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Logistics 4.0: a systematic investigation leading to an innovative logistics system

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Abstract: **It examines the development and effects of supply chain management and logistics in the context of Industry 4.0, the fourth industrial revolution. This research explores how logistics operations could include modern digital technologies such as cyber-physical systems, machine learning, artificial intelligence (AI), Internet of Things (IoT), and big data analytics. The study shows the shift towards smart factories by examining the evolution from previous logistical phases to Logistics 4.0. It highlights the importance of connectivity, automation, and real-time data availability. The goal of the research is to give a thorough understanding of how these technologies affect current logistics by increasing efficiency, flexibility, and adaptation, which will eventually shape supply chains in the future.**

Keywords: **Logistics 4.0, Industry 4.0, Industry Evolution, Internet of Things (IoT), Artificial Intelligence (AI), Supply Chain Management, Automation.**

1. INTRODUCTION

The fourth mechanical transformation, or "industry 4.0," is characterized by utilizing advanced innovations in generation and manufacturing methods. To build smart factories and increase production efficiency, it entails utilizing technologies like the Internet of Things (IoT), artificial intelligence (AI), machine learning, big data analytics, and cyber-physical systems.

A key component in the value chain for manufacturers, suppliers, and retailers is now logistics. They cannot compete in the market if they do not have the right goods in the right quantity and quality at the right time, at the right place, in the right condition, and at the right cost. These are the popular essentials for logistics [1].

Addressing these demands is becoming more and more challenging in a logistical environment that is unpredictable and continually evolving. Large, complex logistic networks and extremely dynamic, unpredictable logistic markets call for new methods, goods, and services. The modern consumer creates both new opportunities and challenges for logistics. Traditional supply chains are giving way to open supply networks.

The integration of new intelligent technologies is necessary to achieve aspects like flexibility, adaptability, and self-organization, which are becoming increasingly important. Technology-driven initiatives have the potential to bring about significant and even drastic changes, whereas problem-initiated approaches typically only result in small improvements [2].

Value chains and networks are already changing as a result of the start of the fourth industrial revolution. Modern machinery, storage systems, logistical equipment, and products can all communicate with one another thanks to broad connectivity, which enables autonomous actions and continuous activity control. Complete transparency from supplier to customer, networked processes, decentralized management, as well as affordable small batch manufacturing, and a large variety of variants, are the main features of the Industrial Internet. Only a digitized supply chain shaped by Logistics 4.0 can achieve these goals [3,4].

The prominent feature of Logistics 4.0 is its usage and implementation across the world in a supply chain process. There are numerous technological systems such as WMS (Warehouse Management System, TMS (Transportation Management System), driverless distribution systems, and interconnected containers. These components alone make up only a portion of the digital supply chain. Their contribution must be incorporated into the wider concept of total connectivity throughout the supply chain. This research paper reviews earlier versions and presents the "Logistics 4.0" concept, focusing on the subject of what revolutionary changes would result from the fourth industrial revolution.

2. REVIEW OF THE LITERATURE

- Evolution of Logistics Process

There have been three major changes in logistics in the past. The "mechanization of transport" in the late 19th century is what led to the first invention, logistics 1.0, and the early 1900s. The "automation of handling system" from the 1960s is the inspiration behind the second invention, Logistics 2.0.

"The system of logistics management" from the 1980s is an image of the third innovation (Logistics 3.0). We are currently at the start of Logistics 4.0, the fourth innovation in logistics. The Internet of Things and Services is the primary motivation.

