

IMPACT OF INDUSTRY 4.0 TOOLS IN LOGISTICS: CASE ANALYSIS IN COLOMBIA

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ABSTRACT

This work presents an analysis of the application scenarios of industry 4.0 tools (3D printing, cloud computing, augmented reality (AR), the internet of things (IoT) and autonomous robots) and their impact on logistics on an international scale with an emphasis in the Colombian context, finding benefits in terms of cost and time reduction as well as resource optimization and the contribution of said tools in decision-making within organizations. An analysis was also carried out of 43 companies at an international level that have implemented 4.0 tools, pointing out their main areas of application. Finally, the potential areas of application for each tool in Colombia were identified whilst keeping in mind the differences between their development level worldwide and in the country.

KEYWORDS: Industry 4.0, 4.0 Tools, Logistics, Productivity

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1. INTRODUCTION

Nowadays, the development of new technologies has enabled industries to improve their logistics processes. A growing trend is the application of industry 4.0 tools in productive systems, information management, automation, warehouse management, and transportation (Tang & Veelenturf, 2019).

Amongst the main industry 4.0 tools, some include: 3D printing, cloud computing, augmented reality (AR), autonomous robots, and the internet of things (IoT) (Witkowski, 2017). These tools can be applied in many areas of logistics such as warehouse management, information management, transportation, and distribution, among others. This translates into benefits in the supply chain such as the automation of a factory, higher productivity, improvement of efficiency, reduction of logistics-related costs and operation times (Rodríguez Molano et al., 2018).

According to this statement, the present article sought to identify and depict the impact of industry 4.0 tools in the production logistics of goods and services on an international scale and their applications in the country. Scientific publications and applications in companies that have implemented these tools in their processes are analyzed to visualize the differences between technological breakthroughs worldwide and in Colombia. Lastly, it is noteworthy to mention that the projects led by the government in the country are reviewed to identify which tools receive more support from the state.

2. METHODOLOGY

This article considers different databases such as Science Direct, IEEE, and Springer Link, furthermore, a review

was made in Google Scholar of theses and reports, using the keywords industry 4.0, logistics and tools, and the main 4.0 tools were selected for this study: 3D printing, cloud computing, augmented reality (AR), the internet of things (IoT) and autonomous robots.

Afterward, different case studies and breakthroughs were reviewed on a national and international scale. Hence, articles published since 2015 were revised and those related to the implementation of the aforementioned tools in any logistics process were chosen. Then, they were analyzed and classified in terms of the application areas as seen in Table 1.

Table 1: Application areas

Acronym	Description
MF	The flow of raw material and products within the plant.
Mn	Manufacture: Operations involved in the production process.
AP	Agricultural production: It encompasses the activities of the agricultural and livestock sectors.
WM	Warehouse management: It refers to the identification of the different types of products within a warehouse, for Inventory purposes.
GT	Ground transportation: Determination of the optimal routes and variables that intervene in the performance within the supply chain.
IM	Information management: Process in which agents of the supply chain handle information.

An analysis was performed on the companies that have implemented these tools both nationally and internationally. Furthermore, the government-led projects that are currently in progress in the country were researched to cross the information, to identify the development of 4.0 tools in Colombia compared to global progress and approaches.

Finally, the information analysis was used to establish a series of suggestions on which areas and tools can be applied to improve the national logistics performance. Based on this methodology, the article is organized as follows: Section 3 shows the application scenarios on an international scope, section 4 presents some technological advances made nationally, section 5 discusses the information obtained and section 6 presents a set of conclusions.

3. INTERNATIONAL APPLICATION CASES

Based on the literary review, the results of case studies are described, regarding industry 4.0 tools in addition to the area and country of application.

3.1. Autonomous robots

The use of autonomous robots in the industry has seen exponential growth, with a forecast stating that by 2020 Asia will lead this trend with 320.000 units, representing 69.8% worldwide, followed by Europe (17.2%) and America (12.8%). The countries with the most units will be China, Japan, United States, South Korea, and Germany (Müller et al., 2019). In addition to these countries, other countries showed some progress in autonomous robot implementation as seen in Table 2.

Table 2: Applications of autonomous robots

Source	Area	Result	Country
(Stasewitsch et al., 2020)	AP	The time of cleaning areas is reduced.	Germany
(Jennings & Figliozzi, 2019)	GT	Savings in terms of costs, delivery times, and reduction of last-mile connections.	USA
(Culler & Long, 2016)	WM	Rapid identification of the types of products within the warehouse.	USA
(Cho et al., 2018)	WM	The inventory control was automated in a large-scale warehouse with an accuracy of 98.08%.	South Korea
(Kumar & Kumar,	WM	Optimization of paths taken by the robot to prepare orders in real-	India

(2018)		time.	
(Rey et al., 2019)	MF	Optimization of the material picking task compared to the manual task.	Spain
(Jun et al., 2020)	MF	Delays are minimized, reload times are lowered and robot availability is increased.	USA
(Levratti et al., 2019)	MF	The effort in tasks was reduced by 57%.	Italy
(Schuster et al., 2017)	Mn	A pick-and-place process is automated in piece manufacture.	Germany
(De Preter et al., 2018)	AP	Robots can pick at least 70% of ripe fruits, also, to count strawberries, and quantify its different maturity stages.	Belgium

Table 2 shows that the robots have a wide range of applicability in the flow of raw materials and products and the optimization of processes within a factory. This contributes to the automation of said processes while replacing 8.5% of the worldwide manufacturing workforce by 2030 (Oxford Economics, 2019).

