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Simulation-based analysis of AGV workload used on aircraft manufacturing system: a theoretical approach

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Simulation-based analysis of AGV workload used on aircraft manufacturing system: a theoretical approach

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Abstract:

competitiveness in the aircraft manufacturing industry requires continuous improvement and modernization of its manufacturing processes, in order to keep the companies competitive in the market. In this context, the use of advanced manufacturing technologies and systems has been incessantly pursued to achieve productivity gains, sustainability and reduction of production costs, as well as being important in the individuals' quality of life. Autonomous robotic systems such as Automated Guided Vehicles (AGVs) have been used on shop floor to assist the aggregation of these competitive advantages to the business. Coupled to the use of these vehicles, other technologies such as the internet, digital factory and cloud-computing have been integrated into manufacturing in direction of the so-called advanced manufacturing, or Industry 4.0. Thus, this work aims to apply the concepts of digital factory in an example of aircraft manufacturing system, to analyze the efficiency and workload of the AGVs that transport materials from the warehouse to the assembly stations. Based on a theoretical approach by discrete-event simulation method and guided by the principles of Industry 4.0, analysis related to needed amount of AGVs, cycle times, deliveries and downtime of the vehicles were performed for different situations. Thus, it searches for better results in terms of productivity and decision-making support regarding adding-value related to materials transporting and information over long distances, delays, waiting and unnecessary movement of workers, in order to obtain improvement and profits for the aircraft manufacturing system.

Keywords: AGV, aircraft manufacturing, industry 4.0, simulation, industrial process.

Introduction

Competitiveness and demands of the aviation market experienced by aircraft manufacturers leads to the need of continuous improvement in their manufacturing systems (Exler & Lima, 2012).

In this scenario, technology advances are extremely relevant to the industrial sector, requiring manufacturing systems to be adapted to this competitive market, which demands the use of new technologies.

In manufacturing environment, robots are being widely used in several areas of industry, such as: production, food, services, health, defense and space. The robotics was initially introduced to soiled, rough and dangerous tasks, but actually it is used in broader applications, as a key factor to help individuals in their work, leisure and domestic activities. Issues related to economic growth, quality of life and safety remain key factor in the use of robots.

Considering this trend, the use of Automated Guided Vehicles (AGVs) has become very important. Impacts, advantages and positive effects of AGVs in actual industry related to sustainability, productivity,

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labor cost savings, reduction of energy and safety has been presented by several studies (Negahban & Smith, 2014; Acciaro, Ghiara & Cusano, 2014; Bechtsis, Tsolakis, Vlachos & Iakovou, 2017).

In order to attend such changes on the manufacturing environment, the trend of 4th industrial revolution (Industry 4.0) that is grounded on intelligent manufacturing system intend to integrate the systems for the human-machine interface, providing data and the framework of the process in a faster and more intuitive way, allowing to make adjustments in their parameters. Thus, AGVs, IoT (Internet of Things), cloud and digital factory have been improving the development of new procedures, reducing the cycle time of factory processes. This way, digital factory means a graphic tool used to plan manufacturing processes through specific software, based on the simulation of manufacturing line to evaluate the operation output, workload and ergonomic conditions, in order to apply the best conditions to avoid waste of time in unnecessary movements when using robots (Vidal, Kaminski, & Netto, 2009).

Hence, this paper aims to apply the concepts of digital factory in an example of aircraft manufacturing system to analyze the efficiency and workload of AGVs that transports materials from warehouses to assembly stations, oriented by the principles of Industry 4.0. Based on a case study, it searches for better results in terms of productivity regarding adding-value related to transport of materials and information over long distances, delays, waiting and unnecessary movement of workers. For that purpose, simulations are used to verify the minimum amount of AGVs necessary to deliver material to the assembly line, the number of working hours, number of deliveries performed and idle time of each AGV. Based on this information, it is possible to understand how the assembly line will behave in different scenarios. This type of simulation is very useful for any manufacturing system in defining its workload and production capacity in order to balance the assembly line. Therefore, the approach presented herein can be used as a decision support tool for design of aircraft manufacturing systems that looks for a leaner and more competitive process.