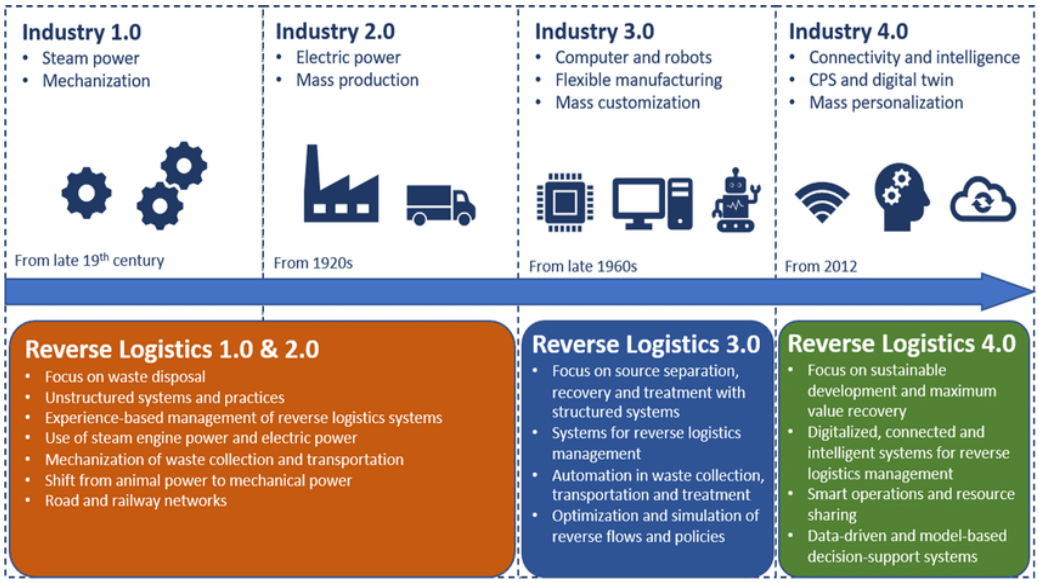

Fig. 1. Evolution of Logistics Process [5]

1. Logistics 1.0: The word "logistics" has French linguistic roots; it is derived from the term "logic," which denotes agreement among organizations. The preparation and transportation of military forces by armies were expressed through the idea of logistics in the early 19th century. In 1964, logistics emerged as a commercial activity and was initially named business logistics. At that point, business logistics only included the actual delivery of goods. The optimization of the first three letters of place, period, and pattern—P3—is what logistics is all about [6].

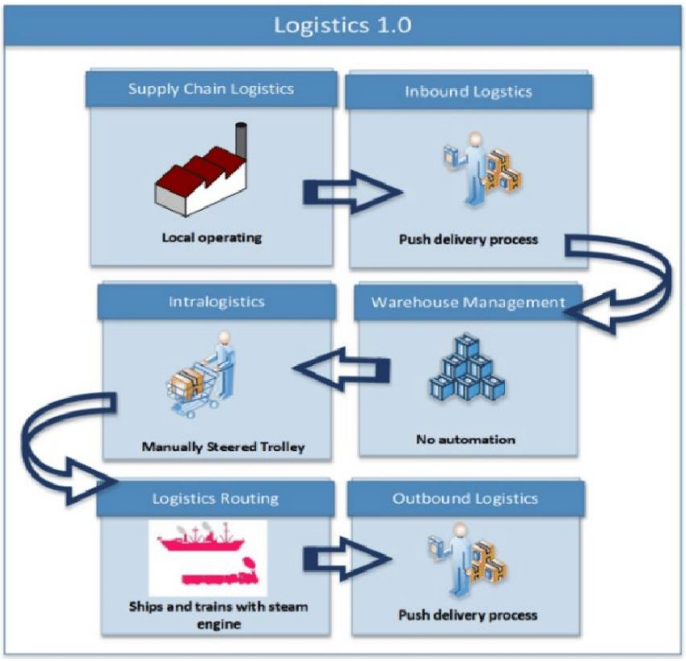

Fig. 2. Logistics 1.0 [8]

Place (both location and destination); to add value for consumers by transporting things to areas that offer the most value. Period, Pace, and Speed (time value); to focus on time and provide value for customers. At the same time, this condition becomes better for stock management.

Pattern (buy orders); to provide value through an order by highlighting the products' chosen models [7].