3.2.3D Printing

In terms of 3D printing, the countries with the most experience in this technology in 2019 were South Korea (81%), followed by China (78%) and Canada (71%) (Karevska et al., 2019). On another note, the progress strived in logistics found in the literature are presented in Table 3.

Table 3: 3D printing applications

Source	Area	Result	Country
(Montalvo Navarrete & Caldeira, 2019)	Mn	The weight of each piece is reduced by 48%. They can be crafted in less time and using less material.	United Arab Emirates
(Roach et al., 2019)	Mn	Time is reduced compared to current manufacturing strategies.	USA
(Zaki et al., 2020)	Mn	The glass was printed in 3D with optical quality and functionality.	France
(Albar et al., 2020)	Mn	Pieces with optimal properties of freshness and hardening were manufactured.	United Kingdom
(Baumung & Fomin, 2019)	Mn	Printing times were predicted more accurately, which reduces inactivity times.	Germany

Table 3 shows that the applicability of 3D printing was focused on manufacturing processes since it contributes to reducing time and costs. However, Karevska et al. (2019) signal that the main setbacks of this tool are the high cost in materials (90%) and the system (87%) as well as the lack of usage-related knowledge in companies (50%).

3.3. Augmented reality

According to a report from (XR Association & perkinscoie, 2019), the investment in augmented reality is mostly seen in North America (62%) and the Asia-Pacific region (13%). Nonetheless, the literary review also focused on applications in European and Latin-American countries as seen in Table 4.

Table 4: Augmented reality applications

Source	Area	Result	Country
(Mourtzis et al., 2019)	WM	The available inventory can be checked and product identification is sped up in-warehouse.	Italy
(Limeira et al., 2020)	WM	Warehouse logistics is automated.	Brazil
(Loch et al., 2016)	Mn	Assembly time and errors are reduced.	Germany
(Frigo et al., 2016).	Mn	40% reduction in the time used to identify mistakes in	France

		pieces.	
(Sreekanta et al., 2020)	Mn	Manufacturing errors can be detected in real-time which increases the efficiency of processes.	USA
(Matsumoto et al., 2019)	WM	The speed of transactions in warehouses is improved by 13% and the collection time is reduced by 38%.	Japan
(Lai et al., 2020)	Mn	The system helps to reduce the time (33.2%) and errors (32.4%) in the given assembly tasks.	USA
(Ferraguti et al., 2019)	Mn	Production costs were reduced during the surface polishing stage, thus improving product quality.	EU countries
(Vorraber et al., 2020)	Mn	Times were lowered by 67% and efficiency was improved by 83%.	Austria
(Mourtzis et al., 2020)	Mn	Costs and re-equipment of machines were diminished, in addition to extending their lifecycle.	Greece

As shown in the previous table, augmented reality is mostly applied in manufacturing, given that one of its main advantages is to offer guidelines to operators in different processes so these can be optimized.

3.3.Cloud computing

A study from “BSA Global Cloud Computing Scorecard 2018” argues that the countries that are better prepared for the adoption of cloud services are Germany, followed by Japan and the United States. In Latin America, Mexico, Argentina and Brazil lead the pack (BSA, 2018). Furthermore, some countries showed some progress in this matter (Table 5):

Table 5: Cloud service applications

Source	Area	Result	Country
(Zhang et al., 2016)	GT	Path optimization	China
(Qian et al., 2019)	Mn	Machine preparation times are reduced.	China
(Qu et al., 2016)	Mn	Operational costs are reduced by 50% and the product delivery rate is improved by 30%.	China
(Cedillo-Elias et al., 2019)	IM	The dataflow was optimized and security was improved.	México
(Zhu et al., 2020)	IM	Suitable suppliers are identified in 99% of the requests for 3D printing services.	USA
(Mejjaoui & Babiceanu, 2018)	GT	Savings in transportation costs for food production (strawberries).	USA
(Rudolph & Emmelmann, 2017)	WM	The efficiency of order processing was increased.	Germany
(Simeone et al., 2020)	IM	Clients can visualize solutions based on processing times and costs.	Italy

A cloud platform is a tool mostly used in information management and manufacturing as seen in Table 5, given that its benefits are related to the identification of convenient suppliers, information display for all supply chain agents, and reduction in manufacturing times. It is also important to highlight that terrestrial transportation can be implemented to reduce operational costs.

