Applications of Augmented Reality to Reduce Risk in Supply Chain Management

Angela Colabella, Collette Lee, Lane Pledger, Monique Cendejas, Vikrant Mannemela and Mohamed Awwad
Industrial and Manufacturing Engineering Department
California Polytechnic State University
San Luis Obispo, CA 93407, USA
acolabel@calpoly.edu, clee244@calpoly.edu, lpledger@calpoly.edu, mmcendej@calpoly.edu, vmanneme@calpoly.edu, mawwad@calpoly.edu

Abstract

Augmented reality (AR) has a strong potential for success in improving supply chain operations and can impact how the manufacturing and distribution sectors are handled. The application of AR devices can reduce cost, time, and error rates as well as increase usability of a system and productivity. There is a need for augmented reality within inventory management to help order picking, assess product damage, and display inventory instructions. AR technology can be applied to improve the following networks within supply chains: it can instruct workers on where to find inventory within a warehouse and help to reduce time, workers could identify objects quicker without having to scan or type codes, and products can be sorted faster with lower error rates. Further, manufacturing tool maintenance can be more easily monitored and addressed remotely. Standard picking and packing procedures can be displayed for workers increasing worker safety and efficiency, and fewer workers would be needed to achieve inventory goals. These improvements can result in a decrease in the cost of labor and production time, increased accuracy, and expanded production capacity for companies. The purpose of this paper is to review current case studies regarding the use of AR technology in supply chain operations, specifically in inventory management, and showcase the potential cost reductions by applying AR to these operations.

Keywords
Augmented Reality, Inventory Management, Time Reduction, Accuracy, Supply Chain

1. Introduction
Warehouse operations are key factors in supply chains because they focus on the movement and storage of materials and any processes associated with them (Warehouse Management: Supply Chain 24/7 2020). These processes include recording transactions in shipping, receiving, put-away and picking. The customers expect to purchase and receive their products the following day (Romaine 2020). Therefore, within the supply chain, there is always a need to improve warehouse operations' speed and efficiency. When industries cannot meet this expectation, they will lose customers and ultimately profit; thus, there has been a considerable focus on improving warehouse operations.

With the pandemic and lockdown starting in the United States in March 2020, there has been a demand to integrate automation into US-based warehouses. Companies realized they could not rely on people to perform all their functions in their warehouses. This led to the need for the integration of automation to help reduce labor demand. There needs to be a way to have operators work faster without an increase in error rate or labor force. With augmented reality, operators can have direct, real-time access to a company's inventory database so they can improve their put-away and picking processes. Through this report, we hope to educate the audience on the opportunities AR can bring into warehouses.

1.1 Objectives

The use of augmented reality has been increasing over the last decade (Bagassi et al. 2020). The implementation of AR in warehouse operations can benefit companies on multiple levels. The application of AR devices can reduce cost, time, and error rates as well as increase usability of a system and productivity. The case studies analyzed in this paper will prove how AR has been used to achieve these goals.

1.2 Paper Outline

The following paper is organized into three sections that will provide proof of concept for our AR proposition: literature review, case studies, and results and discussion. The literature review section defines AR, discusses how AR works, and AR's general functions. This section also investigates the fundamentals of Supply Chain management and the importance of warehouse operations. In the case studies section, we examine four case studies related to AR's implementation and uses. The first case study analyzes AR in warehouse operations, specifically AR's opportunities and barriers. The second case study looks at AR implementations in a paper-making factory. The third case study researches cloud-based augmented reality remote maintenance through shopfloor monitoring. Finally, the fourth case study explores AR applications in virtual training. In the discussion section results, the four cases described are further investigated to see how AR can help companies achieve their objectives. Additionally, recommendations regarding where AR should be used within facilities and what AR types are best for a warehouse facility are introduced.

