francisco, CA, USA, 2022; Available online: https://www.businesswire.com/news/home/20220404005541/en/Global-Logistics-Market-2022-to-2027---Industry-Trends-Share-Size-Growth-Opportunity-and-Forecasts---ResearchAndMarkets.com (accessed on 25 September 2022).
2. Matthess, M.; Kunkel, S.; Xue, B.; Beier, G. Supplier Sustainability Assessment in the Age of Industry 4.0—Insights from the Electronics Industry. *Clean. Logist. Supply Chain.* **2022**, *4*, 100038. [CrossRef]
3. Hua, X. *China's Logistics Sector Reports Steady Growth in 2021*; Chinadaily: Beijing, China, 2022; Available online: https://www.chinadaily.com.cn/a/202202/14/WS620a0b84a310cdd39bc86849.html (accessed on 20 September 2022).
4. Xu, M.; Li, J.; Ping, Z.; Zhang, Q.; Liu, T.; Zhang, C.; Aldieri, L.; Xu, M.; Li, J.; Ping, Z.; et al. Can Local Government's Attention Allocated to Green Innovation Improve the Green Innovation Efficiency? *Sustainability* **2022**, *14*, 12059. [CrossRef]
5. Narayanan, R. *Indian Logistics Sector Is Expected to Reach 380 Billion Mark by 2025 Nilesh Ghule Truckbhejo*; Express Mobility: Noida, Uttar Pradesh, India, 2022; Available online: https://www.financialexpress.com/express-mobility/indian-logistics-sector-is-expected-to-reach-380-billion-mark-by-2025-nilesh-ghule-truckbhejo/2466424/ (accessed on 25 September 2022).
6. Iyer, A. Moving from Industry 2.0 to Industry 4.0: A Case Study from India on Leapfrogging in Smart Manufacturing. *Procedia Manuf.* **2018**, *21*, 663–670. [CrossRef]
7. Priyadarshini, J.; Kr Singh, R.; Mishra, R.; Mustafa Kamal, M. Adoption of Additive Manufacturing for Sustainable Operations in the Era of Circular Economy: Self-Assessment Framework with Case Illustration. *Comput. Ind. Eng.* **2022**, *171*, 108514. [CrossRef]
8. Luthra, S.; Kumar, A.; Zavadskas, E.K.; Mangla, S.K.; Garza-Reyes, J.A. Industry 4.0 as an Enabler of Sustainability Diffusion in Supply Chain: An Analysis of Influential Strength of Drivers in an Emerging Economy. *Int. J. Prod. Res.* **2020**, *58*, 1505–1521. [CrossRef]
9. Sun, S. *Size of Logistics Market in India FY 2017–2025*; Transportation & Logistics: Hamburg, Germany, 2022; Available online: https://www.statista.com/statistics/1288177/india-size-of-logistics-market/ (accessed on 20 September 2022).

10. Mangiaracina, R.; Perego, A.; Seghezzi, A.; Tumino, A. Innovative Solutions to Increase Last-Mile Delivery Efficiency in B2C e-Commerce: A Literature Review. *Int. J. Phys. Distrib. Logist. Manag.* **2019**, *49*, 901–920. [CrossRef]
11. Borghetti, F.; Caballini, C.; Carboni, A.; Grossato, G.; Maja, R.; Barabino, B. The Use of Drones for Last-Mile Delivery: A Numerical Case Study in Milan, Italy. *Sustainbility* **2022**, *14*, 1766. [CrossRef]
12. Winkelhaus, S.; Grosse, E.H. Logistics 4.0: A Systematic Review towards a New Logistics System. *Int. J. Prod. Res.* **2020**, *58*, 18–43. [CrossRef]
13. Ola, J.; Logan, S.; Vallandingham, R.; Fragapane, G.; Wessel, J.; Aili, S.; Hætta, B.; Nakul, S. Logistics 4.0 and Emerging Sustainable Business Models. *Adv. Manuf.* **2017**, *5*, 359–369. [CrossRef]
14. Garay-Rondero, C.L.; Martinez-Flores, J.L.; Smith, N.R.; Caballero Morales, S.O.; Aldrette-Malacara, A. Digital Supply Chain Model in Industry 4.0. *J. Manuf. Technol. Manag.* **2020**, *31*, 887–933. [CrossRef]