3.4.IoT

According to a study made by the IDC (2019), the region with the highest investment in IoT is the Asian Pacific with 35.7%, followed by the United States with 27.3% and Europe with 21.2%. However, different countries also developed some contributions as seen in the Table 6:

Table 6: IoT applications

Source	Area	Result	Country
(Zhao et al., 2020)	GT	The location of vehicles was improved for product dispatch to 96.7%.	China
(Guerrero-Ibañez et al., 2017)	AP	The optimization of resources and access in real-time was achieved in crop supervision.	Mexico
(Zhao et al., 2018)	WM	Inventory supervision in real-time and optimization of the order preparation process.	China
(Halawa et al., 2020)	WM	Reduction of management times by 43% as well as the reduction of the traveling times of forklifts by 2.6%.	USA
(Tejesh & Neeraja, 2018)	WM	The mobility and storage of products can be monitored at a low cost.	India
(Nawandar & Satpute, 2019)	AP	67% of water was saved over the traditional platform.	India
(Lototsky et al., 2019)	WM	Costs of excessive inventory were significantly reduced as well as delivery times.	Russia
(Pachayappan et al., 2020)	AP	The waste in resources and crops was minimized.	India
(Wang et al., 2020)	WM	The waiting times of clients and the dispatch costs were minimized.	China
(Muangprathub et al., 2019)	AP	Computer-assisted agriculture was optimized, thus cutting costs and increasing productivity.	Thailand
(Laxmi & Mishra, 2018)	WM	Products can be tracked in the warehouse, leading to lower operational costs and the improvement of data availability in real-time.	India
(Materne & Inoue, 2018)	AP	Plagues and diseases in crops can be predicted with 91% accuracy at a low cost.	Japan
(Khattab et al., 2019)	AP	Diseases were identified in crops and resources used to mitigate them were minimized.	Egypt
(Foughali et al., 2019)	AP	Information can be obtained on crop conditions, helping the prevention of diseases.	Tunisia

Table 6 shows that the impact of IoT in mainly focused on warehouse management and agricultural production. The technology allows the improvement of inventory control and order management in the former, lowering operational costs and, regarding the latter, variables that affect crops can be identified and controlled in addition to facilitating the design of systems that contribute to the optimization of the involved resources.

3.5.Companies that use Industry 4.0 tools worldwide

In addition to the aforementioned cases, it was found that 43 international companies apply industry 4.0 tools and their contributions were classified to determine which ones have had the largest applications, founding that 4.0 tools have been mostly implemented in the manufacturing sector (49%), followed by information management (19%), ground transportation (19%), and warehouse management (9%). The main tools used in manufacturing were 3D printing and augmented reality. In information management, cloud-based services were the most adopted technologies, and autonomous robots and IoT were the most representative in ground transportation. It is noteworthy to mention that the analysis included companies such as DHL, Airbus, Amazon, IBM, Microsoft, BMW, Hyundai, Volkswagen, Boeing, and Ford, which reveals that large multinational powerhouses have seen a positive impact derived from the implementation of industry 4.0 tools in their logistics processes.

4.APPLICATION SCENARIOS IN COLOMBIA

In the Colombian context, the arrival industry 4.0 has had a slow process. However, different breakthroughs have been

found in literature such as the ones described in Table 7.

Table 7: Progress related to industry 4.0 in Colombia

Area	Robots – result
AP	Light Unmanned Aerial Vehicle (LUAV) minimizes energy consumption through path optimization in crops (Campo et al., 2020).
Mn	The proposed methodology generates trajectories so that robots in charge of assembly tasks can locate pieces with 87.7% accuracy (Duque et al., 2019).
Area	Augmented reality – result
Mn	The AR system can guide operators in maintenance operations leading to time and cost reduction throughout the process (Castellanos & Navarro-Newball, 2019).
Area	Cloud platform - result
IM	The implementation of a platform in the cloud for robot navigation let to the reduction of the average time needed to complete one task by 10.8% (Mello et al., 2019).
WM	A web system is developed to handle multiple order operations at the same time (Carrillo et al., 2016).
Area	Internet of things – result
AP	The losses in tomato production are reduced from 53% to 18% and resources such as water and fertilizers are optimized (Núñez V. et al., 2018).
AP	Real-time identification of nutrient deficiencies in crops contributing to the optimization of fertilizers (Culman et al., 2017).
AP	An IoT system is developed to monitor the protected crops and deliver information in real-time for decision-making (Gómez et al., 2017).
IM	The system can recover product historical data, from its arrival to the farm up to the delivery to the wholesaler collection center (Manosalva Barrera & Cangrejo Aljure, 2018).