The first-ever change in logistics was the Manual process given place to machinery. Life in the countryside gave way quickly to industrial life. During this time, machines utilized for the transportation of people and goods replaced manual tools and animal power. James Watt's introduction of the steam machine in 1782 marks the revolution's ultimate achievement.

It is acknowledged that the first innovation in the logistics industry was mechanization in transportation in the late 19th and early 20th centuries. To properly transport goods and containers over large distances, steam-powered ships, and trains began to replace the power of people and animals as the primary mode of transportation. [2].

2. Logistics 2.0: the second industrial revolution was all about mass production and its importance. Cargo handling automation was viewed as a development in the logistics industry [9]. Companies began interacting with one another in the 1980s to control and coordinate physical flow both within and outside of their buildings Logistics 2.0 explored how to raise the optimization level for additional process improvements. As a result, there was a rise in the level of interaction between various businesses that serve as one another's suppliers. As a result, the coordination process between various entities that are a part of the same chain was the focus of Logistics 2.0 [6].

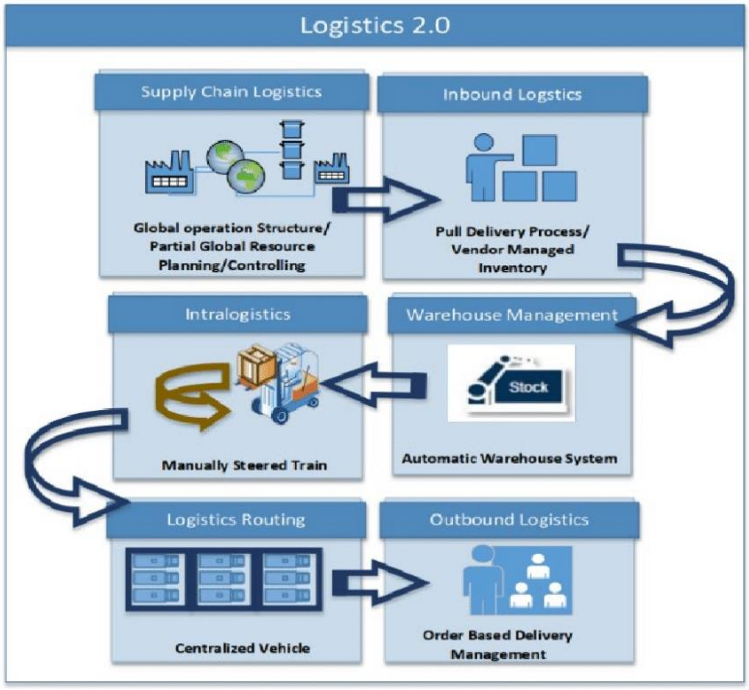

Fig. 3. Logistics 2.0 [10]

The automation of cargo handling is the second achievement in logistics, and it is named after the development of electric power and mass production in manufacturing. The majority of the heavy lifting in logistics may be performed by electrically motorized machinery because of the practical usage of logistic equipment, such as automated loading and unloading systems, automated warehouses, and automatic sorting systems. The mechanism for managing goods at ports is modified by the regular use of container ships.

3. Logistics 3.0: When the first industrial robot was produced in 1968, the third industrial revolution—also known as Industry 3.0—began. Also, the industry was introduced to Numerically Controlled (NC) machinery at that time. In the field of logistics, "Systems of logistics management" gave rise to the third logistical revolution. After Logistics 2.0 companies divided their activities into Product Development, Operation & Supply Chain Management.

Automating and improving logistics administration, inventory, and dispatch has been made much easier with the introduction of IT systems in logistics, such as WMS (Warehouse administration System) and TMS (Transport Management System). Given these conditions, it became necessary to add the fifth "p" to the 4Ps (Place, Period & Pace, Pattern, and

Process Coordination/Partnerships management) to optimize logistics-related tasks. The name of this new "p" was "Pliancy." Businesses in that new era concentrated on managerial decision-making, financial flows, service flows, workflows, and idea-generating processes—all the flows that add value for the client.

