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A DEMONSTRATION OF THE AUGMENTED REALITY BENEFITS WHEN APPLIED IN AEROSPACE FABRICATION

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Abstract. *In response to an increase of competitiveness it has been necessary an improvement of Lean Manufacturing using new technologies that may also contribute to reduce recurrent costs. One of these technologies to aid in this regard is the Augmented Reality. The main purpose of this work is to identify through scientific papers, journals, congresses and company statements the Augmented Reality (AR) applications on manufacturing processes in order to demonstrate the benefits and advantages that can be reached by this technology application. In this way, potential opportunities in aerospace manufacturing environment are listed to demonstrate gains of labor qualification, training costs reduction, poka-yoke system and productivity of the business. Then, a case study is presented to show a real technical situation that can be improved when AR is applied and its contribution to provide competitive advantages in terms of tangible and intangible earnings. These potential gains were presented due to the performed analysis based on research and technical feasibility studies, although the solution has not yet been implemented on shop floor.*

Keywords: *Augmented Reality, Industrial AR, Aerospace Fabrication, Complex Manufacturing.*

1. INTRODUCTION

According to Salgado *et al*. (2009) the market is undergoing transformations forming a new dynamic context for organizations where their products must compete on price and quality with competitors from all over the world, whether from countries with high level of technological development or countries with lower levels, continuously developing new technologies and products in order to reduce costs, time of new products development, of non-conformities, maintenance and even expanding market.

According to Womack and Jones (1996), Lean Manufacturing helps to identify what has value to the customer, eliminate waste occurring during the processes and generate a flow of value to the customer, in order to contribute to gains in competitiveness.

To avoid waste, analyzing the fact of the emerged of computers, Kirner and Siscoutto (2007) show that with computers a new form of interaction was possible with the industries, bringing more sophisticated processes that show new ways to avoid waste developing faster and simpler ways to perform operations by changing the level of knowledge required to perform these operations.

Virtual Reality emerges in the 60's when, according to Tori, Kirner and Siscoutto (2006) it was possible to exist a new generation of ways to interactions between man and machine, which inserts the user in a three dimensional environment of applications running on the computer relating its ability to react to the user actions instantly when it is detected in order to modify aspects of the application.

By the use of special equipment and the necessity to create a virtual environment, the mass utilization of Virtual Reality was braked. However, in the 90's with the unbridled progress of technology, according to Caudell *et al*. (1992), Augmented Reality (AR) emerged looking into manufacturing using a head-mounted display to superimpose design diagrams on real parts.

Azuma (1997) presents the Augmented Reality being applied in six different categories: medical, manufacturing and repair, annotation and visualization, robot path planning, entertainment, and military. The focus of this article is in the use of AR for manufacturing and repair tasks. The main goal of this research work is focused on Manufacturing and Repair category driven to AR application for aircraft manufacturing industries to provide processes that are more agile and at lower cost for the business.

Therefore, the contribution of this paper makes a comparison between the conventional process and AR technology applied to a factual aircraft fabrication process. This paper presents a case study that intends to demonstrate gains, benefits and advantages related to the AR application in this specific segment of industry.

2. LITERATURE REVIEW

2.1 Lean manufacturing and aerospace industry

According to Seitz & Steele (1985), the manufacturing of aircrafts, in addition to being one of the most important sectors of manufacturing of durable goods due to its high added value, is also the sector that most encourages the development of new technologies and which employs more skilled labor, such as technicians, engineers and researchers.

Aerospace industry is open to new enterprises but these investments should be done with extreme care, since the cost of development of new products is extremely high in this kind of industry. This makes it clear that errors are not allowed when it is invested in aircrafts fabrication (Barbosa, 2012).

From 1945 to the end of the World War II, Japan began to produce passenger cars. Until then, cars were produced only in the United States and Europe. Therefore, the Japanese consumer market was restricted and demanded several different models, which prevented the adoption of mass production system developed by Taylor and Ford, which prevailed until the 90's. At the end of World War II, comes the Toyota Production System, developed by Taiichi Ohno, engineer and vice president of Toyota Motor, in order to meet the Japanese market and its peculiarities. Ohno began to examine what could be changed in the production line based on the mass production system.

The Toyota Production System is currently referred to as Lean Manufacturing and, according to Ghinato (2000), "is much more efficient, flexible, agile and innovative than mass production; a system able to better face an ever-changing market".

The term lean was first coined by John Krafcik (1988) in his article, "Triumph of the Lean Production Systems", and was later popularized by Womack, *et al*. (1990).