The previous table showed some progress made with each tool in the Colombian context. The main findings are now summarized:

- The implementation of autonomous robots is proposed in manufacturing and agricultural production given that they facilitate the assembly of pieces and crop monitoring.
- Augmented Reality has been proposed in the manufacturing sector.
- In terms of IoT, the main contributions have taken place in the agricultural production given that it enables the design of systems to obtain real-time information from crops and cut resource consumption.

4.1.Colombian Companies that have Implemented Industry 4.0 tools.

The implementation of 4.0 tools in Colombia has been slow. According to data from the digital economy observatory (CCB & MinTIC, 2018), the percentage of companies that have adopted them is fairly low, where the most implemented tool has been the cloud platform, represented with only 28% of the companies. However, other companies prefer other tools: Rappi, Éxito Group, and Ecopetrol use autonomous robots, Concreto uses 3D printing, and Vision AR works on augmented reality as its name suggests. Furthermore, pilot projects are undergoing such as Identidad IoT and the alliance between BID Lab, CIAT, and SoftBank involving IoT.

4.2.Projects Supported by the Colombian Government

In addition to the mentioned companies, other entities have benefited from industry 4.0 tools in the form of projects and initiatives issued by the Ministry of Information and Communication Technologies (MinTIC, 2020), where in the IoT there are projects such as: Center of Excellence and Appropriation in IoT, Remote COVID19 patient monitoring system and IoT Lab and with the cloud have been developed: Oracle training program and Training for cloud service acquisition.

5.DISCUSSIONS

Based on the literary review, the main areas of logistics where they have been implemented industry 4.0 tools are identified and are shown in the summary figure (Figure 1), where the agricultural production area uses IoT the most, material flow uses autonomous robots, warehouse management uses IoT and autonomous robots, manufacturing uses AR mostly and information management uses cloud.

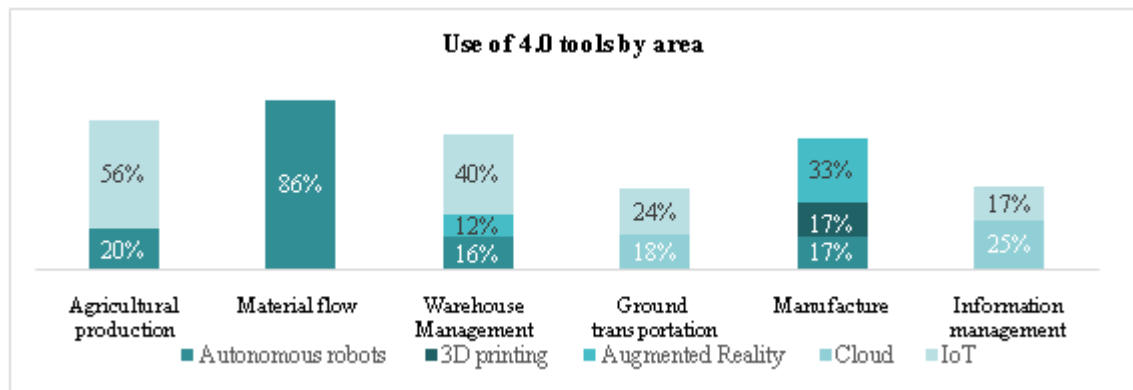


Figure 1: Use of 4.0 tools by area

Lastly, a series of recommendations are defined for Colombia in each area:

- **Agricultural production (AP):** IoT systems could be implemented to monitor conditions in crops and stables to prevent diseases and optimize resources. The use of autonomous robots could also be extended to milking and collection systems.
- **Material flow (MF):** The use of autonomous robots is suggested in this logistics aspect given that it optimizes the distances traveled and releases humans from this task, contributing to the increase of productivity.
- **Warehouse Management (WM):** The main tool recommended in this area is IoT since it allows control inventories in real-time, reduce operational costs, and excessive inventory. Autonomous robots can be used to automate the dispatch of orders saving time. Augmented reality can improve the picking process in the warehouse.
- **Ground transportation (GT):** In this area IoT and cloud platforms can achieve traceability of products throughout the supply chain, thus guaranteeing that all agents have access to information in real-time.
- **Manufacture (Mn):** Augmented reality, 3D printing and autonomous robots are advised in manufacturing since they can improve most of the processes leading to a reduction in errors, waste of materials, and operational costs.
- **Information management (IM):** Given that supply chains process large amounts of data, IoT is recommended that can capture the data and cloud platforms can store said data safely.

6.CONCLUSIONS

This article shows that industry 4.0 tools have had more applications in China, the United States, and Germany with a major focus in manufacturing. This is possible thanks to the support of local governments that have established industrial policies promoting the development of industry 4.0, in contrast with countries such as Colombia where policies are oriented to promoting the mastery of said tools.

Industrialized countries specialize on the creation of smart machines and systems that automate processes within factories and the design of models that improve information analysis by merging different tools. The opposite case is seen in developing countries that are currently elaborating proposals for the implementation of said tools, without integrating them into a single system.