15. Salam, M.A. Analyzing Manufacturing Strategies and Industry 4.0 Supplier Performance Relationships from a Resource-Based Perspective. *Benchmarking Int. J.* **2018**, *28*, 1697–1716. [CrossRef]
16. Karpova, N.P. Modern Warehouse Management Systems. *Lect. Notes Netw. Syst.* **2022**, *304*, 261–267. [CrossRef]
17. Bank, R.; Murphy, R. Warehousing Sustainability Standards Development. *IFIP Adv. Inf. Commun. Technol.* **2013**, *414*, 294–301. [CrossRef]
18. Veile, J.W.; Kiel, D.; Müller, J.M. Lessons Learned from Industry 4.0 Implementation in the German Manufacturing Industry Implementation. *J. Manuf. Technol. Manag.* **2019**, *31*, 977–997. [CrossRef]
19. Juliet Orji, I.; Ojadi, F.; Kalu Okwara, U. The Nexus between E-Commerce Adoption in a Health Pandemic and Firm Performance: The Role of Pandemic Response Strategies. *J. Bus. Res.* **2022**, *145*, 616–635. [CrossRef]
20. Pan, S.; Trentesaux, D.; McFarlane, D.; Montreuil, B.; Ballot, E.; Huang, G.Q. Digital Interoperability in Logistics and Supply Chain Management: State-of-the-Art and Research Avenues towards Physical Internet. *Comput. Ind.* **2021**, *128*, 103435. [CrossRef]
21. Gupta, H.; Yadav, A.K.; Kusi-Sarpong, S.; Khan, S.A.; Sharma, S.C. Strategies to overcome barriers to innovative digitalisation technologies for supply chain logistics resilience during pandemic. *Technol. Soc.* **2022**, *69*, 101970. [CrossRef]
22. Zhou, K. Industry 4.0: Towards Future Industrial Opportunities and Challenges. In Proceedings of the 12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD), Zhangjiajie, China, 15–17 August 2015; pp. 2147–2152.
23. Attaran, M. Digital Technology Enablers and Their Implications for Supply Chain Management. *Supply Chain Forum* **2020**, *21*, 158–172. [CrossRef]
24. Goswami, M.; Daultani, Y. Make-in-India and Industry 4.0: Technology readiness of select firms, barriers and socio-technical implications. *TQM J.* **2021**, *34*, 1485–1505. [CrossRef]
25. Chhabra, D.; Kr Singh, R. Analyzing barriers to green logistics in context of Circular Economy and Industry 4.0 in the Indian manufacturing industry. *Int. J. Logist. Res. Appl.* **2022**, 1–14. [CrossRef]
26. Naseem, M.H.; Yang, J.; Xiang, Z. Prioritizing the solutions to reverse logistics barriers for the e-commerce industry in pakistan based on a fuzzy ahp-topsis approach. *Sustainability* **2021**, *13*, 12743. [CrossRef]
27. Mangla, S.K.; Govindan, K.; Luthra, S. Critical Success Factors for Reverse Logistics in Indian Industries: A Structural Model. *J. Clean. Prod.* **2016**, *129*, 608–621. [CrossRef]
28. Kinkel, S.; Baumgartner, M.; Cherubini, E. Prerequisites for the Adoption of AI Technologies in Manufacturing—Evidence from a Worldwide Sample of Manufacturing Companies. *Technovation* **2022**, *110*, 102375. [CrossRef]
29. Sarkar, B.D.; Shankar, R.; Kar, A.K. Severity analysis and risk profiling of port logistics barriers in the Industry 4.0 era. *Benchmarking Int. J.* 2022; *ahead of print*. [CrossRef]
30. Marcon, É.; Soliman, M.; Gerstlberger, W.; Frank, A.G. Sociotechnical factors and Industry 4.0: An integrative perspective for the adoption of smart manufacturing technologies. *J. Manuf. Technol. Manag.* **2022**, *33*, 259–286. [CrossRef]
31. Lahane, S.; Kant, R. Evaluating the Circular Supply Chain Implementation Barriers Using Pythagorean Fuzzy AHP-DEMATEL Approach. *Clean. Logist. Supply Chain* **2021**, *2*, 100014. [CrossRef]