Literature review

To help understand the originality of the work, proposed application and its contribution for aircraft business competitiveness, a literature review related to aircraft manufacturing system, Industry 4.0, AGVs, digital manufacturing, event-discrete simulation and their impact on assembly lines was carried out. It was accomplished aiming to be aware updated on the current researches on the topics related to the proposed work.

Aircraft manufacturing system

The aircraft manufacturing segment is an important branch of the industry, showing a high level of technology on its processes and the industrial development of a nation (Ma, Cao, Luo, & Qiu, 2016), due to its important characteristics related to the complexity, efficiency, high quality and value-added of the product. Aircraft industry is leading in the use of advanced manufacturing technologies on its assembly lines due to the challenges related to this segment of industry (Crawford, 2017). The assembly line is an industrial process composition that involves multiple production methods, complexes jigs and tools, machines and skilled manpower (Mas, Rios, & Menendez, 2012). It consists in a set of workstations that could be in line or docks, movable or static respectively. For both cases, all components arrive to a workstation in order to be assembled, after the subassemblies were built (for example: bodies of fuselage or wings parts). Specifically, to assemble in lines, after joining fuselage bodies, the product goes to the next workstation for completion and final assemblage. In the aeronautical segment, all workstations usually have the same cycle time and the assembly line is named synchronous, based on the production-balancing (Gomez, Rios, Mas, & Vizan, 2016).

Thus, the aviation manufacturing business always searches for advanced manufacturing technologies and development of innovative solutions by feasible investments. Thereby, digital design of the product and manufacturing processes have been developed based on computational simulations (Yong, Jian, & Yuqing, 2009). Aircraft manufacturing systems are initially designed by digital environments, developed by software tools in order to provide analyzes and simulations of the manufacturing processes.

Industry 4.0

Published by German National Academy of Science and Engineering (acatech), the main ideas of Industry 4.0 originated the document 'Recommendations for implementing the strategic initiative Industrie 4.0' (Kagermann, Wahlster, & Helbig, 2013).

The Industry 4.0 term defines the 4th industrial revolution, where machines, warehouses and production units are inserted in the form of Cyber-Physical System (CPS), meaning that they are capable of changing information, give commands and control each other, in a horizontal hierarchy level. It is necessary to follow the product throughout all steps of production to compare many different ways of production and choose the most appropriated (Kagermann, Lukas, &Wahlster, 2011).

A key concept of Industry 4.0 is IoT (Internet of Things). IoT allows devices as RFID (Radio Frequency Identification), sensors, actuators and smartphones to communicate with each other. Industry 4.0 composes concepts and technologies along the value chain. In 'Smart Factories' structured in a modular way, the CPS monitors physical processes, creates a virtual copy of the real world and take decentralized decisions. Through 'Internet of Things', different CPSs communicate with each other and with people in real time (Hermann, Pentek, & Otto, 2015).

In addition, the use of Industry 4.0 concepts contributes to less waste in the process, a reduced lead time, financial savings and reduced inventory.

AGV

AGV history started in 1953 in the USA when the first equipment was installed as a tractor-trailer. It was boosted by the growth of global economy after the World War II, when the industrial production was high all over the world (Wu, Wu, & Chi, 2017).

AGV is an autonomous vehicle used to transport components or loads from one place to another, on shop floor or warehouse, without a driver. It is a self-guided vehicle with magnetic or an embedded optical guided sensor that follows a prescribed path as well as performing turning and parking functions used on industrial applications (Ingle et al., 2015). The fast development of sensors and microelectronics technology pushed the AGV to intelligent and high-tech vehicles. After that, studies and manufacturing of AGVs have developed rapidly and continue nowadays (Das, 2016). An example is the purchase of the Kiva System company by Amazon. Kiva has exploited the idea of using mobile robots to accomplish logistical deliveries to people who work in warehouses, sparing them from a long run to pick up the products (D'Andrea, 2012).

In addition to the AGVs, cloud-computing technology and IoT have been studied, topics that are key to Industry 4.0 (Dehury & Sahoo, 2016; Lee, 2017; Douzis, Sotiriadis, Petrakis, & Amza, 2018). A statistical study concluded that 80% of accidents with forklifts involve pedestrian, on average 1 every 3 days (Bostelman, Teizer, Ray, Agronin, & Albanese, 2014).