In the Colombian context, the most commonly used tool has been IoT, with specific emphasis on agricultural production through the design of pilot systems, for the monitoring of crops. These strategies should be combined with other tools to generate robust systems that can gather, store, and analyze information in a smart manner, which is the method adopted in first-world countries.

REFERENCES

1. Albar, A., Chougan, M., Al- Kheetan, M. J., Swash, M. R., & Ghaffar, S. H. (2020). *Effective extrusion-based 3D printing system design for cementitious-based materials*. *Results in Engineering*, 6. <https://doi.org/10.1016/j.rineng.2020.100135>
2. Baumung, W., & Fomin, V. V. (2019). *Predicting production times through machine learning for scheduling additive manufacturing orders in a PPC system*. *IEEE ICIASE 2019*, 47–50. <https://doi.org/10.1109/ICIASE45644.2019.9074152>
3. BSA. (2018). *2018 BSA Global cloud computing scorecard. Powering a Bright Future*. In Business Software Alliance. https://cloudscorecard.bsa.org/2018/pdf/BSA_2018_Global_Cloud_Scorecard.pdf
4. Campo, L. V., Ledezma, A., & Corrales, J. C. (2020). *Optimization of coverage mission for lightweight unmanned aerial vehicles applied in crop data acquisition*. *Expert Systems with Applications*, 149. <https://doi.org/10.1016/j.eswa.2020.113227>
5. Carrillo, M. H., Franky, C., Páez, P. S., & Pedraza, A. F. (2016). *S-CLOUDPY: Sistema Informático Web de Multi-Tenencia para el Procesamiento en la Nube de Pedidos de PYMES*. *Informacion Tecnologica*, 27(1), 181–194.
6. Castellanos, M. J., & Navarro-Newball, A. A. (2019). *Prototyping an augmented reality maintenance and repairing system for a deep well vertical turbine pump*. *CONIELECOMP*, 36–40. <https://doi.org/10.1109/CONIELECOMP.2019.8673254>
7. CCB, & MinTIC. (2018). *Observatorio de Economía Digital en Colombia*. <https://bibliotecadigital.ccb.org.co/handle/11520/22589>
8. Cedillo-Elias, E. J., Larios, V. M., Orizaga-Trejo, J. A., Lomas-Moreno, C. E., Beltran Ramirez, J. R., & Maciel, R. (2019). *A cloud platform for smart government services, using SDN networks: The case of study at Jalisco State in Mexico*. *2019 IEEE International Smart Cities Conference (ISC2)*, 372–377. <https://doi.org/10.1109/ISC246665.2019.9071680>
9. Cho, H., Kim, D., Park, J., Roh, K., & Hwang, W. (2018). *2D Barcode Detection using Images for Drone-assisted Inventory Management*. *2018 15th International Conference on Ubiquitous Robots (UR)*, 461–465. <https://doi.org/10.1109/URAI.2018.8441834>
10. Culler, D., & Long, J. (2016). *A Prototype Smart Materials Warehouse Application Implemented Using Custom Mobile Robots and Open Source Vision Technology Developed Using EmguCV*. *Procedia Manufacturing*, 5, 1092–1106.
11. Culman, M. A., Gomez, J. A., Talavera, J., Quiroz, L. A., Tobon, L. E., Aranda, J. M., Garreta, L. E., & Bayona, C. J. (2017). *A Novel Application for Identification of Nutrient Deficiencies in Oil Palm Using the Internet of Things*. *2017 5th IEEE International Conference on Mobile Cloud Computing, Services, and Engineering*, 169–172. <https://doi.org/10.1109/MobileCloud.2017.32>
12. De Preter, A., Anthonis, J., & De Baerdemaeker, J. (2018). *Development of a Robot for Harvesting Strawberries*. *IFAC-PapersOnLine*, 51(17), 14–19. <https://doi.org/10.1016/j.ifacol.2018.08.054>

