Industry 4.0 and Autonomous Transportation: The Impacts on Supply Chain Management

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Abstract. Within the span of three centuries of industrial revolution and through the introduction of modern technology, the environmental and socio-economic impacts are of greater importance than ever. The gradual but steady adoption of autonomous transportation in Industry 4.0 (I4.0) is now a growing research area and on identifying ways for industries to operate their functions. The implementation of autonomous guidance vehicles in all aspects of human life, from self-driving cars and unmanned aircraft, to package delivery drones and robot vacuum cleaners, is a clear indication that the future is here now. The potentials for cost reduction and profit maximisation have been realised by the involved corporations and a significant number of them is already investing heavily on the new technologies. This has become a critical factor when designing and implementing such autonomous guided vehicles (AGV) and the introduction of more eco-friendly technologies will be of vital importance for their future development. The paper aims to focus on the impacts of Autonomous Transportation that affects the logistics industry and will explain the reasons that have led to the ever-growing adoption of AGV's but will also take into consideration the desire of humans to retain final control over their creations.

1 Introduction

In 1898 Nikola Tesla performed his first demonstration of a concept vehicle, the unmanned surface vehicle (USV) [1]. Although Tesla was a pioneer in engineering, it was an era in which supply chain and logistics were unborn. After 120 years and since Industrial Revolution 1, subsequent industrial revolutions have driven manufacturing in radical evolutions, from steam energy to electrical and digital automated production. The processes of manufacturing have become increasingly sophisticated, automated and sustainable, at a level that workers can operate machineries simply, efficiently and effectively [2]. The term autonomous guided vehicle (AGV) after a century sounds the same with Tesla's USV and practically is the same indeed. The difference between them is 100 years of evolutional technology if AGVs are connected and depended, like a gear is to a machine, on a new system of applications and services such as the internet of things (IoT), the cyber-physical systems (CPS), the block chains, the big data and the virtualisation. These tools represent a new industrial revolution, the fourth. The industry 4.0 is the mainstream, up to date digitalised industry which is not yet mature enough to be established completely but it is already started its flight and is at the phase of "take off". The next two decades, people will not only experience it, but it will be a routine in all sectors of life as we see in science fiction movies. This paper examines the application of autonomous transportation systems within the supply chain and their impact on logistics. The findings of this research have led to the creation of three divisions of impacts: economic, environmental and social. Paradigms of certain studies prove the demand for automatisation in industries. The results have mostly positive impacts on many different sectors such as Car industry, Manufacturing industry, Chemical industry , Energy production industry, Hospital industry, Pharmaceutical industry, Food and Beverage industry, Warehousing industry [3], and a collection of advantages and disadvantages of AGVs presented also as a result of clarification between specialists of the sector by exploring on their websites, as long as AGVs are not a good fit for every industry or set of operations [4].

2 Literature Review

The research methodology used to prepare this article is bibliographical and comparative. Initially, information was collected, sorted and analysed from reliable bibliographic sources, and the data were then compared, ranked, and concluding remarks were made. Several publications have been analysed in international scientific journals or key-word conferences and books such as "autonomous guided vehicles", "industry 4.0", "industrial revolution", "digitalisation", "autonomous transportation"," AGVs impacts", "supply chain", "logistics", etc.

2.1 Industry 4.0 and Big Data

As defined by many studies, the industry 4.0 or the fourth industrial revolution is the combination of the existing information and communication technologies together towards the production of products and services. Some researchers also define it as the complete automation, digitalisation and the cybernetics of all aspects and interactions with humans (cloud computing,

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cyber-physical systems, internet of things and other). The introduction of industry 4.0 within manufacturing and production environments is regarded highly as the greatest impact over the entire supply chain. Collaboration through suppliers, manufacturers and customers is very important to enable the transparency through the order processing stages through the product lifecycle. Similarly, due to the advancement and introduction of digitalisation and automation of many processes, supply chain management structures are also impacted. To understand and evaluate the opportunities and threats from the introduction of some of these technological advances, it is necessary to analyse the impacts of industry 4.0 (I4.0) and that of Big data adoption on the supply chain. Hence, this paper aims to examine the preliminary analysis of I4.0 on SCM and will aim to provide further insight towards the conceptual idea and introduction of SCM 4.0 concepts [5]. Most of the industry 4.0 and that of its interconnection focusses towards the key functions such as procurement, logistics and transport, warehousing and order fulfilment. As suggested by earlier research study that Industry 4.0 involves an overview on ways that production floor is currently operating. With the introduction of digitalisation and that of the World Wide Web, the industrial and commercial communities consider this change as the fastest moving industrial revolution within the manufacturing and services industries. Some of the transformations observed focusses towards improvement within all aspects of manufacturing process, from design, development, manufacturing, operations and service optimisation.