32. Subramanian, N.; Gunasekaran, A.; Abdulrahman, M.D.; Qiao, C. Out-in, in-out Buyer Quality Innovation Pathways for New Product Outcome: Empirical Evidence from the Chinese Consumer Goods Industry. *Int. J. Prod. Econ.* **2019**, *207*, 183–194. [CrossRef]
33. Parhi, S.; Joshi, K.; Gunasekaran, A.; Sethuraman, K. Reflecting on an Empirical Study of the Digitalization Initiatives for Sustainability on Logistics: The Concept of Sustainable Logistics 4.0. *Clean. Logist. Supply Chain* **2022**, *4*, 100058. [CrossRef]
34. Merkert, R.; Bliemer, M.C.J.; Fayyaz, M. Consumer Preferences for Innovative and Traditional Last-Mile Parcel Delivery. *Int. J. Phys. Distrib. Logist. Manag.* **2022**, *52*, 261–284. [CrossRef]
35. Senna, P.P.; Ferreira, L.M.D.F.; Barros, A.C.; Bonnín Roca, J.; Magalhães, V. Prioritizing Barriers for the Adoption of Industry 4.0 Technologies. *Comput. Ind. Eng.* **2022**, *171*, 108428. [CrossRef]
36. Montreuil, B. Toward a Physical Internet: Meeting the Global Logistics Sustainability Grand Challenge. *Logist. Res.* **2011**, *3*, 71–87. [CrossRef]
37. Allen, J.; Browne, M.; Woodburn, A.; Leonardi, J. The Role of Urban Consolidation Centres in Sustainable Freight Transport. *Transp. Rev.* **2012**, *32*, 473–490. [CrossRef]
38. Lu, Y. Industrial Integration: A Literature Review. *J. Ind. Int. Manag.* **2016**, *1*, 650007. [CrossRef]
39. Siddiqui, A.A.; Vita, S. Impact of Logistics Performance on Trade with Specific Reference to Garment Sector in Cambodia, Bangladesh and India. *Glob. Bus. Rev.* **2021**, *22*, 517–531. [CrossRef]

40. Kopczewski, M.; Grobelny, Z.; Płucienniczak, M. Telematics–Electronic Data Interchange/EDI/in Port Transport Logistics. *J. Decis. Syst.* **2020**, *29* (Suppl. 1), 301–311. [CrossRef]
41. Sampaio, P.; Carvalho, A.M.; Domingues, P.; Saraiva, P. Guest Editorial: Quality in the Digital Transformation Era. *Int. J. Qual. Reliab. Manag.* **2022**, *39*, 1309–1311. [CrossRef]
42. Schmidt, C.G.; Wagner, S.M. Blockchain and Supply Chain Relations: A Transaction Cost Theory Perspective. *J. Purch. Supply Manag.* **2019**, *25*, 100552. [CrossRef]
43. Staudt, F.H.; Alpan, G.; Di Mascolo, M.; Rodriguez, C.M.T. Warehouse Performance Measurement: A Literature Review. *Int. J. Prod. Res.* **2015**, *53*, 5524–5544. [CrossRef]
44. Lemardelé, C.; Estrada, M.; Pagès, L.; Bachofner, M. Potentialities of Drones and Ground Autonomous Delivery Devices for Last-Mile Logistics. *Transp. Res. Part E Logist. Transp. Rev.* **2021**, *149*, 102325. [CrossRef]
45. Wong, L.W.; Leong, L.Y.; Hew, J.J.; Tan, G.W.H.; Ooi, K.B. Time to Seize the Digital Evolution: Adoption of Blockchain in Operations and Supply Chain Management among Malaysian SMEs. *Int. J. Inf. Manag.* **2020**, *52*, 01997. [CrossRef]
46. Jena, A.; Patel, S.K. Analysis and Evaluation of Indian Industrial System Requirements and Barriers Affect during Implementation of Industry 4.0 Technologies. *Int. J. Adv. Manuf. Technol.* **2022**, *120*, 2109–2133. [CrossRef]
47. Mothilal, S.; Gunasekaran, A.; Nachiappan, S.P.; Jayaram, J. Key Success Factors and Their Performance Implications in the Indian Third-Party Logistics (3PL) Industry. *Int. J. Prod. Res.* **2012**, *50*, 2407–2422. [CrossRef]
48. Gentili, M.; Mirchandani, P.B.; Agnetis, A.; Ghelichi, Z. Locating Platforms and Scheduling a Fleet of Drones for Emergency Delivery of Perishable Items. *Comput. Ind. Eng.* **2022**, *168*, 108057. [CrossRef]