The study of (Wan, Cai, & Zhou, 2015) mentioned that AGV is as a great contribution on industrial transportation and a wireless AGV can be used for intelligent factory even in confined spaces, where trucks are inconvenient. Also, the use of software and AGVs in manufacturing are aligned with the lean manufacturing model, eliminating non-value activities like transportation, inventory and motion waiting (Abdulmalek & Rajgopal, 2007).

Digital factory

Inside the Industry 4.0, the major components are controlled by digital equipment, it is necessary to visualize the factory for development and validation of changes and production monitoring, something that can be seem in a computer, tablet or smartphone. For that, an industry can use a planning tool called digital factory. Digital factory can be defined as a network of 3D models, methods and simulation tools that are connected by data exchange. The goal is to plan, validate and improve the processes and the resources related to the product. The production elements are designed by CAD (Computer Aided Design) tool, in the same way that they are planned to be used in a physical factory. After an element is validated in a digital factory, it can be used in a real factory. That validation allows a safety and quality planning, since different concepts of production can be tested in advance, reducing waste of material resources and time (Zülch & Stowasser, 2005).

A digital factory can have as a model just descriptive elements like CAD and architecture draws or dynamic elements like animations and simulations. The choice of these elements depends on what needs to be analyzed. The characteristics analyzed which define the model of digital factory used are: space; time; model behavior; physical principles; human resources; results obtained and the model visualization (Wenzel, Jessen, & Bernhard, 2005). The goal of a digital factory is, through simulation, achieve a big development of processes and devices, using product models developed digitally (Haepp & Giereing, 2001). Thus, a simulation can be used to design a change and measure the benefits in a low-cost way (Melton, 2005).

Discrete-event simulation

The discrete-event simulation is a computational tool capable of simulating the production system, in order to identify the takt-time of the process and the minimum number of machines and people needed.

It is one of the most commonly used techniques for modeling systems. In 1950 the discrete-event simulations were written in machine code, when the simulation was beginning to expand. Nowadays, one of the challenges is improving the simulation time which increases with the complexity of the system (Robinson, 2005).

On manufacturing, discrete-event simulation is a very strategic tool that can be used to quantify the benefits of lean manufacturing implementation (Detty & Yingling, 2000) or to calculate the costs of a manufacturing system based on the time of production (Spedding & Sun, 1999). In addition to the manufacturing environment, this type of simulation can also be used in other segments, for example health services (Alvarado, Cotton, Ntaimo, Perez, & Carpentier, 2018).

Material and methods

The development of this project consists in the use of discrete-event simulation on a digital factory environment in order to plan and simulate the delivery process of resources (materials and consumables) to be used on aircraft manufacturing system. This proposal aims to analyze the AGV paths and its workloads during delivery of materials to assembly stations, based on number of requests from assemblers located at final assembly line and away from the warehouse.

Thus, this work contributes presenting analysis regarding time and space for the further analysis of productivity and dimensioning of manufacturing system, based on simulation of the entire process. The study of (Thiers, Sprock, McGinnis, Graunke, & Christian, 2016) shows the potential of discrete-event simulation in an automated manufacturing system.

This theoretical approach considers that the workers on stations request the resources needed to the assembly by smartphone, which could be tools, consumables or small parts. The mobile device runs a specific App in the cloud to perform the task. When the warehouse worker receives the information from the workstation, he sends the AGV (loaded with needs) to the station using the smartphone again (Barbosa et al., 2017). This system was designed aiming to use the concepts of CPS and IoT, where a smartphone is used to send a message to the storage that a consumable supply is needed. Following, the storage can send an AGV to the station. The relationship among storage, station, AGV and smartphone, is presented below in Figure 1.

Accordingly, the monitoring of overall assembly line could be performed by a specific App/software that is attached to the concept of Digital Factory and allows the communication between workers (from warehouse and stations).

To perform the assembly line conception, the aircraft manufacturing system was modeled using a CAD tool called Google SketchUp®.

Figure 2 shows the workstations in docks located inside the assembly hangar.