13. Duque, D. A., Prieto, F. A., & Hoyos, J. G. (2019). Trajectory generation for robotic assembly operations using learning by demonstration. *Robotics and Computer-Integrated Manufacturing*, 57, 292–302. <https://doi.org/10.1016/j.rcim.2018.12.007>
14. Ferraguti, F., Pini, F., Gale, T., Messmer, F., Storchi, C., Leali, F., & Fantuzzi, C. (2019). Augmented reality based approach for on-line quality assessment of polished surfaces. *Robotics and Computer-Integrated Manufacturing*, 59, 158–167.
15. Foughali, P. P. K., Fathallah, K., & Frihida, A. (2019). A Cloud-iot based decision support system for potato Pest Prevention. *Procedia Computer Science*, 160, 616–623. <https://doi.org/10.1016/j.procs.2019.11.038>
16. Frigo, M. A., da Silva, E. C. C., & Barbosa, G. F. (2016). Augmented Reality in Aerospace Manufacturing: A Review. *Journal of Industrial and Intelligent Information*, 4(2), 125–130. <https://doi.org/10.18178/jiii.4.2.125-130>
17. Gómez, J., Castaño, S., Mercado, T., Garcia, J., & Fernandez, A. (2017). Sistema de internet de las cosas (IoT) para el monitoreo de cultivos protegidos. *Revista Ingeniería e Innovación*, 5(1), 24–31.
18. Guerrero-Ibañez, J. A., Estrada-Gonzalez, F. P., Medina-Tejeda, M. A., Rivera-Gutierrez, M. G., Alcaraz-Aguirre, J. M., Maldonado-Mendoza, C. A., Toledoñuiga, D., & Lopez-Gonzalez, V. I. (2017). SGreenH-IoT: Plataforma IoT para Agricultura de Precisión. *Revista Iberoamericana de Sistemas, Cibernética e Informática.*, 14(2), 53–58.
19. Halawa, F., Dauod, H., Lee, I., Li, Y., Yoon, S. W., & Chung, S. H. (2020). Introduction of a real time location system to enhance the warehouse safety and operational efficiency. *International Journal of Production Economics*, 224. <https://doi.org/10.1016/j.ijpe.2019.107541>
20. IDC. (2019). New IDC Forecast Expects the Internet of Things Spending in Asia/Pacific* to Reach USD 398.6 Billion by 2023. International Data Corporation. <https://www.idc.com/getdoc.jsp?containerId=prAP45362119>
21. Jennings, D., & Figliozzi, M. (2019). Study of Sidewalk Autonomous Delivery Robots and Their Potential Impacts on Freight Efficiency and Travel. *Transportation Research Record*, 2673(6), 317–326. <https://doi.org/10.1177/0361198119849398>
22. Jun, S., Lee, S., & Yih, Y. (2020). Pickup and delivery problem with recharging for material handling systems utilising autonomous mobile robots. *European Journal of Operational Research*. <https://doi.org/10.1016/j.ejor.2020.07.049>
23. Karevska, S., Steinberg, G., Müller, A., & Wienken, R. (2019). 3D printing: hype or game changer? A global EY Report 2019. https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/advisory/ey-3d-printing-game-changer.pdf
24. Khattab, A., Habib, S. E. D., Ismail, H., Zayan, S., Fahmy, Y., & Khairy, M. M. (2019). An IoT-based cognitive monitoring system for early plant disease forecast. *Computers and Electronics in Agriculture*, 166. <https://doi.org/10.1016/j.compag.2019.105028>
25. Kumar, N. V., & Kumar, C. S. (2018). Development of collision free path planning algorithm for warehouse mobile robot. *Procedia Computer Science*, 133, 456–463. <https://doi.org/10.1016/j.procs.2018.07.056>
26. Lai, Z. H., Tao, W., Leu, M. C., & Yin, Z. (2020). Smart augmented reality instructional system for mechanical assembly towards worker-centered intelligent manufacturing. *Journal of Manufacturing Systems*, 55, 69–81. <https://doi.org/10.1016/j.jmsy.2020.02.010>
27. Laxmi, A. R., & Mishra, A. (2018). RFID based Logistic Management System using Internet of Things (IoT). *ICECA 2018*, 556–559. <https://doi.org/10.1109/ICECA.2018.8474721>
28. Levratti, A., Riggio, G., Fantuzzi, C., De Vuono, A., & Secchi, C. (2019). TIREBOT: A collaborative robot for the tire workshop. *Robotics and Computer-Integrated Manufacturing*, 57, 129–137. <https://doi.org/10.1016/j.rcim.2018.11.001>
29. Limeira, M., Piardi, L., Kalempa, V. C., Schneider, A., & Leitao, P. (2020). Augmented Reality System for Multi-robot Experimentation in Warehouse Logistics. *Robot 2019: IV Iberian Robotics Conference*, 1092, 319–330.