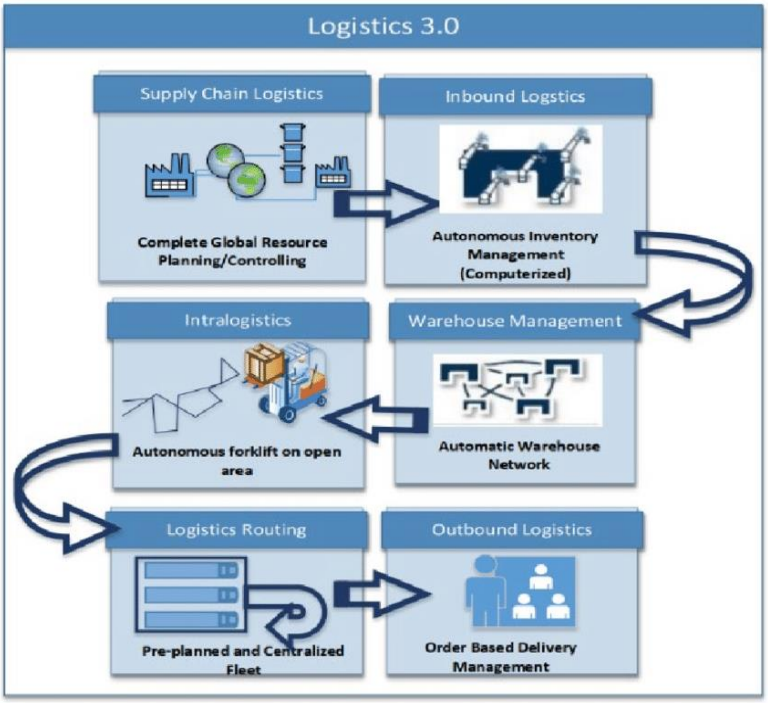

Fig. 4. Logistics 3.0 [11]

4. Logistics 4.0: In Germany, the phrase "industry 4.0" was first used in 2011. Around the same time, other European nations started implementing significant improvements known as "Smart Manufacturing facilities," "Industrial Internet of Things" (IIoT), or simply Smart Industry [12].

Industries 4.0 refers to the idea of linking products, systems, machines, and people so they can communicate, share information, and take care of one another and themselves. According to this model, everything is a living thing with the capacity to independently regulate, and interact with its surroundings. It refers to the total digitalization and automation of company processes as well as how they interact with the outside world. This results in the creation of a virtual reality model that makes it feasible to oversee and control every procedure and activity. Information and communication technology, software programs, and information platforms play the most important role in Industry 4.0 since they enable the connection of real and virtual business systems [13].

It is defined by a rise in digitalization and the interdependence of new business models, value chains, and goods. This idea stands for a new management standard and control over the value chain throughout a product's life. The cycle's starting and finishing points are the product idea, client request, design, manufacture, order placing, delivery, and recycling. All supply chain operations as well as extra steps involved in adding value to the product are included in the value chain. The foundation of Industry 4.0 is the real-time availability of all necessary data. This is achieved by linking every step in the value chain [14]. The imperative parts of the new industrial revolution are Cyber-Physical Systems (CPS), IoT, IoS, Robotics, Big Data, Cloud Computing, and Automatic Guide vehicles.

All parties involved in the supply chain, from suppliers to customers, will have access to the supply chain management, which will be a large network. All orders from suppliers and customers are managed online and in real-time via an Internet platform.

A routed program based on predictive incoming logistics drives autonomous forklifts, AGVs, and robots, fully automating the intralogistics, or transportation of items within the factory. Every logistical operation will rely on data obtained from the internet platform that all parties utilize.

Because the orders for suppliers and customers are handled simultaneously, the cost of the warehouse can be minimized or possibly eliminated [15].

