Supply Chain 4.0: Autonomous Vehicles and Equipment to Meet Demand

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***Abstract*– The term Supply chain 4.0 refers to the application of industry 4.0 technologies to the supply chain, aiming to plan with greater efficiency and better to meet the demand. Considering this reality, the study aims to verify which equipment and vehicles are being applied and which one presents the best benefits to each stage of the supply chain demand. To define the vehicles and equipment to be analyzed, were presented a supply chain process model, divided among industry, warehouses and customer. Thus, each ones were characterized and the best equipment could be adopted more precisely. The vehicles and equipment were analyzed, considering as the main aspects the maintenance cost, security, operation, product handling, delivery time and sustainability. The results show that the main vehicles to be applied are automated guided vehicles, autonomous trains and drones, each one being applied in different processes of the supply chain.**

Keywords – *Supply chain 4.0, Supply chain, Supply Chain Processes, Industry 4.0, Autonomous vehicles, Autonomous equipment*

1. Introduction

The fourth industrial revolution (Industry 4.0) is changing not only the manufacturing industry but connecting the supply chain as well [1]. To create an innovative business environment the companies are adopting in their process modern technologies, features of the industry 4.0 such as: 3D print, internet of things, data analysis, cyber-physical systems, cloud computing and autonomous vehicles [2]. These technologies significantly transform the behavior of the supply chain management [3]. The term "Supply Chain 4.0" is related to the application of some concepts of the Industry 4.0 in the supply chain, such as: reduction, reuse, technology, information readiness, and prompt information exchange channels [4].

In a recent study from McKinsey points out that the supply chain areas have a digital level of 43%, and it is the lowest between the searched business areas. The study suggests, on average, that the companies that use the modern technologies – on a large scale – in the supply chain could have an annual profit growth of 3,2% and annual revenue growing of 2,3% [24].

A view of the origin of the cost reduction through the modern application of the technologies is represented on the Figure 1, from a McKinsey study. According the Figure 1, the "Transport and warehousing costs" can reduce from 15% to 30%, can reduce between 15% and 30% in Supply Chain 4.0, provided that the correct tools are applied.

Equipped with radar, global positioning system (GPS), computer vision, among others, the autonomous vehicles are, according [5], vehicles with ability to detect the environment around them through sensors, allowing it to travel without human intervention. Nowadays, companies as Google, Tesla and UBER are developing new solutions in autonomous vehicles, according [5]. In a report of McKinsey & Company from 2016, the autonomous vehicles will occupy 15% of the vehicle sales of automobile industry by 2030 [6].

For this reason, major automotive industries such as Ford, Volvo and Toyota announced that in the coming years will be selling autonomous vehicles [5]. According the authors, is expected that these vehicles reduce traffic congestion, increase efficiency and safety, save money and improve the mobility of children, elderly and people with disabilities.

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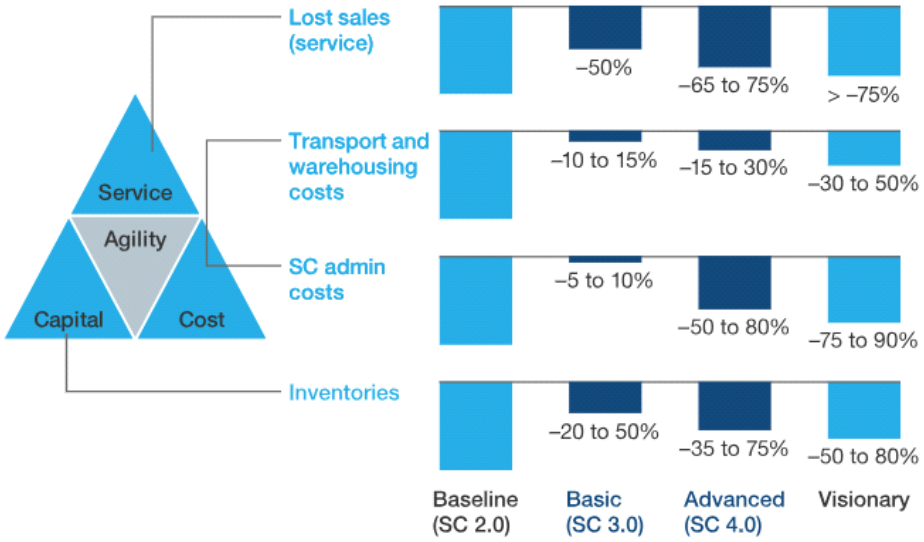

Figure 1. Costs reduction applying modern technologies

According [7], new products and services could be developed through autonomous vehicles, beyond processes (supply chain), transport of loads and deliveries, that are being revolutionized by the application of vehicles and autonomous solutions.