In order to have a representative condition, a Boeing 737 aircraft was used as reference. This layout has been created to measure distances and shows the positioning of assembly stations. With that information, the discrete-event simulation can be used to show what is the minimum number of AGVs needed to deliver the resources, as well as and the configuration that maximize the working time of these AGVs. This concepted model follows the sequence described below:

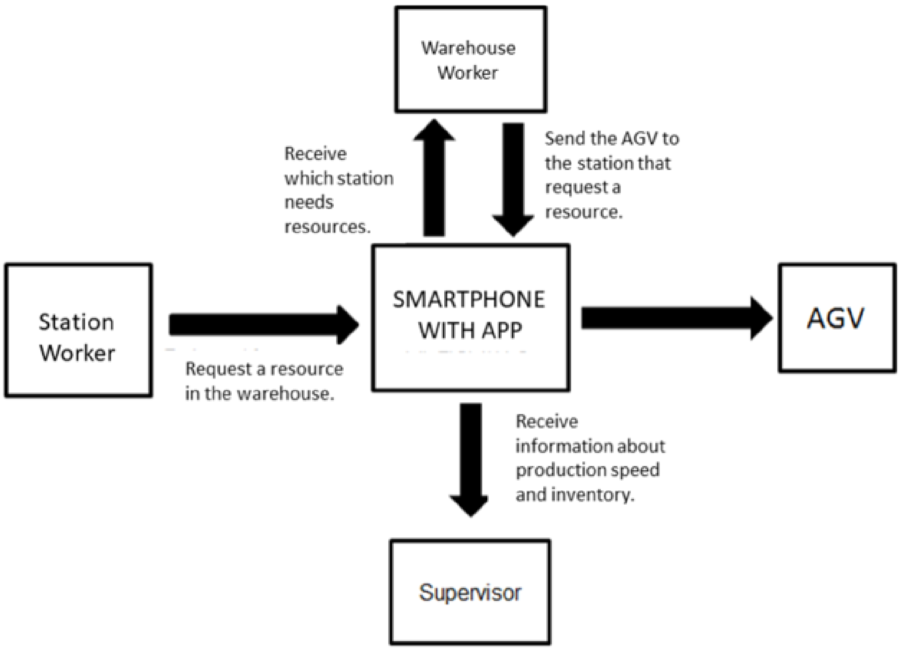

FIGURE 1.
Communication framework of CPS elements.

The warehouse is equipped with AGVs that delivers the needs to stations.

AGV follows one of the six paths to attend the worker request in the workstation.

After a certain time, AGV gets back to the workstation, to know how many AGVs are used in each simulation, as soon the AGV gets back to queue it will be the first to attend any other request from any station (this is the First In First Out queue, or FIFO).

Figure 3 illustrates all paths and their distances from warehouse to workstations.

Based on that, the workflow of the process is presented below in Figure 4.

The simulation was executed in open source software called JaamSim® (JaamSim Development Team, (2016). The entity was the AGV and the six paths for the workstation are the entity flows. In this model some assumptions were made. All workstations have the same probability of calling the AGV, but the frequency between one simulation and the other can change. The AGV moves at constant velocity of 1 m/s and the distance between the warehouse and the workstation are 165, 240, 265, 340, 365 and 440 m, as shown in Figure 3.

The simulation program with all the components is shown in Figure 5.

An exponential distribution was applied to model the frequency in which the AGVs are called to some station, with a mean (μ) of 15, 30 and 45 minutes, with a maximum value of 60 minutes. This distribution was chosen because it is the one recommended for estimating time between events (Lamota & Guasch, 2017). The cumulative distribution (D) is described by the Equation 1 and is shown in Figure 6.

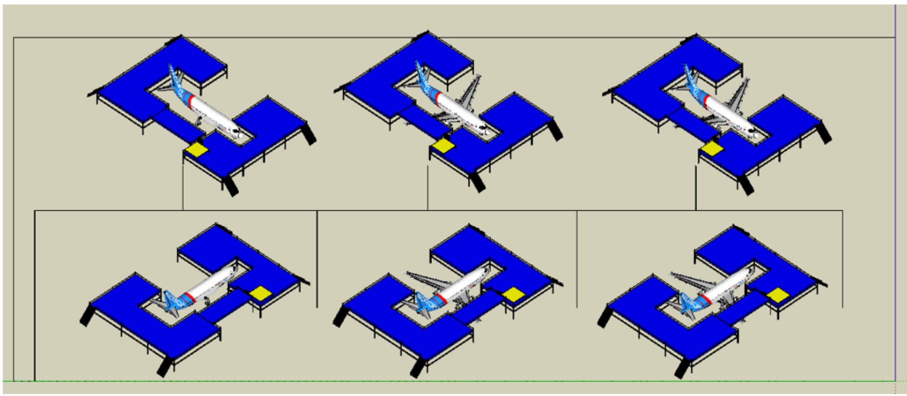

FIGURE 2.
Assembly line configuration.