The Lean Thinking is characterized as a powerful antidote to waste and able to make the most satisfying work, turning waste into value. According to Womack and Jones (1996), Lean Thinking can be feature as a way to specify value, line up in the best sequence of actions that create value, perform these activities without interruption whenever someone calls and makes them more effectively.

According to Ohno (1988), waste is understood as any element, which raises production costs without representing value to the product. Lean Manufacturing assumes that there are seven types of waste also known as Muda (Japanese term) that occur inside companies we should eliminate. They are waste of excessive transportation, waste of inventory, waste of motion, waste of waiting, waste of over production, waste of over processing and waste of Defects (rejects or re-work).

Hines and Taylor (2000) claim that when we think about industry waste we can define it in three different activities, the activities that generate value for the product or service, unnecessary activities that do not generate value, and necessary activities but do not generate value.

The Aerospace sector has recognized the opportunity to eliminate huge amounts of waste within its value streams with Lean Manufacturing. Cook (1999) mentioned that Lean will do for aircraft industries what it did for car industries, affirming that panels and components damaged in operation can be quickly replaced at the front line without special customization in much the same way that car parts are ordered up and fitted in the commercial world. Employees involved in all aspects of production from design stage to logistics support are grouped into teams, where each team is responsible for its own budget and accountable for its particular section of the aircraft.

The aerospace industry is in the grip of a revolution. Its name is Lean and its guiding principle is the elimination of waste from the production cycle. The revolution is moving out of the prototyping shops and on to the assembly lines, with dramatic results. The automotive industry has been Lean for years. In aerospace, avionics and engine manufacturers embraced Lean thinking long before the airframe makers. Now airframers are moving fast to catch up. Their motivation is the promise of faster development, better quality and lower cost (Flight International, 1999).

Inside the aerospace industry, the Lean Manufacturing concepts have been applied increasingly, being the continuous flow an important factor in defining the assembly process. This condition favors the fluidity of the product along the line showing the evolution of the assemblies at each stage. Another important reason is the fact that there is no need for returns, thus avoiding difficulties and delays during assembly. Figure 1 shows the concept of Boeing 777 aircraft moving assembly line that started in 2006 at Everett, USA.

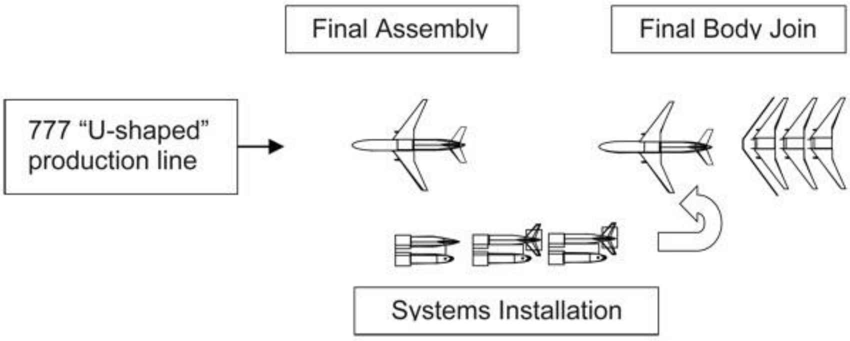

Figure 1. Boeing 777 Moving Assembly Line (source: Airways News, 2013)

The execution of the final aircraft assembly in moving line conception, according to Barbosa (2007) is a big manifestation of companies in relation to Lean Manufacturing. "Mobile line is the most powerful tool available to identify and eliminate waste in the production system", said Elizabeth Lund, Boeing 777 production director. The moving line drives the system, because it makes problems become visible and creates a sense of urgency in solving the root cause of all problems (Airways News, 2013).

2.2 Virtual Reality (VR)

Kirner and Siscoutto (2007) defined Virtual Reality (VR) as an advanced user interface to access applications running on the computer, allowing the display, handling and user interaction, in real time, in three-dimensional computer-generated environments. The sense of sight is usually the main sense in VR applications, but the other senses like touch, and hearing among others, can also be used in order to enhance the user experience.

VR has its origins in the 60's, but only gained force in the 90's, when technological advances provided conditions for the implementation of interactive computer graphics in real time. Even with the advantages of virtual reality, it required special equipment such as helmet, gloves, stereoscopic glasses, among others to insert the user into the application space, where their interactions are performed. In addition, the insertion of the user to the virtual environment caused an initial discomfort and difficulties of interaction. Therefore, training was often necessary. These problems inhibited the popularization of virtual reality as a new user interface (Kirner and Siscoutto, 2007).