49. Jennings, D.; Figliozzi, M. Study of Road Autonomous Delivery Robots and Their Potential Effects on Freight Efficiency and Travel. *Transp. Res. Rec.* **2020**, *2674*, 1019–1029. [CrossRef]
50. Ezaki, T.; Imura, N.; Nishinari, K. Towards Understanding Network Topology and Robustness of Logistics Systems. *Commun. Transp. Res.* **2022**, *2*, 100064. [CrossRef]
51. Bachofner, M.; Lemardelé, C.; Estrada, M.; Pagès, L. City Logistics: Challenges and Opportunities for Technology Providers. *J. Urban Mobil.* **2022**, *2*, 100020. [CrossRef]
52. Zhong, R.Y.; Huang, G.Q.; Zhang, Q.Y.D.T. Mining SOTs and Dispatching Rules from RFID-Enabled Real-Time Shopfloor Production Data. *J. Int. Manuf.* **2012**, *25*, 825–843. [CrossRef]
53. Babiceanu, R.F.; Seker, R. Computers in Industry Big Data and Virtualization for Manufacturing Cyber-Physical Systems: A Survey of the Current Status and Future Outlook. *Comput. Ind.* **2016**, *81*, 128–137. [CrossRef]
54. Li, X. RFID-Based Tracking and Monitoring Approach of Real-Time Data in Production Workshop. *Assem. Autom.* **2018**, *39*, 648–663. [CrossRef]
55. Gupta, S.; Borges, R.M. Density-Dependent Fitness Effects Stabilize Parasitic Hitchhiking within a Mutualism. *Funct. Ecol.* **2019**, *33*, 2304–2315. [CrossRef]
56. Chaabane, A.; Montecinos, J.; Ouhimmou, M.; Khabou, A. Vehicle Routing Problem for Reverse Logistics of End-of-Life Vehicles (ELVs). *Waste Manag.* **2021**, *120*, 209–220. [CrossRef] [PubMed]
57. Chandrasiri, C.; Dharmapriya, S.; Jayawardana, J.; Kulatunga, A.K.; Weerasinghe, A.N.; Aluwihare, C.P.; Hettiarachchi, D. Mitigating Environmental Impact of Perishable Food Supply Chain by a Novel Configuration: Simulating Banana Supply Chain in Sri Lanka. *Sustainabilty* **2022**, *14*, 12060. [CrossRef]
58. He, Y.; Wang, X.; Zhou, F.; Lin, Y. Dynamic Vehicle Routing Problem Considering Simultaneous Dual Services in the Last Mile Delivery. *Kybernetes* **2020**, *49*, 1267–1284. [CrossRef]
59. Zhang, M.; Pratap, S.; Zhao, Z.; Prajapati, D.; Huang, G.Q. Forward and Reverse Logistics Vehicle Routing Problems with Time Horizons in B2C E-Commerce Logistics. *Int. J. Prod. Res.* **2021**, *59*, 6291–6310. [CrossRef]
60. Zhang, W.; Zhang, M.; Zhang, W.; Zhou, Q.; Zhang, X. What Influences the Effectiveness of Green Logistics Policies? A Grounded Theory Analysis. *Sci. Total Environ.* **2020**, *714*, 136731. [CrossRef]
61. De Koster, M.B.M.; Balk, B.M. Benchmarking and Monitoring International Warehouse Operations in Europe. *Prod. Oper. Manag.* **2008**, *17*, 175–183. [CrossRef]
62. Holeczek, N. Hazardous Materials Truck Transportation Problems: A Classification and State of the Art Literature Review. *Transp. Res. Part D Transp. Environ.* **2019**, *69*, 305–328. [CrossRef]
63. Khan, J.; Ketzel, M.; Kakosimos, K.; Sørensen, M.; Jensen, S.S. Road Traffic Air and Noise Pollution Exposure Assessment—A Review of Tools and Techniques. *Sci. Total Environ.* **2018**, *634*, 661–676. [CrossRef]
64. Choi, S.H.; Park, K.B.; Roh, D.H.; Lee, J.Y.; Mohammed, M.; Ghasemi, Y.; Jeong, H. An Integrated Mixed Reality System for Safety-Aware Human-Robot Collaboration Using Deep Learning and Digital Twin Generation. *Robot. Comput. Integr. Manuf.* **2022**, *73*, 102258. [CrossRef]
65. Pang, J.; Ong, S.K.; Nee, A.Y.C. Image and Model Sequences Matching for On-Site Assembly Stage Identification. *Robot. Comput. Integr. Manuf.* **2021**, *72*, 102185. [CrossRef]