The first discovery and identification was carried out in Germany, however there has been many similarities and that of differences towards the concepts of I4.0, including that of early 3D printing (also referred as Additive Manufacturing), Smart Manufacturing, Advanced Manufacturing, Smart Factories, Factories of Future (FoF) and Industrial Internet of Things (IIOT). Although, our study mainly focusses towards industry 4.0 and that of autonomous transportation methods within supply chain management, with studies relating to logistics, transportation and shipping sectors, there are far more examples and existing literature that focuses towards manufacturing environments. For example, Smart factories are mainly seen as towards the use of innovative digital advancements such as cloud computing, internet of things, big data and big data analytics, additive (3D) manufacturing, robotics and automation, and digital services. Within the transportation and logistics environments, the digital and automation is heavily influencing through more advanced robotics and automation, including navigation and global positioning systems, delivery and scheduling technologies, and that of single sharing platforms across multiple stages of supply chain entities [5].

2.2 Supply Chain Management and Sustainability

Sustainability triple bottom lines are becoming an inseparable part of every business environment in today’s world. Likewise, environmental impacts, social well-being and increase of profitability are being taken into consideration within all the operations and components of every supply chain network. Hence, it can be interpreted that sustainability dimensions can be applied through entire processes within the supply chain, from where the raw materials are being obtained to their processing, customer delivery and recycling or disposal stage. This evaluation basically refers to the life-cycle assessment of products from their cradle to cradle which is a new term replaced by cradle to grave due to the full closed loop of recycling of most of the products

Considering the environmental responsibility of autonomous transportation, the sustainable product design, sustainable supply chain design and product stewardship need to be considered. From upstream suppliers to downstream end-users, sustainable product design itself requires a robust design team working on material efficiency, sustainable production, sustainable usage and effective recovery. Autonomous transportation is a novel industrial advancement and requires extra budgets and technological improvements; therefore, moving further and going green with the aid of techniques such as Industry 4.0 would be even trickier which needs specific infrastructures and investments. Considering social factors, there would be a challenge within human-oriented usage or corporate social responsibility (CSR), meaning that as a negative point, by increase of autonomous transportation usage, millions of people become unemployed while losing their working skills and reducing their life expectancy as well as several social harms. However, AGV is a potential threat to jobs of taxi and bus drivers and other forms of group travel, the outsourced driving accounts for only 2% of personal transportation. In terms of economic impacts, the use of automotive vehicles will gradually become universal soon and it is predicted that with gaining a large share of automotive market, the economic impacts of so would be potentially over $1.2 trillion or $3800 per American per year [6].

However, AGV is still in its infancy stages and hence, these statistics are uncertain and would change within the next few years. The benefits of AGV will affect the routine life of society and businesses such as reduction of congestion, traffic police, legal services, and economic savings in auto repair, medical, insurance and law industries, car crashes by human errors, increased productivity and hands-free driving environment. Considering all the points, significant areas of future research studies should be addressed. One of the focus area is to develop methods and practices to redesign urban landscapes that will enable to correspond towards autonomous vehicles and transportation services. Similarly, research should also emphasise towards developing responsive methods and tools to address any human job losses in workforce and infrastructure, and the different types of transportation systems.

2.3 Impact of I4.0 and Automation on SC Logistics

The application of Information and communication technologies (ICT) towards efficiency of modern manufacturing operations, supply chains and distribution networks are inevitable. Specifically, within the Industry 4.0 context, there are some challenges regarding the linkages between IoT and the logistic networks, for instance the key success factors of supply chain such as supply chain visibility and delivery of the goods at right quantity, right time, right place, right condition and accurate cost [7]. Due to the variable needs and demand of customers for highly personalized products, transformation of control and planning practices are needed. In this regard, the technology-driven "Smart Logistics" can be used to offer smart products and smart services to increase flexibility, respond to market changes, make closer ties between company and customers as well as production optimization and reduction of manufacturing and warehousing costs [8]. Likewise, and in a broader level, logistics 4.0 is combination of application of innovations within logistics activities provided by "Cyber Physical Systems" (CPS). This paradigm is a result of enhanced use of internet enabling an effective communication and information sharing between humans and machines referring to advanced digitalisation as well. The key technological applications within Logistics 4.0 are to address resource planning, warehouse management systems, transportation management systems, intelligent transportation systems and information security [8].