2.3 Augmented Reality (AR)

Augmented Reality (AR) is the augmentation of the real world with digitally generated sensory inputs like images and sounds. When applied to visuals, as it was done by the current work, digital objects are registered spatially and rendered within the physical world often using a display device like a tablet or cell phone (Richardson *et al*., 2014).

2.4 Augmented Reality Applications - Manufacturing and Repair

In the early 1990s, Boeing had already begun looking into the use of augmented reality for manufacturing using a head-mounted display to superimpose design diagrams on real parts (Caudell *et al*., 1992 *apud* Glockner *et al*., 2014). Research here has shown that reductions in both time and errors can be gained by using AR (Nakanishi *et al*., 2007 *apud* Glockner *et al*., 2014), as mentioned by Richardson *et al*. (2014) in his research work, as well as the ease of computers use and their new technologies in the automotive and aerospace industry, started to develop project to use AR in manufacturing processes.

The use of AR for work instruction delivery has been an area showing possible benefit to industry (Nee *et al*., 2012 *apud* Glockner *et al*., 2014). Assembly, maintenance and repair of complex machinery is the objective application of this category where the goal is to make the instructions easier to understand if they were available as 3D drawings superimposed upon the actual equipment showing how the tasks need to be done step-by-step with animations to let the directions even more explicit (Glockner *et al*., 2014).

More and more logistics providers offer added value to customers with services such as assembly and repair. For example, DHL not only collects materials from component providers for Audi, but also assembles these components into interior door panels that are then delivered to the Audi production plant in Germany (Glockner *et al*., 2014).

Currently, skilled workers are required for such tasks, and each must be individually trained. However, in the future AR could train and aid employees to assemble a variety of products and ensure that high standards of service are maintained, potentially reducing cost for customers (Glockner *et al*., 2014).

2.5 Augmented Reality in Aircraft Manufacturing

The advantages and benefits of AR have been widely applied by important aircraft manufacturers in global market. Airbus is an aircraft manufacturing with facilities mainly in France, Germany, Spain and the United Kingdom and others, with a global diversity highlighted by the multi-cultural workforce of more than 58,000. The company's manufacturing operations around the world set industry benchmarks in both quality and efficiency standards.

Airbus produces and markets the world's largest passenger airliner, the A380. Seating capacity ranges from 544 passengers up to 853 depending on the selected configuration, its unique size allows airlines to maximize their revenue potential through an optimized, segmented cabin, boosting their contribution to profit by up to 65 per cent per flight. (Airbus, 2015). Figure 2 shows Airbus A380 final assembly line.

Figure 2. Final assembly line of A380. (source: Airbus, 2015)

With the master for a new aircraft production process developed entirely with digital tools, Airbus collaborated to create the Mixed Reality Application (MiRA) in 2009.

This app increases productivity in production lines by using AR to scan parts and detect errors. On the A380, MiRA, which today consists of a tablet PC and a specifically developed sensor pack and software, has reduced the time needed to check tens of thousands of brackets in the fuselage from 300 hours to an astonishing 60 hours. Furthermore, late discoveries of damaged, wrongly positioned or missing brackets have been reduced by 40% (Glockner, 2014). Figure 3 shows a quality inspection with MiRA.

Figure 3. MiRA Solution. (source: Glockner, 2014, p. 11).

In the more commercial aerospace world, Airbus is using a technology known as MiRA, or Mixed Reality Application, where engineers installing equipment inside aircraft fuselages use a tablet computer and a sensor pack, which tracks their position and relates it to a Realistic Human Ergonomics Analysis (RHEA) tool, a full-scale 3D digital model of the aircraft they are working on. This enables them to call up an image of a bracket installation in the area where they are working to ensure that they have fixed it correctly. Geolocation devices attached to the aircraft interact with the sensor pack to allow them to view their work location from any angle. The RHEA is updated as each component is installed. This technique has helped reduce the time to inspect the 80,000 brackets inside an A380 fuselage, which hold systems such as hydraulics pipes, from three weeks to three days (The Engineer, 2015).

2.6 Hardware and Software to implement AR in manufacturing

To implement an AR system as MiRA for quality gate is necessary acquires hardware as Panasonic Toughpad tablet FZ-G1, a HD camera and the Geolocalization electronic system managing the user tracking system (Fig. 4).