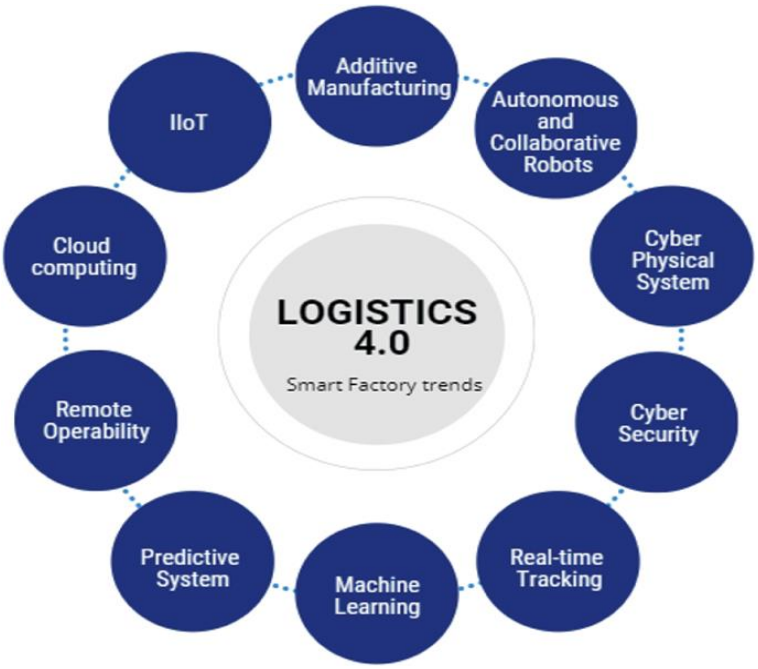

Fig. 5. Logistics 3.0 [11]

New processes are enabled by new comprehensive software solutions. Tracking helps determine an object's position and delivery status. Using tracing, one can examine the value-added chain systemically. Logistical processes, security duties, and paperwork all make use of video control. The video sequences are automatically inspected, and in response to anomalous circumstances, the actors act out or offer indications. AR contributes to improved process quality by preventing logistical errors and boosting worker productivity by cutting out useless search procedures. Within the context of an integrated strategy, SCM enables the discovery of potential savings and the prevention of performance losses. The foundation of big data is data analysis methods for identifying patterns and other useful information [16].

3. OVERVIEW OF INDUSTRY 4.0

All things considered, industry 4.0 involves incorporating revolutionary ICTs (information and communications technologies). Implications of different technical components have fostered intelligent product networking. The ensuing introduces the fundamental technical elements of Logistics 4.0. These include networking, smart sensing, real-time location, data analysis, automatic identification, and business services technology.

1. Big Data: Technologies for storing, transmitting, processing, and analyzing massive volumes of data that are not suitable for being saved, processed, and analyzed by standard instruments and database technologies are referred to as big data. Such data sets can provide new knowledge and information through the application of various analytical techniques, which can have an impact on management and decision-making within the business system [17] Finding hidden links, logic, rules, and knowledge inside the data is made possible by data mining. DM can be used to forecast user behavior, and market trends, identify the root causes of illnesses, and more.

2. Internet of Things: The Internet of Things (IoT) is built on the most advanced ICT, which allows for intelligent object management, communication, tagging, and identification. According to this theory, objects develop into intelligent beings capable of identification, dialogue, and interaction. The development of a virtual reality model, made possible by the realization of IoT, will allow business models to control processes and activities in real-time based on data about the current status of things. The implementation of identification technologies across many logistical objects has resulted in the creation of intelligent containers, pallets, packages, trucks, shelves, forklifts, infrastructure, ports, and terminals, among other things. Various Internet-based connectivity models can be found in logistic systems, which are first-generation IoT solutions that eventually enable worldwide connectivity for all users and items.

3. Real-Time Locating System: Usually used in a building or other enclosed space, real-time locating systems (RTLS) are used to automatically identify and track the location of objects or persons in real time. Wireless RTLS tags are worn by users or fastened to objects. In the majority of RTLS, the tags' location is determined by the fixed markers receiving wireless signals from the tags.