https://doi.org/10.1007/978-3-030-35990-4_26

30. Loch, F., Quint, F., & Brishtel, I. (2016). Comparing video and augmented reality assistance in manual assembly. 2016 12th International Conference on Intelligent Environments (IE), 147–150. <https://doi.org/10.1109/IE.2016.31>
31. Lototsky, V., Sabitov, R., Smirnova, G., Sirazetdinov, B., Elizarova, N., & Sabitov, S. (2019). Model of the automated warehouse management and forecasting system in the conditions of transition to industry 4.0. IFAC-PapersOnLine, 52(13), 78–82. <https://doi.org/10.1016/j.ifacol.2019.11.137>
32. Manosalva Barrera, N. E., & Cangrejo Aljure, L. D. (2018). Arquitectura tecnológica IoT para la trazabilidad de productos frescos. Revista Cubana de Ciencias Informáticas, 12(1), 28–42. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S2227-18992018000100003
33. Materne, N., & Inoue, M. (2018). Potential of IoT System and Cloud Services for Predicting Agricultural Pests and Diseases. 2018 IEEE Region Ten Symposium (Tensymp), 298–299. <https://doi.org/10.1109/TENCONSpring.2018.8691951>
34. Matsumoto, T., Kosaka, T., Sakurada, T., Nakajima, Y., & Tano, S. (2019). Picking work using AR instructions in warehouses. 2019 IEEE 8th Global Conference on Consumer Electronics (GCCE), 31–34. <https://doi.org/10.1109/GCCE46687.2019.9015334>
35. Mejjaoui, S., & Babiceanu, R. F. (2018). Cold supply chain logistics: System optimization for real-time rerouting transportation solutions. Computers in Industry, 95, 68–80. <https://doi.org/10.1016/j.compind.2017.12.006>
36. Mello, R. C., Sierra, S. D., Munera, M., Cifuentes, C. A., Ribeiro, M. R. N., & Frizera-Neto, A. (2019). Cloud robotics experimentation testbeds: A cloud-based navigation case study. CCAC 2019, 1–6. <https://doi.org/10.1109/CCAC.2019.8921387>
37. MinTIC. (2020). Ministerio de Tecnologías de la Información y las Comunicaciones de Colombia. <https://www.mintic.gov.co/portal/inicio/>
38. Montalvo Navarrete, J. I., & Caldeira, T. (2019). Smart Manufacturing of 3D Printed Robots. 2019 Advances in Science and Engineering Technology International Conferences (ASET), 1–5. <https://doi.org/10.1109/ICASET.2019.8714537>
39. Mourtzis, D., Angelopoulos, J., & Panopoulos, N. (2020). Recycling and retrofitting for industrial equipment based on augmented reality. Procedia CIRP Journal, 90, 606–610. <https://doi.org/10.1016/j.procir.2020.02.134>
40. Mourtzis, D., Samothrakis, V., Zogopoulos, V., & Vlachou, E. (2019). Warehouse Design and Operation using Augmented Reality technology: A Papermaking Industry Case Study. Procedia CIRP, 79, 574–579. <https://doi.org/10.1016/j.procir.2019.02.097>
41. Muangprathub, J., Boonnam, N., Kajornkasirat, S., Lekbangpong, N., Wanichsombat, A., & Nillaor, P. (2019). IoT and agriculture data analysis for smart farm. Computers and Electronics in Agriculture, 156, 467–474. <https://doi.org/10.1016/j.compag.2018.12.011>
42. Müller, C., Wyatt, S., Bieller, S., Qu, D., & Song, X. (2019). IFR Press Conference: Shanghai 18th September 2019. In International Federation of Robotics. [https://ifr.org/downloads/press2018/IFR World Robotics Presentation - 18 Sept 2019.pdf](https://ifr.org/downloads/press2018/IFR%20World%20Robotics%20Presentation%20-%2018%20Sept%202019.pdf)
43. Nawandar, N. K., & Satpute, V. R. (2019). IoT based low cost and intelligent module for smart irrigation system. Computers and Electronics in Agriculture, 162, 979–990. <https://doi.org/10.1016/j.compag.2019.05.027>
44. Núñez V., J. M., Fonthal R., F., & Quezada L., Y. M. (2018). Design and Implementation of WSN and IoT for Precision Agriculture in Tomato Crops. 2018 IEEE ANDESCON, 1–5. <https://doi.org/10.1109/ANDESCON.2018.8564674>
45. Oxford Economics. (2019). How robots change the world. What automation really means for jobs and productivity. In

Oxford Economics. <http://resources.oxfordeconomics.com/how-robots-change-the-world>