Figure 4. MiRA Solution. (source: Testia, 2015)

A software to load CAD Mock-Up (Product Structure + Parts) defines the list of parts to be inspected and converts CAD Mock-Up, synchronizing the Reality with the DMU (TAG usage), superimposing on real time the DMU on Reality through HD Camera capture, following the inspection scenario defined (list of parts to be checked) and automatic creation of inspection report status

3. RESEARCH METHODOLOGY

The objectives of the research work in the augmented reality applications are to find out the potential gains in aircraft production lines. This work specifies a comparison between an application already carried out and a particular case study to demonstrate the resulting savings.

To demonstrate a real application of AR in aerospace fabrication environment, this contribution has simulated the results of Airbus implementation cited above, in order to show benefits in a narrow body aircraft wing assembly. To reduce time and ensure the assembly during the quality gate phase, the check of all brackets of the wing is needed.

The basic steps used to conduct this research:

1. Being aware of AR applications in industries;
2. Research AR cases in the aerospace sector;
3. Understanding of savings and reduction of non-conformities related to AR applications;
4. Discussions with experts in AR available in the market;
5. Definition of a real situation for the study;
6. Case Study as a comparison method.

4. CASE STUDY

Faced to the real case of Airbus Company, the wing assembly of a narrow body aircraft has been chosen to demonstrate the potential saving that could be getting through the AR application on it.

To reduce re-work time in an unexpected moment and ensure the assembly, during the quality gate phase the check of all brackets of the wing is needed. Quality gates are necessary although it is a kind of production waste, since it does not generate value to the product as discussed earlier.

Brackets are little components installed in the aircraft during the assembly with the function of guiding the electrical wires and hydraulic lines for example, or they also serve as structural support for aircraft equipment and devices, among others. Figure 5 shows a common aircraft bracket, which can be found in aircraft wings and fuselages.

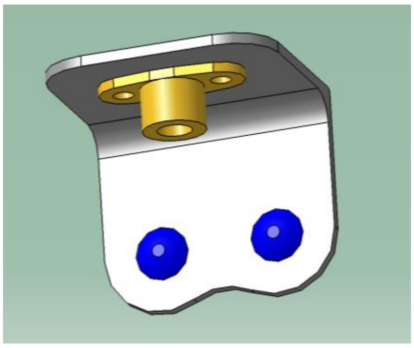

Figure 5. An example of aircraft bracket.

Figure 6 shows a bracket highlighted in red, which is installed in the region of the wing tip.

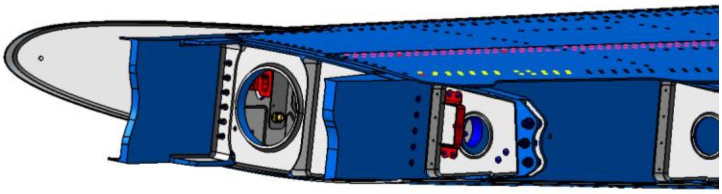

Figure 6. A bracket of wing tip region.

Figure 7 shows examples of brackets highlighted in red, which are installed in the region of the Wing Stub.

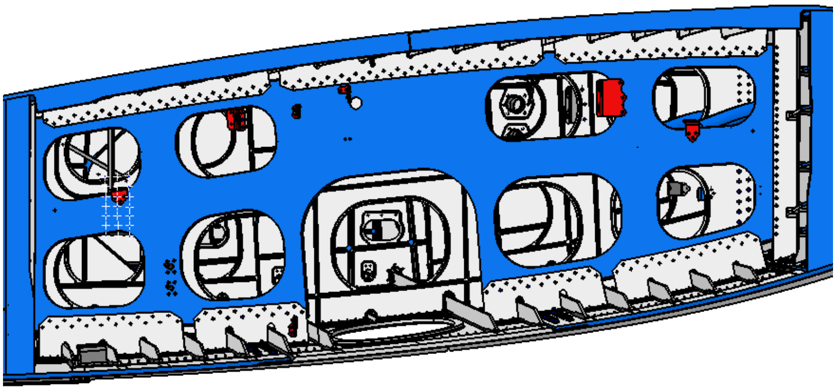

Figure 7. Brackets of the region of the Wing Stub.

Some hardware (tablets) have been acquired in order to achieve the paperless concept in assembly line, it could be adapted to AR solutions as MiRA to make it easier to implement AR in the final quality gate. Supposing that a software will be developed to attend the requirements of the hardware, it was possible to simulate gains with that solution, disregarding the software cost.