Based on the importance of transportation along the supply chain, and the new solutions that are emerging, the companies, must embrace these technologies to better attend their customers and to reduce costs, since, according to [8], product delivery at the right time is one of the main challenges in supply chain planning.

Thus, this search has the purpose of verify the main autonomous equipment and vehicles used in industries, warehouses, transportation and product delivery, aiming to define the more suitable ones according the criteria established, evaluating their advantages and disadvantages. In addition, the application of autonomous equipment and vehicles contribute to decrease the risks in the supply chain, which can implicate in an inability to meet customer demand [9]-[10].

In the section 2 is presented the literature review, addressing the topics of Supply chain 4.0 and autonomous vehicles and equipment. In the section 3 is described the search methodology, with the correspondent delimitations and analysis. The section 4 presents the results of the search and the last one, section 5, presents the final considerations regarding the topic.

2. Literature review

The literature review of this article presents information regarding supply chain 4.0 and autonomous vehicles and equipment.

2.1 Supply Chain 4.0

Supply Chain has increasingly the complexity and global reach [8], resulting in the massive use of new technologies, robotics and artificial intelligence [11]. As a consequence of the globalization according [12], the current objective of supply chain is to ensure the integration of the operations adequately from the suppliers to customers.

To [13], the Supply Chain Integration involves collaboration, information-sharing and system standardization, seeking joint decisions about costs, inventory and customer service from a perspective of the whole process, instead to manage every single function separated. According [14], the integration includes the use of new technologies to improve the exchange of information and to facilitate the monitoring of the physical goods throughout the process.

Recently, to manage the demand, complexity and integration, the automation has been applied to the Supply Chain since 2010, according [8] and has increased with the use of tools of the Industry 4.0, resulting in the Supply Chain 4.0. The Figure 2 represents a future view which incorporates the digitalization and automation to the entire Supply Chain, integrating all the processes, suppliers and customers, allowing the exchange of information in real time [15].