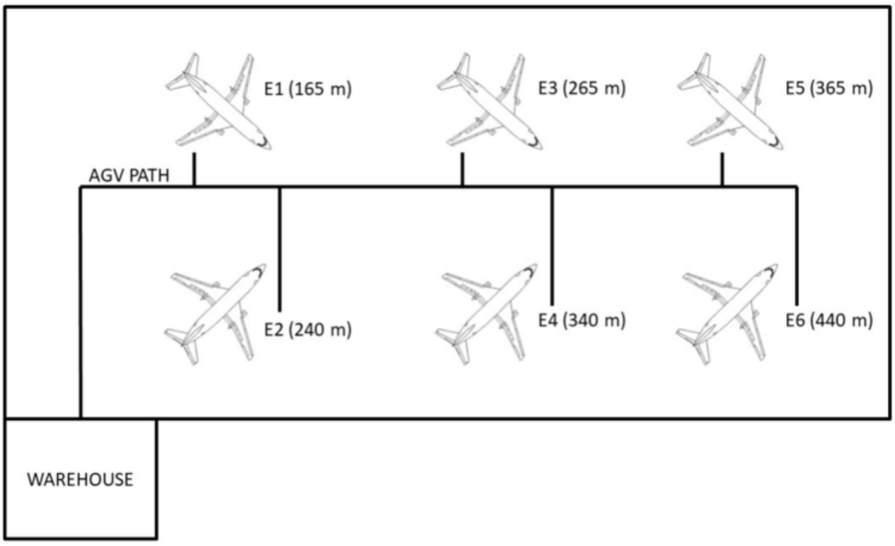

FIGURE 3.
Simulation model representation

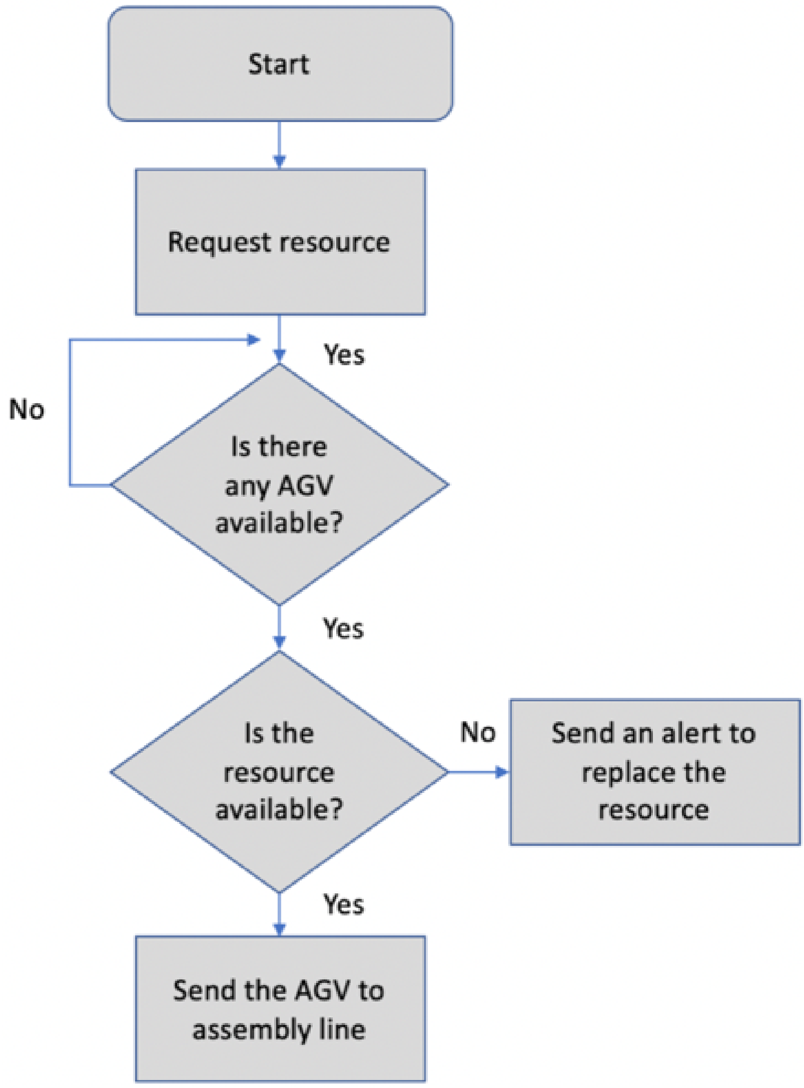

FIGURE 4.
Delivery workflow

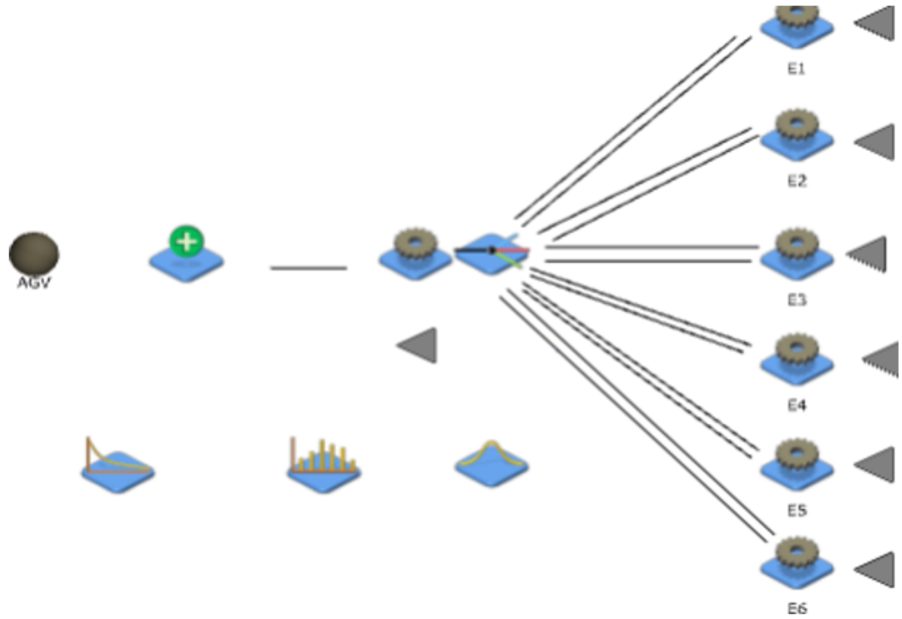

FIGURE 5.
Simulation in JaamSim®.

$$D(x) = \begin{cases} 1 - e^{\frac{-x}{\mu}}, \wedge x < 60 \\ 1, \wedge x \geq 60 \end{cases} \quad (1)$$

Figure 6 shows this cumulative distribution of this function.

The goals in these simulations were: show what is the minimum amount of AGVs that does not affect the number of deliveries on the assembly line, the amount of time that the queue was empty with no AGV available and the average of AGV working hours. All the simulations used the same seed and have the same duration of 160 hours, which is equivalent to one shift of 8 hours a day, in a period of 20 days, simulating a period close to a month of work. This simulation time can be increased or decreased to simulate different periods of time, but shorter times can generate unreliable results.

Results and discussion

The number of deliveries of the AGVs is the consequence of the seed used, frequency of requests on workstations, and number of AGVs.

The goal is to establish how many AGVs are necessary to keep the number of delivery maximum at the seed and the average working time of each vehicle.

The number of deliveries of the AGV is shown in Figure 7.

The minimum number of AGVs necessary to keep the number of deliveries at maximum is 7 for the mean value of 15, 6 for 30 min., and 5 for 45 min., respectively.

Figure 8 shows the amount of time that any AVG is available.

The graph shows the relation between the time with the empty queue and the number of deliveries. When the number of deliveries drops, the amount of time that the queue is empty increases significantly.