Analyzing the Airbus case that was presented before, the table below was made considering the information cited by Glockner (2014) and The Engineer (2015). Table 1 shows the comparison between conventional and MiRA solution.

TABLE 1 – Comparison between conventional inspection and MiRA solution

Airbus A380 – Fuselage brackets		
Quantity	Conventional Solution	MiRA Solution
80,000	300 hours	60 hours
1	13.5 seconds	2.7 seconds

Analyzing the table 1, we can compare the results of the conventional solution with the MiRA solution and imply that a reduction of 80% of inspection time is reached.

The inspection of each wing bracket takes longer than the fuselage bracket due to difficult access for inspections of several wing brackets. In the fuselage, it is possible to evaluate brackets inside the own fuselage, but in the wing it is necessary to use the access doors to view some brackets. Figure 8 shows an example of a bracket highlighted in red that to be inspected is necessary to look through the access door.

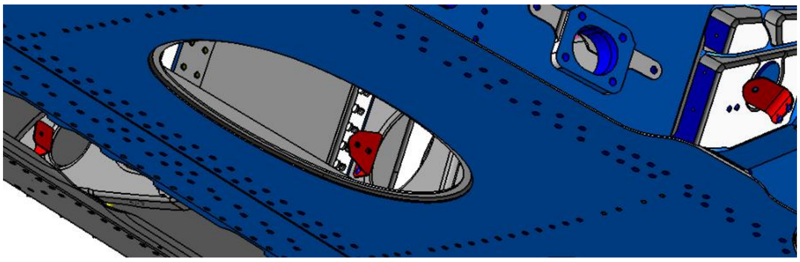

Figure 8. Brackets inside of the wing access door.

Considering that each half wing contains around of 714 brackets and the average of all brackets' inspection is performed in 2 shifts (16 hours), the company in study will reach the result showed in Tab. 2.

TABLE 2 – Comparison between conventional inspection and AR solution

Case – Wing brackets		
Quantity	Conventional Solution	AR Solution
1428	16 hours	3.2 hours
1	40.3 seconds	8.07 seconds

According to Recruiter (2015), aircraft assemblers will normally get a pay level of $ 45,300.00 per year. It would represent an average of $ 27 per hour, considering 141 work hours per month.

In this case study, each set of wing assembly will reduce 12.8 hours of work. This saving will earn about $ 346 for each set of wing. Considering the production ratio of 12 set of wing per month, it will represent $ 49,824.00 per year, only considering the earnings for the national salary average as mentioned previously.

5. CONCLUSION

These new technologies offer manufacturers a faster production, higher quality and reliability for the production processes, as well as increasing the company's competitiveness.

Early detection of non-conformities, avoiding costly corrections when performed later in the process are some of the benefits as well as a considerable inspection time reduction and the improvement with quality control process. Some cases may have higher costs if non-conformities are not early detected, for example, moving people from one activity to perform the rework, have to take out the fuel from the wing, or in some cases even have to reject components that have been stressed due to incorrect position of the installed bracket.

The cost to implement AR just for wings may be not valuable, but implementing on wings and fuselage, that have more numbers of brackets to be inspected, considering that the company will implement AR for all aircraft models assembled by the manufacturer then, this implementation may be very valuable.

This work does not bring the cost of software as MiRA, even then any company that wishes to study the feasibility of implementation can adopt the methodology of this work and replace the values of the case study for the values of their own reality and compare with the cost of implementation received through a budget or internal study.

6. REFERENCES

Airbus, 2015. "Company". 3 Apr. 2015. <http://www.airbus.com/company/>.

Airways News, 2013. "A History of Boeing's Everett Plant Part Three: The Magificent Seven". 2 Apr. 2015. <http://airwaysnews.com/blog/2013/10/31/history-boeings-everett-plant-part-three-magificent-seven/>.

Azuma, R. T., 1997. "Survey of Augmented Reality". *Presence*, v.6, n.4, p. 355-385.

Barbosa, G. F., 2007. *Aplicação da metodologia DFMA – Design for Manufacturing and Assembly no projeto e fabricação de aeronaves*. Programa de Pós-Graduação em Engenharia Mecânica, Escola de Engenharia de São Carlos da Universidade de São Paulo, Dissertação (Mestrado).