66. Wang, K. Logistics 4.0 Solution-New Challenges and Opportunities. In Proceedings of the 6th International Workshop of Advanced Manufacturing and Automation, Manchester, UK, 10–11 November 2016; Atlantis Press: Paris, France, 2016; pp. 68–74. [CrossRef]
67. Strozzi, F.; Colicchia, C.; Creazza, A.; Noè, C.; Strozzi, F.; Colicchia, C.; Creazza, A.; Noè, C. Literature Review on the 'Smart Factory' Concept Using Bibliometric Tools. *Int. J. Prod. Res.* **2017**, *7543*, 1–20. [CrossRef]

68. Ali, S.S.; Kaur, R. Effectiveness of Corporate Social Responsibility (CSR) in Implementation of Social Sustainability in Warehousing of Developing Countries: A Hybrid Approach. *J. Clean. Prod.* **2021**, *324*, 129154. [CrossRef]
69. Giusti, R.; Manerba, D.; Bruno, G.; Tadei, R. Synchromodal Logistics: An Overview of Critical Success Factors, Enabling Technologies, and Open Research Issues. *Transp. Res. Part E Logist. Transp. Rev.* **2019**, *129*, 92–110. [CrossRef]
70. Jain, V.; Ajmera, P. Modelling the Enablers of Industry 4.0 in the Indian Manufacturing Industry. *Int. J. Prod. Perform. Manag.* **2019**, *70*, 1233–1262. [CrossRef]
71. Inkinen, T.; Hämäläinen, E. Reviewing Truck Logistics: Solutions for Achieving Low Emission Road Freight Transport. *Sustainbility* **2020**, *12*, 6714. [CrossRef]
72. Villa, R.; Monzón, A. A Metro-Based System as Sustainable Alternative for Urban Logistics in the Era of e-Commerce. *Sustainbilty* **2021**, *13*, 4479. [CrossRef]
73. Mirzaei, M.; Zaerpour, N.; de Koster, R. The Impact of Integrated Cluster-Based Storage Allocation on Parts-to-Picker Warehouse Performance. *Transp. Res. Part E Logist. Transp. Rev.* **2021**, *146*, 102207. [CrossRef]
74. Kumar, S.; Raut, R.D.; Narwane, V.S.; Narkhede, B.E.; Muduli, K. Implementation Barriers of Smart Technology in Indian Sustainable Warehouse by Using a Delphi-ISM-ANP Approach. *Int. J. Product. Perform. Manag.* **2022**, *71*, 696–721. [CrossRef]
75. Warfield, J.N. Crossing Theory and Hierarchy Mapping. *IEEE Trans. Syst. Man. Cybern.* **1977**, *7*, 505–523. [CrossRef]
76. Bakhtari, A.R.; Waris, M.M.; Sanin, C.; Szczerbicki, E. Evaluating Industry 4.0 Implementation Challenges Using Interpretive Structural Modeling and Fuzzy Analytic Hierarchy Process. *Cybern. Syst.* **2021**, *52*, 350–378. [CrossRef]
77. Anderson, T.; Liam, R.; Garrison, D.R.; Archer, W. Assessing teaching presence in a computer conferencing context. *J. Asynchronous Learn. Netw.* **2001**, *5*, 1–17. Available online: http://hdl.handle.net/2149/725 (accessed on 25 September 2022). [CrossRef]
78. Kapse, C.P.; Kumar, A.; Dash, M.K.; Zavadskas, E.K.; Luthra, S. Developing textile entrepreneurial inclination model by integrating experts mining and ISM-MICMAC. *Int. J. Prod. Res.* **2018**, *56*, 4709–4728. [CrossRef]
79. Qureshi, M.R.N.M. A Bibliometric Analysis of Third-Party Logistics Services Providers (3PLSP) Selection for Supply Chain Strategic Advantage. *Sustainability* **2022**, *14*, 11836. [CrossRef]
80. Cheng, Y.; Chen, K.; Sun, H.; Zhang, Y.; Tao, F. Data and Knowledge Mining with Big Data towards Smart Production. *J. Ind. Inf. Integr.* **2017**, *9*, 1–13. [CrossRef]
81. Bag, S.; Yadav, G.; Dhamija, P.; Kataria, K.K. Key Resources for Industry 4.0 Adoption and Its Effect on Sustainable Production and Circular Economy: An Empirical Study. *J. Clean. Prod.* **2021**, *281*, 125233. [CrossRef]