The average working time of AGVs is shown in Figure 9, It is important considering that in 160 hours, the AGV must work for the longer available period of time to maximize the use of the machine capability. The best configuration in these models has the average work time between 40 and 50 hours per AGV.

The use of discrete model simulation and CAD can be used in different configuration, either frequency of requests, other conditions of delivery, and different layouts or AGV path. The results of the simulation can help the production manager make more precise decisions, such as how many AGV are necessary for a process, or where can be positioned the assembly station, as well as choose the AGV path.

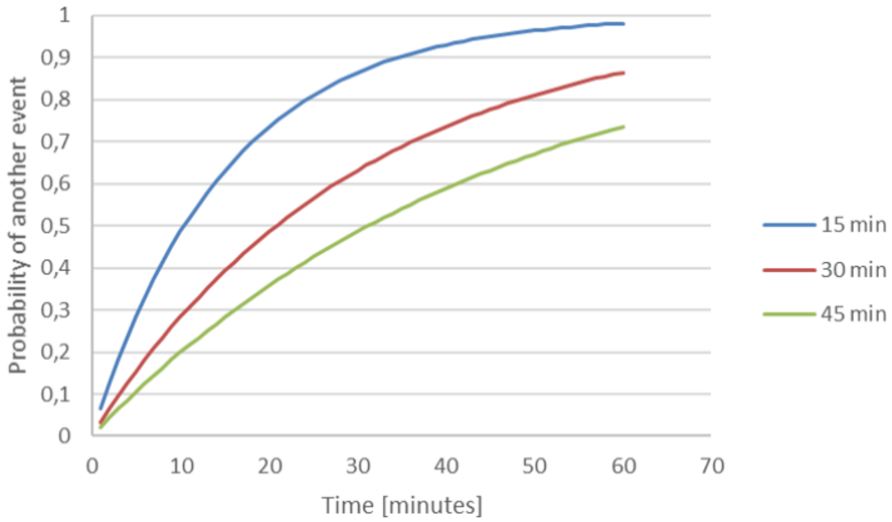

FIGURE 6.
Cumulative distribution of the exponential distribution used in the simulation.

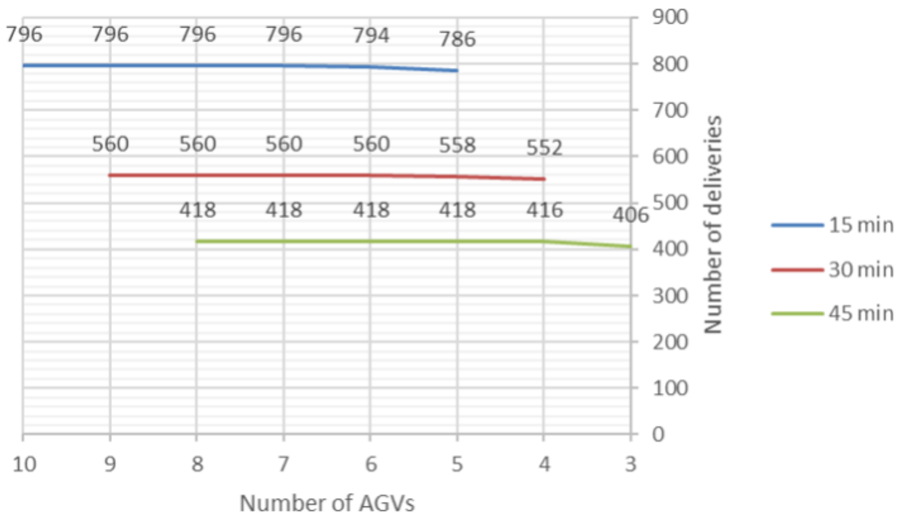

FIGURE 7.
Number of deliveries of all AGVs.