Barbosa, G. F., 2012. *Desenvolvimento de um modelo de análise para implantação de automação na manufatura aeronáutica, orientado pelos requisitos das metodologias de Projeto para Excelência (DFX – Design for Excellence) e Produção Enxuta (Lean Manufacturing).* Programa de Pós-Graduação em Engenharia Mecânica e

Área de Concentração em Manufatura, Escola de Engenharia de São Carlos da Universidade de São Paulo, Tese (Doutorado).

Caudell, T. P., and Mizell, D. W., 1992. "Augmented reality: an application of heads-up display technology to manual manufacturing processes". *Proceedings of the Twenty-Fifth Hawaii International Conference on System Sciences*, vol.2. doi:10.1109/HICSS.1992.183317, p. 659–669.

Cook, M., 1999. "The race is on in lean production". *Interavia Business & Technology 54*, p. 15-18.

Flight International, 1999. "Lean stories", p.42.

Ghinato, P., 2000. Elementos Fundamentais do Sistema Toyota de Produção. In: ALMEIDA, A.T. & SOUZA, F. M. C. *Produção e Competitividade: Aplicações e Inovações*. Recife: Editora da UFPE.

Glockner, H.; Jannek, K.; Mahn, J. and Theis, B., 2014. *Augmented Reality in Logistics: Changing the way we see logistics – a DHL perspective*. DHL Customer Solutions & Innovation, Germany.

Hines, P. and Taylor, D., 2000. *Going Lean: a guide to implementation*. Lean Enterprise Research Center. Cardiff, UK.

Kirner, C.; Siscoutto, R., 2007. *Realidade Virtual e Aumentada: Conceitos, Projeto e Aplicações*. Livro do Pré-Simpósio, IX Symposium on Virtual and Augmented Reality, Petrópolis/RJ, Brasil.

Krafcik, J. F., 1988. "Triumph of the Lean Production System". *Sloan Management Review*, v.30, n.1.

Nakanishi, M.; Ozeki, M.; Akasaka, T. and Okada, Y., 2007. "Human factor requirements for Applying Augmented Reality to manuals in actual work situations". *IEEE International Conference on Systems, Man and Cybernetics*, doi:10.1109/ICSMC.2007.4413588, p. 2650–2655.

Nee, A. Y. C.; Ong, S. K.; Chryssolouris, G. and Mourtzis, D., 2012. "Augmented reality applications in design and manufacturing". *CIRP Annals - Manufacturing Technology*, 61(2), doi:10.1016/j.cirp.2012.05.010, p. 657–679.

Ohno, T., 1988. *The Toyota Production System: Beyond Large-Scale Production.* Productivity Press, Portland, Oregon.

Richardson, T.; Gilbert S.; Holub, J.; Thompson, F.; MacAllister, A.; Radkowski, R.; Winer, E.; Davies, P.; Terry, S., 2014. "Fusing Self-Reported and Sensor Data from Mixed-Reality Training". *Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC)*, paper n. 14158, p. 1-12.

Recruiter, 2015. "Salary for Aircraft Structure, Surfaces, Rigging, and Systems Assemblers". 21 May. 2015 <http://www.recruiter.com/salaries/aircraft-structure-surfaces-rigging-and-systems-assemblers-salary/>.

Salgado, E. G.; Mello, C. H. P.; Silva, C. E. S.; Oliveira, E. S.; Almeida, D.A., 2009. Análise da aplicação do mapeamento do fluxo de valor na identificação de desperdícios do processo de desenvolvimento de produtos. *Gestão & Produção*, São Carlos, v. 16, n. 3, p. 344-356.

Seitz, F. and Steele, L. W., 1985. *The competitive status of the U.S. civil aviation manufacturing industry*. National Academy Press, Washington DC.

Testia, 2015. "MiRA". 18 Mar. 2015 < http://www.testia.com/SMW-mira>.

The Engineer, 2015. "In touch with reality: the digital future of the factory". 6 May. 2015 <http://www.theengineer.co.uk/in-depth/the-big-story/in-touch-with-reality-the-digital-future-of-the-factory/1019837.article#ixzz3ZMlhpIwq>.

Tori, R.; Kirner, C.; Siscoutto, R., 2006. *Fundamentos e Tecnologia de Realidade Virtual e Aumentada*. Livro do Pré-Simpósio, VIII Symposium on Virtual Reality, Belém/PA, Brasil.

Womack, J. P.; Jones, D. T.; Roos, D., 1990. *The machine that changed the world*. Rawson Associates, New York.

Womack, J. P. and Jones, D. T., 1996. *Lean Thinking: banish waste and create wealth in your corporation*. Simon & Schuster, New York.

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