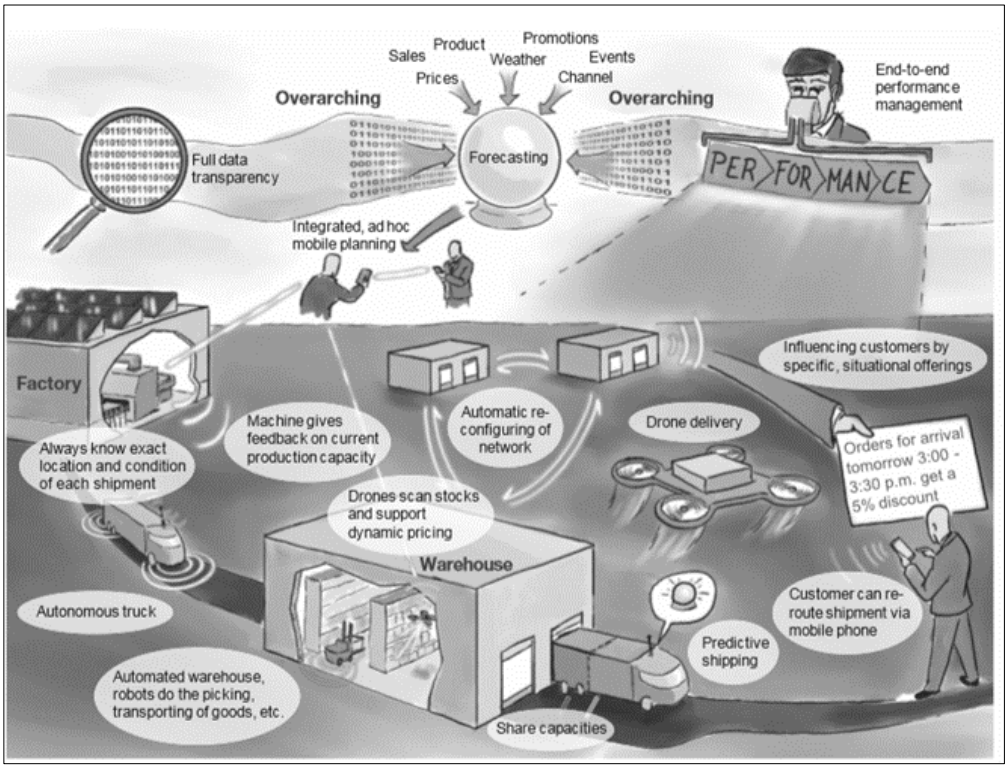

Figure 2. Innovation in the supply chain process

Among the many elements of the industry 4.0 presented by [25] in the Figure 2, the ones that can be stand out, according [8] are: cyber-physical systems and connected robots in the industry, connected trucks for primary logistic, automated warehouses, autonomous shared trucks to the secondary logistic and drones to last mile deliveries. The Internet of Things (IoT) also has an important role in this process, once the information during the goods transportation or in the warehouses are updated in real time [8].

The potential benefits that can be reached with the application of the supply chain 4.0, according [8]-[11]-[25] are:

a)speed: these are the predictive analyses of the demand, market trends, and production data that make the sales forecasts more accurate, which can go from monthly to weekly and/or daily. The concept of "predictive transport", by patented Amazon, suggests that the products may be shipped before the customer´s request, reducing the delivery lead time. That is, the speed is related to the capacity to respond as quick as possible the customer demand;

b)flexibility: the online planning enables that companies to respond with more flexibility to changes in demand, reducing the planning cycle and delivery time and, even once shipped, customers can redirect the products to others destination;

c)individual delivery: with customers demanding more unique and individual products, is expected that supply chain 4.0 through techniques as micro-segmentation, mass customization and sophisticated scheduling practices, provides individualized deliveries. The last mile delivery process can include drones;

d)precision: the delivery management system monitored in real time the exact position of the trucks, vehicles and drones that make the deliveries to the customers. The monitoring also allows to the stakeholders the capacity of make quicker decision more precisely;

e)efficiency: the automation of tasks as picking, transportation and planning increase the supply chain efficiency. Thus, to increase the efficiency are being used autonomous devices as robots, vehicles and drones.

The authors [8]-[16]-[18], also highlight the concerning with the environment and sustainability in the supply chains, which is gaining space with the application of new technologies, mainly in the transportation area.

As a consequence, according [8], this benefits results in the competitive advantage, since it allows the decision making in a more agile and precise way. In addition, the flexibility of the system allows route changes, ensuring individual delivery and customer satisfaction [8].

2.2 Autonomous vehicles and equipment

The number of autonomous vehicles and their applications have been increasing considerably and, to [19], this is a result of the following reasons: complexity and quantity of traffic variables; aging of the pedestrian population; the transport importance; market, environment and government demand.

As result of these demands, [20] inform that a lot of solutions and applications have being developed based on the integration between Internet of vehicles (IoT) and autonomous vehicles, seeking to offer transports solutions, creating smart systems, connected with the cloud and enabling the quick change of necessary information.

This connection of autonomous vehicles to other devices is called by [20], as vehicle to everything (V2X). The authors defined 5 connection ways between vehicles and objects: vehicle-to-vehicle (V2V); vehicle-to-roadside unit (V2R); vehicle-to-infrastructure (V2I); vehicle-to-personal devices (V2P) and vehicle-to-sensors (V2S).

According to [20] the connection ways needs systems with uninterrupted internet connection (*Wireless*, 4G, among others), which enables the connection and information change between many exchange of information between several areas of transport intelligence.