46. Pachayappan, M., Ganeshkumar, C., & Sugundan, N. (2020). Technological implication and its impact in agricultural sector: An IoT Based Collaboration framework. *Procedia Computer Science*, 171, 1166–1173. <https://doi.org/10.1016/j.procs.2020.04.125>
47. Qian, C., Zhang, Y., Liu, Y., & Wang, Z. (2019). A cloud service platform integrating additive and subtractive manufacturing with high resource efficiency. *Journal of Cleaner Production*, 241, 1–16. <https://doi.org/10.1016/j.jclepro.2019.118379>
48. Qu, T., Lei, S. P., Wang, Z. Z., Nie, D. X., Chen, X., & Huang, G. Q. (2016). IoT-based real-time production logistics synchronization system under smart cloud manufacturing. *Int J Adv Manuf Technol*, 84, 147–164. <https://doi.org/10.1007/s00170-015-7220-1>
49. Rey, R., Corzetto, M., Cobano, J. A., Merino, L., & Caballero, F. (2019). Human-robot co-working system for warehouse automation. *ETFA 2019*, 578–585. <https://doi.org/10.1109/ETFA.2019.8869178>
50. Roach, D. J., Hamel, C. M., Dunn, C. K., Johnson, M. V., Kuang, X., & Qi, H. J. (2019). The m4 3D printer: A multi-material multi-method additive manufacturing platform for future 3D printed structures. *Additive Manufacturing*, 29. <https://doi.org/10.1016/j.addma.2019.100819>
51. Rodríguez Molano, J. I., Cueva Lovelle, J. M., Montenegro, C. E., Rainer Granados, J. J., & González Crespo, R. (2018). Metamodel for integration of Internet of Things, Social Networks, the Cloud and Industry 4.0. *Journal of Ambient Intelligence and Humanized Computing*, 9, 709–723. <https://doi.org/10.1007/s12652-017-0469-5>
52. Rudolph, J. P., & Emmelmann, C. (2017). A Cloud-based Platform for Automated Order Processing in Additive Manufacturing. *Procedia CIRP*, 63, 412–417. <https://doi.org/10.1016/j.procir.2017.03.087>
53. Schuster, A., Kupke, M., & Larsen, L. (2017). Autonomous Manufacturing of Composite Parts by a Multi-Robot System. *Procedia Manufacturing*, 11, 249–255. <https://doi.org/10.1016/j.promfg.2017.07.238>
54. Simeone, A., Caggiano, A., & Zeng, Y. (2020). Smart cloud manufacturing platform for resource efficiency improvement of additive manufacturing services. *Procedia CIRP*, 88, 387–392. <https://doi.org/10.1016/j.procir.2020.05.067>
55. Sreekanta, M. H., Sarode, A., & George, K. (2020). Error Detection using Augmented Reality in the Subtractive Manufacturing Process. *CCWC 2020*, 592–597. <https://doi.org/10.1109/CCWC47524.2020.9031141>
56. Stasewitsch, I., Schattenberg, J., & Frerichs, L. (2020). Cleaning Robot for Free Stall Dairy Barns: Sequential Control for Cleaning and Littering of Cubicles. *Robot 2019: IV Iberian Robotics Conference.*, 1092, 115–126. https://doi.org/10.1007/978-3-030-35990-4_10
57. Tang, C. S., & Veelenturf, L. P. (2019). The strategic role of logistics in the industry 4.0 era. *Transportation Research Part E*, 129, 1–11. <https://doi.org/10.1016/j.tre.2019.06.004>
58. Tejesh, B. S. S., & Neeraja, S. (2018). Warehouse inventory management system using IoT and open source framework. *Alexandria Engineering Journal*, 57(4), 3817–3823. <https://doi.org/10.1016/j.aej.2018.02.003>
59. Vorraber, W., Gasser, J., Webb, H., Neubacher, D., & Url, P. (2020). Assessing augmented reality in production: remote-assisted maintenance with HoloLens. *Procedia CIRP*, 88, 139–144. <https://doi.org/10.1016/j.procir.2020.05.025>
60. Wang, J., Lim, M. K., Zhan, Y., & Wang, X. F. (2020). An intelligent logistics service system for enhancing dispatching operations in an IoT environment. *Transportation Research Part E: Logistics and Transportation Review*, 135. <https://doi.org/10.1016/j.tre.2020.101886>

61. Witkowski, K. (2017). *Internet of Things, Big Data, Industry 4.0 - Innovative Solutions in Logistics and Supply Chains Management*. *Procedia Engineering*, 182, 763–769. <https://doi.org/10.1016/j.proeng.2017.03.197>
62. XR Association, & perkinscoie. (2019). *2019 Augmented and virtual reality. Survey report*. <https://www.perkinscoie.com>
63. Zaki, R. M., Strutynski, C., Kaser, S., Bernard, D., Hauss, G., Faessel, M., Sabatier, J., Canioni, L., Messaddeq, Y., Danto, S., & Cardinal, T. (2020). *Direct 3D-printing of phosphate glass by fused deposition modeling*. *Materials and Design*, 194. <https://doi.org/10.1016/j.matdes.2020.108957>
64. Zhang, Y., Liu, S., Liu, Y., & Li, R. (2016). *Smart box-enabled product–service system for cloud logistics*. *International Journal of Production Research*, 54(22), 6693–6706. <https://doi.org/10.1080/00207543.2015.1134840>
65. Zhao, Z., Zhang, M., Xu, G., Zhang, D., & Huang, G. Q. (2020). *Logistics sustainability practices: an IoT-enabled smart indoor parking system for industrial hazardous chemical vehicles*. *International Journal of Production Research*. <https://doi.org/10.1080/00207543.2020.1720928>
66. Zhao, Z., Zhang, M., Yang, C., Fang, J., & Huang, G. Q. (2018). *Distributed and collaborative proactive tandem location tracking of vehicle products for warehouse operations*. *Computers & Industrial Engineering*, 125, 637–648. <https://doi.org/10.1016/j.cie.2018.05.005>
67. Zhu, X., Shi, J., Huang, S., & Zhang, B. (2020). *Consensus-oriented cloud manufacturing based on blockchain technology: An exploratory study*. *Pervasive and Mobile Computing*, 62. <https://doi.org/10.1016/j.pmcj.2020.101113>