The main aim of technologies such as CPS and IoT are to solve the challenges within conventional supply chains and logistical operations to monitor and synchronise real information from physical processes and SC entities to a cyber space [9]. Despite the common points between Logistics 4.0 and Industry 4.0, it is claimed that the former one's characteristics are based on digitalisation, automisation, networking and mobility [10]. Several technological innovations are being applying to Logistics 4.0 such as the fleet of drones operated by Google to deliver medical goods and services to remote areas. The other ones comprise of self-steering, sensors, GPS, RFID and Machine to machine (M2M) communication [11]. It is also claimed that sustainability triple bottom lines can be positively influenced by technological advancements of logistics 4.0 for instance the choice editing to eliminate the environmental harmful and poor-quality products from the shelves. As an ample example of sustainable logistics, the sharing transportation systems can be mentioned such as the current effort of the rival companies such as United Biscuits and Nestle in UK which can be further expanded utilising IoT or CPS to be translated to Logistics 4.0 operations. However, there are also negative impacts associated such as on-demand and individualised products which necessitate increased transportation activities [9].

2.4 Autonomous Guided Vehicles

It looks like the more mature implementation of autonomous transportation from which we can take and use valid data for the research purposes, as it is not in an experimental phase but it is already adopted by many industries (AMAZON for example), is the Autonomous Guided Vehicles. AGVs are used in a wide range of applications whose expansion is proportional to the time course. The sectors which present most of the interest are agriculture, health management, container terminals, flexible production systems, military operations, warehouses and mines [12]. There are many types of AGVs and so many and different systems with which they work to justify their application [13]. Such vehicles are Towing Vehicles, Unit Load Vehicles, Pallet Trucks, Fork Trucks, Hybrid Vehicles, Light Load AGVs and Assembly Line Vehicles. AGVs consist of different parts, the hardware parts and the software parts. They can separate from many different functions according the implementation they are intended towards.

Table 1. Font styles for a reference to a journal article.

Impact to Supply Chain	**Impact Category *(E=Economic; S=Social; EN=Environmental)***	**Sector**	**Source**
Labour cost, maintenance and fuel consumption costs reduction.	E	Truck industry	[15]
Better manoeuvrability, increased loading performance, increase precision in material handling, overall terminal performance improvement.	E	Port container terminals	[16], [17].
Reduced staff cost and, reduced idle time	E	Hospitals	[16]
Improved efficiency, effectiveness, productivity. Accident prevention.	S	Agriculture	[17]
Low budget autonomous vehicle, improved flexibility and efficiency, increasing accuracy and quality.	E	AGV industry	[18]
Improvement in Productivity, efficiency. Health and safety. Environmentally friendly.	E, S, EN	Robotics	[19]
More flexible, smarter space usage, less operation cost, easy to use interface among other automated systems.	E	AGV industry	[20]
Environmentally friendly. Improved Production flexibility,	E, EN	Automotive industry	[21]

production quality and cost reductions.			
Reduced gas emissions and noise pollution and environmentally friendly. Reduced costs, improved energy efficiency, economic performance.	E, EN	Ports	[22]
Environmentally friendly	EN	Forklift industry	[23]
Reduction in energy consumption. improved operating efficiency	EN	Container terminals	[24]
Increased efficiency, minimised hazards and accidents, reduced human errors	EN, S	Toothpaste industry	[25]
Improved performance, improved time management, reduction in operational costs and human errors.	E, S	Container terminals	[26]
Reduced hazards for injuries cost and indemnifications, loss of time, severity of error, training cost, insurance cost, risk decrease.	E, S	Safety systems	[27]
Minimised social and economically based costs of work, injuries and accidents	E, S	Manufacturing/Assembly	[28]

The impacts of autonomous transportation to the logistics can be divided in three categories. They can be economic impacts as they can reduce different kind of costs, they can be environmental impacts as they can reduce the pollution of industries to the environment and they can be social impacts as they can offer safer and healthier working conditions to workers. The examination of the impacts was from a direct perspective instead an indirect one, because indirectly all three categories are connected [14]. The following table (table 1) presents the impacts of autonomous transportation in the supply chain. The following table (table 2) will present some basic advantages and disadvantages on how companies, specialized to autonomous vehicles, promote the implementation of such vehicles to the transportation industry [35], [4] and how their arguments are identical with the findings of table 1.

Table 2. Advantages and Disadvantages of Autonomous Transportation

Allies of autonomous transportation implementation	Enemies of autonomous transportation implementation
More safety [29], [30], [31], [3], [32].	Regulations and Legislations [33], [29], [30], [34], [31], [32].
Less transportation cost [29], [31].	Technological Obstacles [33], [29], [30], [31], [3], [32].
Better fuel consumption [29], [32].	Social & Ethical Obstacles [33], [29], [34].
Environmental friendly and low emissions [30], [3].	Responsibility Obstacles [34].
Better vehicle exertion [29], [3].	Security Obstacles [32], [33].
Improved road exertion [29], [30].	Substructure obstacles [29].
Improved driver exertion [29], [3].	

Mathematics of the impact cylinder are demonstrating that twelve examples of economic impact referenced to the table 1 research, six examples of environmental and six for social. The usability of the cylinder is to give a geometrical picture of the impacts of autonomous transportation to the logistics instead of simple numbers. After thorough research into scientific articles and studies, some enemies and some allies of autonomous transportation have been identified and presented in Table 3, either contributing to the implementation of new digitization systems or make its implementation impossible.