2. Literature Review

We define augmented reality (AR) as a real-time direct/in-direct view of a physical, real-world environment that has been enhanced by adding information that is virtually computed. In the early 1990s, the first application of AR to support industrial processes was when two employees from Boeing presented a head-up see-through display used to augment an operator's visual field with information related to the task the user was carrying out (Caudell and Mizell 1992). Not only did the two operators, Tom Caudell and David Mizell, coin the term augmented reality, but they furthered the use of AR in an industrial and manufacturing setting (Mealy 2020).

2.1 Augmented Reality

In the past decade, AR prototypes and products' active development has become a high growth market with elevated prospects. Augmented reality technology allows users to see a computer-generated virtual environment combined with the real world. This "virtual world" is an environment that is created and stored in a storage medium using a processor. Using an AR system, the user can access real-time virtual and actual information regarding their environment. The information passed on by the virtual object can help the user in performing daily-tasks work, from order picking to guiding workers through tasks. Currently, there are three major types of displays used in augmented reality – head-mounted displays (HMD), handheld displays, and spatial displays.

An HMD is worn on the head or as part of a helmet and places both images of the real and virtual environment over the user's view of the world. They basically use cameras/mirror technology to help process both these environments and display them.

Handheld displays employ small computing devices with a display that the user can hold in their hands. As that of some of the HMD models, they use video-see-through technology to overlay graphics onto the real environment and employ sensors, such as digital compasses and GPS units for their six degrees of freedom tracking sensors, etc. (Carmigniani 2011). These handheld displays fall into three main classes that are used commercially: smartphones, tablets, and personal display assistants (PDAs). With the advances being made in smartphone technology regarding CPU, battery, camera quality, and such, there is an up-and-coming platform for AR to build on (Carmigniani 2011). While presenting similar pros and cons to smartphones, PDAs are more obsolete due to the on-going advances in smartphone technology. Finally, the Tablet PCs (iPad, Samsung Galaxy) are a lot more powerful than smartphones, but they too heavy for single-handed and even prolonged two-handed use.

The last major AR display, Spatial Augmented Reality (SAR), makes use of video-projectors, optical elements, holograms, and other tracking technologies to display graphical information directly onto physical objects in the "real world" without requiring the user to wear or carry the display (Carmigniani 2011). The key difference in SAR is that the display is separated from the users of the system. Because the displays are not associated with each user, SAR scales naturally up to users' groups, thus allowing for collocated collaboration between users. SAR also represents a key technology for smart manufacturing development due to being barrier-free and fitting most industrial constraints (Mengoli 2018). All these AR displays can be applied in different situations throughout the industry to lower costs and improve productivity.

2.2 Supply Chain Management

Supply Chain Management encompasses a range of activities that goes from the planning to the execution of a product's flow from the start to the end-user. Any carelessness during the various stages in the supply chain can cause it to halt (Joshi 2018). AR has hence become a viable option to help optimize the supply chain by automating it. In the last years, augmented reality technologies have flourished in manufacturing and supply chain research to provide solutions that can support human operations in assembly tasks. AR assembly research currently refers to three main topics: AR assembly guidance, AR assembly training, and AR assembly design simulation. There is a potential opportunity for AR to be effective in multiple facets of the operation, from warehouse operations, inventory management, assembly/repair, and even customer service (Joshi 2018).

AR would have the potential of lowering time, handling and picking costs by digitizing these processes. By equipping workers with handheld AR devices or smart glasses, they can carry out operations with the guidance of real-time digital information and therefore significantly lowering the risk of an error occurring within the factory (Joshi 2018). On the other hand, in the UK, the National Health Service (NHS) has found that using augmented reality for inventory management saves time and improves accuracy. After running a pilot plan in 2018, the NHS has implemented an AR solution across several hospitals to track both inventories and patient data. The result was a 95% improvement in both cost and time efficiency (Edwards 2019). This is more than encouraging to any industry with inventory that needs to be effectively managed.

There is so much potential in AR within the manufacturing industry and within the supply chain, as it is still in relatively early stages- the possible future applications are endless. Figure 1, below, from Statista shows a heavy upward trend in the number of supply chain leaders who invested in AR/VR technology over the past few years (Mazareanu 2020). This goes to show that there is an interest and needs for this technology to be implemented in industry.