According with [7]-[20]-[21], the main expected objectives of the application of autonomous vehicles are:

a)greater security in the traffic, seeking the target "zero accidents" and reduce the fatalities in the traffic;

b)traffic management, optimizing the flow of traffic (sending data of congestion, accidents, among others), controlling the speed, assisting and coordinating the productivity;

c)assist in driving the vehicle with stability control, automatic break, cruise control, fuel consumption, among others;

d)follow and support the operation remotely;

e)the data could be obtained anytime and anywhere, no manual control required;

f)failures can be avoided according the data generated by the vehicles

g)reduction in the emission of polluting gases

h)develop sustainable supply chains.

Besides that, [22], highlight the importance of the autonomous vehicles to increase the quality of the decision-making and to make the process more flexible and efficient.

Not only the deliveries and the traffic will be improved with the application of new solutions, but also the warehouse management [22]. According [23], use autonomous equipment in warehouses contributes to the supply chain, improving the efficient and the reliability of the inventories and reducing the resources effort.

According to [22], as all the parts of the process will be connected, is easy to manage the demand, plan and control all the supply chain. Once the systems are connected by the IoT and sensors, the warehouse has the information about the autonomous vehicle arrival, transmitting the data to the autonomous equipment that prepare the goods to the delivery efficiently [22].

In addition, the use of autonomous equipment has other benefits, such as flexibility, precision, reduction of production damage, increased productivity, cost reduction, reduction in the emission of polluting gases, reduced energy consumption and enhanced safety [16].

3. Methodology

According with [5] many companies around the world have been modernizing and using more and more technological resources to meet their customers and better manage the supply chain, seeking increase the competitiveness and the efficiency of deliveries and availability of products.

To the transportation and handling of various loads, many equipment have been adopted, always focusing on the security in the handling, accident reduction and the delivery management systems provides, in real time, the exact position of trucks and drones, ensuring the delivery, agility and flexibility pointed out by [25], presented in the previous section. Each equipment is used according the necessity and viability.

In this search the purpose was to evaluate the application of these autonomous equipment/vehicles in the products transportation in the logistic process to meet the demand. This process relates the industry, warehouse, final customer and devolution, as presented in Figure 3.

Figure 3. Supply chain to meet the demand

As shown in the Figure 3, the flow part from the industry, that forwards the products to the warehouse and, posteriorly, these products will be intended to the customers, with the possibility to occur the reverse process. This chain demands organization, and that is the reason to operate through adequate logistics planning.

Seeking to assist in the flow presented and ensure the delivery with quality and efficiency, many autonomous vehicles are applied to the operations: trucks, trains, forklifts, drones and others. To this search was selected two types that have been applied or developed/tested, which can be used around the world.

To define them, each part of the supply chain process was characterized, as a way of limiting to which there is feasibility in adopting the equipment and vehicle considered, as well as the presented results of the analysis. The delimitations were:

a)industry: free traffic and suitable space to the autonomous vehicles passage; use of the correct packaging to the product transportation; technological development; adequate Wi-Fi network connectivity; production synchronism; ability to receive product returns and use warehouses;

b)warehouses: free traffic and suitable space to the autonomous vehicles passage; technological development and adequate Wi-Fi network connectivity; ability to receive product returns and use warehouses;

c)customers: desire to receive the product within the stipulated time; monitor the product location; possibility of changing the place of delivery after the purchase; possibility of returning the product and receiving the product without damage to the packaging.

Another important characteristic is that the industry and warehouses must be close in such a way that airplanes or ships are not used, once that these transports will not be considered. The size of the products also was limited to 5 kilograms, limited, that is, small products.

The transportation of the products from the industry to the warehouses will be made in big quantities, and the delivery from the warehouses to the final customer may be in small quantity or unity, according the transport that presents the best benefits.

To the analysis and definition of the autonomous vehicles/equipment were considered the ones that already operates in the supply chain flow and the ones that represents new trends or are under development/tests. At the end of the search, the equipment and vehicles defined are presented in the Table 1. Then, a search of all each equipment and vehicle defined was made, seeking determine those which will bring the best benefits if applied.

Table 1. Vehicles and equipment defined

Flow stage	Equipment/vehicles
Industry	Automated-guided vehicles
	Industrial conveyors
Industry -> Warehouse	Autonomous trucks
	Autonomous trains
Warehouse	Automated-guided vehicles
	Industrial conveyors
Warehouse -> Customer	Autonomous trucks
	Drones

4. Results

In the Table 2 is presented the advantages and disadvantages of the equipment and vehicles analyzed.