Table 3. Advantages and Disadvantages of AGV's

Advantages of AGV's based on specialist reviews.	Disadvantages of AGV's based on specialist reviews.
Reduces the labour costs by eliminating the need for human workers. The company cost is the expense of the equipment plus the necessary service in contrast with human employee costs such as medical coverage, salaries plus bonuses, paid vacation etc.	***High Initial Costs -*** AGV's must be a long-term investment. Initially manual labour and usage of human operated machinery can be cheaper for a small company. It usually takes some time until the cost reducing benefits are realised.
Safety Standards Increment - AGV's are developed with built in safety features and a vast array of sensors that allow them to operate in a tight space environment without interfering with other employees and surrounding structures. In comparison human operated machinery such as forklifts and cranes rely on the human factor for safety as all input is made by them. Fatigue, distraction or adverse weather conditions can result in errors and eventually accidents.	***Equipment servicing costs*** is also a contributing factor. Scheduled or minor unscheduled maintenance can slow down production. Also, this can take place whilst staff is trained and during the initial implementation phase.
Accuracy and Productivity Maximization. AGV's are designed with maximum performance and productivity in mind. By replacing the human worker, the possibility of errors and mistake in the production line is minimized and on the contrary production output reliability and operational	***Unsuitability for non-repetitive production lines***. AGV's shine when tackling repetitive tasks. They are best suited for production line based models, so their usage in other type or style of operations might not be as effective.

availability is maximised.	
Ease of Expansion and upgrading. By utilising a modular implementation process, a company can initially avoid unnecessary costs and gradually increase the usage of AGV's as its operations grow.	***Inflexibility of Operations*** - Due to its fixed construction, an AGV can perform a specific task at a time. It cannot change tasks at will as a human might be able to, and sometimes having a flexible workforce can be more beneficiary for some businesses.

3. Recommendations and Future Research

This paper aims to examine the most important aspects of automation and that of industry 4.0 within logistics and transportation areas of supply chain management. It has been highlighted through various research studies that, research have identified ways to investigate both application and engineering perspectives of some of the technological advances. This paper is part of an ongoing research project within the research centre and includes a preliminary study towards the implications and findings of industry 4.0 and autonomous transportation. The methodology is based on the literature review studies to highlight the current state of the main concepts within the context. The paper would be further utilised towards the development of the research framework towards proposing the interconnection between autonomous guided vehicles and transportation systems for effective service within supply chain context.

4. Conclusion

The implementation of autonomous transportation is one of the many issues that the transport industry will have soon and will affect the cost and therefore the design of the supply chain, as the fourth industrial revolution is at the gates. The impacts will depend on how they will interact in its application to the intelligent industry with other systems, such as the Internet of things, cloud technology, big data and more. It does not seem to be a transient technology that will bring something else in the future, but it is the real evolution of transportation. With great difficulty published scientific articles about autonomous transportation were found. Only a few of them present the enemies and the allies of the autonomous transportation implementation. It seems that soon more and more will come to the surface. Nevertheless, its growth interest is increasing rapidly. Many companies are publishing reports with statistics and trends and are offering new technological solutions and advices. From reports, articles and studies that found around the issue of autonomous transportation, a unison of enemies and allies for the implementation in the logistics industry is describing the present situation. It is obvious from the statistics that the dominant role, from the factors that contribute the impacts to the supply chain, is the economic. There is an effort of crediting the technological evolution to the environmental sustainability and indirectly it is happening, but the main factor is still the money. There is a balance between social and environmental impacts which shows the trends of our times. There is no doubt that the impact cylinder can change in terms of content as the market manipulators decide to change their targets. And this is the point. From an ethical perspective the conclusion that can be made is not to demonstrate the capabilities of autonomous transportation but the goals which the global market has set, and hence the scale is inclined more towards the demand driven supply chain environments.

Most of the research studies contend that autonomous transportation will have positive impacts on the society, the environment and on the economy of the logistics and transportation industry. But on the other hand, many others believe that the negative impacts will be of greater proportion. The supremacy of a robotics and automation is undeniable to the level of accuracy, economy, efficiency, effectiveness and excellence. But many questions arise towards the human and workforce dimensions. What happens to the level of judgement and improvisation? In addition, imagine a world in which millions of people will be replaced by robots. How many raw materials do they need and how many more complicated and sophisticated parts are necessary for their implementation? How environmentally friendly is this and what will be the environmental footprint? The new jobs that will be created will cover the millions of people that they will be replaced from technology? How socially beneficial is this? Recurring questions that are food for thought and can be the subject of future research studies and the authors aim to address these questions as part of this research studies in future.

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