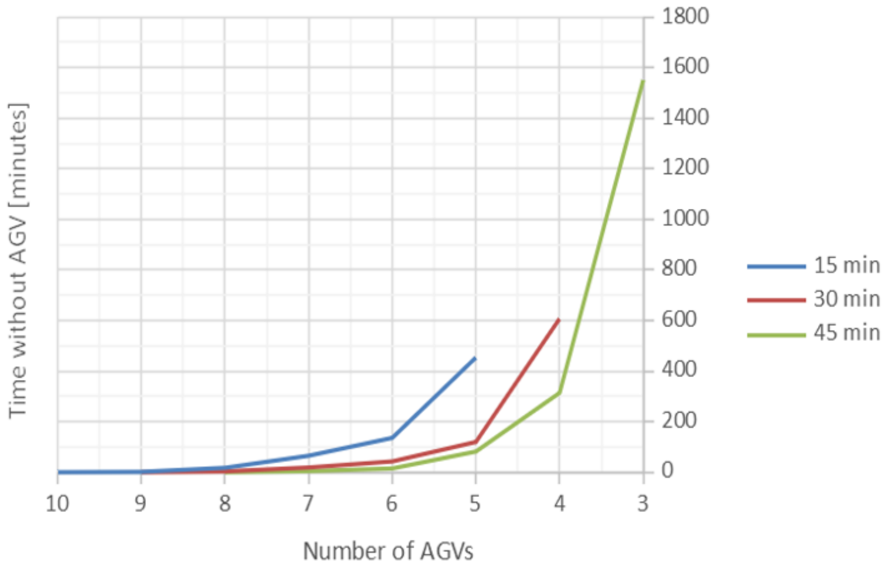

FIGURE 8.
Time without AGV available in minutes.

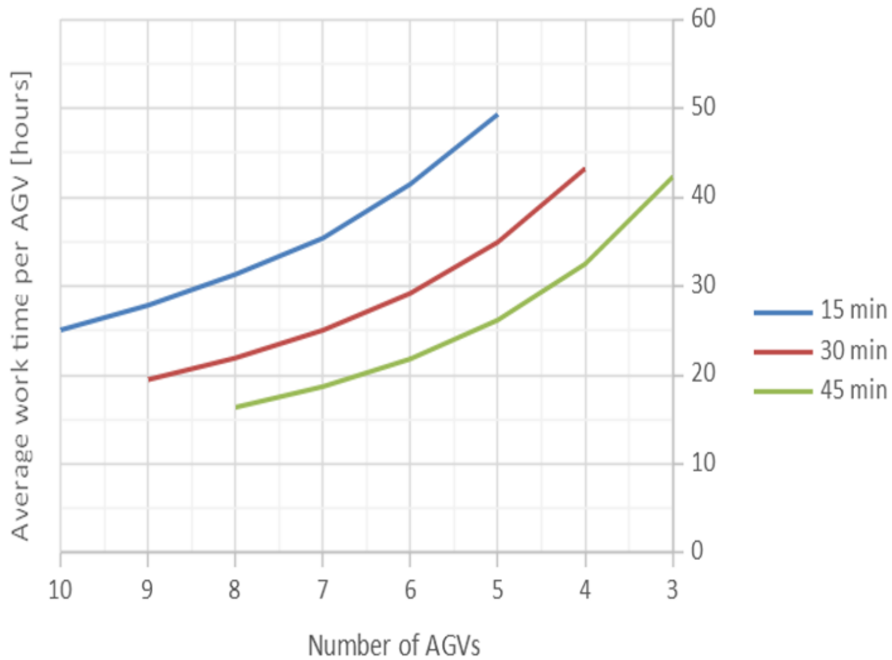

FIGURE 9.
Average working time of AGV in hours.

Conclusion

The development of this paper described the use of concepts of a digital factory in 4.0 industry. In the results, how simulation and CAD can help to solve some planning decisions that an assembly line of aircrafts have, how many machines to buy, how to design the factory layout or decide if it is feasible to automate a process were discussed.

The advantages of this procedure are that few and low-cost resources are used, the discrete-event simulation program is an open source that can be exchanged for a commercial software if necessary, and usually companies have their own CAD tool.

Another advantage is the range of modification that can be made in a virtual model for improved results and for different situations. These other situations can be another layout for the assembly line, different AGV path, and different delivery frequencies.

These approaches on planning the manufacturing process allow the integration between virtual model and real factory, evaluating many aspects of production before implementation in the real process.

Future works could improve this integration by using the indicators obtained in discrete- event model, allowing the manufacturing manager to implement changes in aspects of the factory, such as the number of AGVs in some process, in real time, recalculating the impact that this kind of change makes in the overall process. A more integrated interface could be developed, showing the model of the factory in 3D related with the updated indicators simulated.

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