Table 2. Advantages and Disadvantages

Equipment / Vehicles	Advantages	Disadvantages
Automated-guided vehicles	Security and precision	High cost of implementation
	Process standardization	High cost of maintanance
	Easier and faster implementation of new process	Skilled labor to operate
	Operation costs reduction	
	Reduction in the emission of the polluting gases	
Industrial Conveyors	Reduction of people handling the products	Skilled labor to operate
	Reduction in employee fatigue	
	Fast and dynamic orientation of products	Possible handling to transport other means of transport
		Not very flexible
Autonomous trucks (small and big loads)	Low cost of maintenance, but less frequently	Traffic dependency
	Accidents reduction	Deliverie delay
	Greater traceability of load	Roleplaying difficulties
	Poluents emission reduction	
	Travel long distances	Delivery time
	Transportation of big loads	
Autonomous trains	No traffic dependency	High maintenance cost, but less frequently
	Capacity to transport big quantities of products	
	Low operational cost	
	Security on transport	
	Contributes to the traffic reduction	
	Greater traceability of load	
	Poluents emission reduction	
	Travel long distances	

Drones	Contributes to the traffic reduction	Individual deliveries
	Reduction in the delivery time	Prohibition of use in some countries
	Poluents emission reduction	Dependence on climatic conditions
	Greater traceability of load	Theft and damage to equipment
	Reduction in the delivery cost	Difficulties in the planning routes
	No traficc dependency	Travel small distances
	Low operational and maintenance cost	

To define the types of transport that best benefits each one of the supply chain stages were considered the potential benefits presented in the section 2: speed, flexibility, individualization, precision and efficiency. Beyond these benefits also were analyzed the items of maintenance, operation, sustainability, security and general costs.

In the Table 3 is presented the application proposal of equipment and vehicles of each stages of the supply chain.

Table 3. Proposal for application of equipment and vehicles to each stage of supply chain

Flow stage	Equipment / vehicles
Industry	Automated-guided vehicles
Industry -> Warehouse	Autonomous trains
Warehouse	Automated-guided vehicles
Warehouse -> Customer	Drones

The equipment and vehicles selected present the following characteristics:

a)automated-guided vehicles: the equipment offer lower human contact with the products and higher flexibility and e adaptability from the equipment to any environment;

b)autonomous trains: to transport big quantities of products through long distances, the trains are the best option, since the reduced costs of transport and maintenance, reduction of vehicles circulating in roads and greater agility

c)drones: although there are difficulties related the distances and legalization, the use of drones presents an excellent option to last mile deliveries, provided the adequate adjustments to logistics planning are made.

5. Final considerations

The application of autonomous equipment and vehicles in the supply chain is a trend, even with many of these already applied (*Automated-guided vehicles* and industrial conveyors), new ones are always appearing on the market.

This research had as purpose to analyze the autonomous equipment and vehicles that could be applied in the supply chain process, considering their advantages and disadvantages. For this, the characteristics of the supply chain process were defined, as well the benefits of the application of the tools of the Industry 4.0, which served as the basis for the choice of vehicles and equipment.

To operations inside the industries and warehouses the best equipment pointed is the Automated-guided vehicle, because it is a flexible and security way to move the goods and products in small places. Besides that, this equipment can help to organize and control the inventories.

From the industry to the warehouse the vehicle chosen was the autonomous train, which transport big quantities through long distances, with low cost and a low risk of accidents. But, in general, regarding autonomous vehicles, is noticed that the application is lower in front of the several tests being performed in the supply chain. The main reasons for that are: little available technology,

high costs and lack of interest / political investments in the development and application of new technologies.

Finally, to deliver the product to the customer, the best equipment identified is the Drone. Although it seems a distant reality, some companies already deliver products with the equipment. The main difficulty to make the use of it massive is the legislation of each country.

Based on this and the search delimitations, possible future work is related to difficulties in the application of autonomous vehicles and to increase the number of equipment and vehicles analyzed for each stage of the supply chain. In addition, it is possible to evaluate the feasibility of the application of the proposed model in different countries / regions, since there are peculiarities that can make some of the applications unviable.

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