Pallets of merchandise in a warehouse, medical equipment in a hospital, and vehicles being tracked through an assembly line are a few examples of real-time locating systems. It includes numerous aspects such as Time of arrival (ToA), Line-of-sight (LoS), Multilateration (Time difference of arrival) (TDoA), Angle of arrival (AoA); Two-way ranging (TWR) and time-of-flight (ToF).

4. Wireless Sensor Network: Systems with a sensor and a wireless communication network make up wireless sensor networks or WSNs. It makes it possible for network users, access devices, and sensor nodes to gather and exchange data. Sensors are used to identify items and their physical attributes, such as equipment and traffic infrastructure, locations in warehouses and sales facilities, containers, and qualities of goods [18]. Provide some examples of how WSN is used in logistics: sensors are installed in transport and transshipment equipment, infrastructure, and facilities; work clothes with built-in sensors improve worker safety and health conditions; etc. Quality control of goods is based on analysis of data obtained from sensors.

5. Automatic Guided Vehicles (AGV): For almost 60 years, Automatic Guided Vehicles (AGV) have been utilized in a variety of industrial settings, production workflows, and storage facilities. Unmanned ground vehicles, or AGVs, are powered by artificial intelligence, other ICT, and sensor and video detection technology. Tractors for pulling trailers, unit load vehicles, pallet trolleys, trolleys with extra forks, light load vehicles, assembly line vehicles, special vehicles, etc. are examples of AGV vehicles that are utilized in logistic processes. These vehicles allow for the automated management of equipment and freight, making them useful for previously difficult jobs. The use of AGVs in logistical processes lowers labor costs and increases productivity, dependability, safety, and job quality. It also reduces the chance of errors made by humans and damage.

6. Warehouse Management System: Warehouses have long been an essential center for the movement of commodities in a supply chain. However, they also need to be a major source of competitive advantage for logistics providers in the current economic environment [19]. Adopting the Industry 4.0 concept will bring about significant changes in the modern warehouse workflow.

In particular, the right adoption and deployment of Warehouse Management Systems (WMS) would enable the introduction of "smart" management, which will turn warehouse operations into what the Industry 4.0 concept calls for in terms of incoming logistics [20]. The necessary integration amongst the many supply chain participants will provide complete coordination and alignment across all value chain stages. Thus, to optimize just-in-time and just-in-sequence delivery, for instance, transports will be able to send their position and anticipated arrival time to the intelligent warehouse management system, which will then be able to choose and set up a docking slot. The RFID sensors will simultaneously notify the whole supply chain of what has been delivered and provide track-and-trace data. By the delivery details, the WMS will automatically assign storage space and request the necessary machinery to move the goods to the proper place on its own. Pallets are moved to their designated position, and tags then send signals to the WMS to give real-time visibility into inventory levels. This could help avoid expensive out-of-stock scenarios and improve management's ability to make adjustments [21].

4. CONCLUSION

In conclusion, this paper has provided a comprehensive overview of the evolution and impact of Industry 4.0 on logistics, highlighting the transformative changes brought about by technological advancements. From the mechanization of transport in Logistics 1.0 to the digitalization and automation in Logistics 4.0, each phase has introduced significant improvements in efficiency, cost reduction, and process optimization. The integration of technologies such as Big Data, IoT, RTLS, WSN, AGVs, and WMS has revolutionized supply chain management, enabling real-time data sharing, enhanced tracking, and automated operations. Despite these advancements, it is acknowledged that manual warehouses will continue to exist, emphasizing that logistics remains a people-driven industry where well-managed warehouses will outperform poorly run ones in terms of output, innovation, quality, and safety. The future of logistics lies in the seamless integration of these innovative technologies, ensuring a more efficient, flexible, and responsive supply chain capable of meeting the dynamic demands of the global market.

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