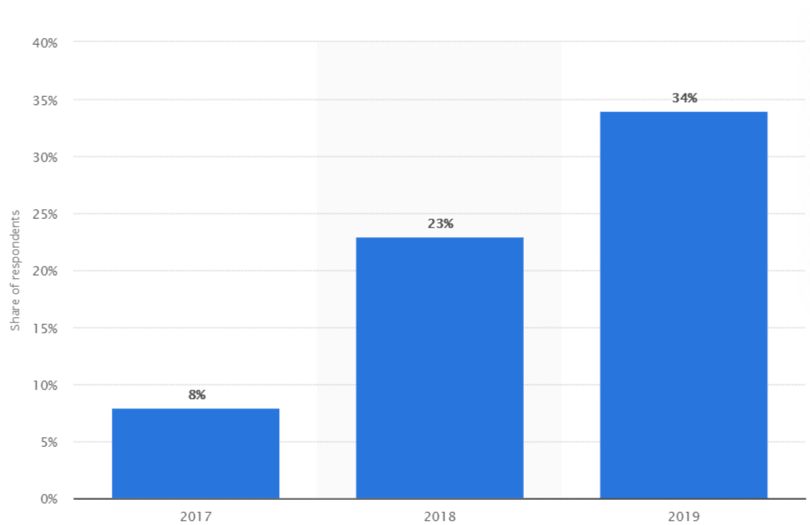

Figure 1: Interest in AR within supply chain leadership world-wide

3. Case Studies

3.1 Case Study 1: Augmented Reality in Warehouse Operations: Opportunities and Barriers

This case study's primary use is to explore different elements within warehouse operations and how augmented reality or AR can be extremely helpful.

The case study then goes into 4 main areas of warehouse operations where AR can be potentially used.

- Receiving: In receiving, there are three potential uses given that AR can improve. Indicate the unloading dock to the incoming truck driver. Check received goods against the delivery note. Show where to put the items/how to arrange them in the waiting zone.
- Storing: In storing, there are six given uses that AR can enhance. Inform an operator about a new allocated task. Display the storage location of incoming items. Display pictures and details of the item to be stored. Indicate route to the storage location. Indicate picker's status as well as the next step of the process. Check locations requiring replenishment while storing.
- Picking: Picking has ten uses for AR. Inform an operator about a new task allocated to them. Display pictures and details of the item to be picked. Display the storage location of the item to be picked. Display picking route. Highlight the physical location with the item required. Inform about errors and disruptions. Scan the item's barcode to assign to the picking cart or to see more information. Highlight where to put each item on the picking cart for sorting while picking. Give information to prevent congestion in aisles. Monitor picker's condition and performance.
- Shipping: Shipping gives six uses for AR. Show what type of cardboard to use. Show the best way to place picked items in a package. Indicate the correct location/pallet for the shipment. Show where to place each order on a pallet/in a truck according to the type of orders, destination, fragility. Indicate appropriate loading area. Check/Count products/orders to be loaded on a truck.

3.1.1 The Experiment

Further, this case study sets out to design an experiment to test how effective AR can be when used in the warehouse picking and sorting jobs. Using the Google Glass technology, the operators were tested using two different AR apps to go along with the glasses.

In each set of experiments, each participant was required to sort ten packaged orders in three trials:

1. Using a scanning app on a smartphone that simulates the current technology. The scanner was assumed to be attached to a fixed computer.
2. Using the "Display App" on the Google Glass. This was designed so that the user can understand the benefits of the wearable technology itself without impact from the software.
3. Using the "Cube App" on the Google Glass to integrate an augmented reality element in the process by projecting a virtual cube.

Figure 2: Display App

Figure 2 shows the view of the operator in trial 2 when doing the task. This display provides the same information with existing applications that do not use augmented reality: it shows the reference of the sorting bin on a screen by displaying a small sentence and the number corresponding to the bin.

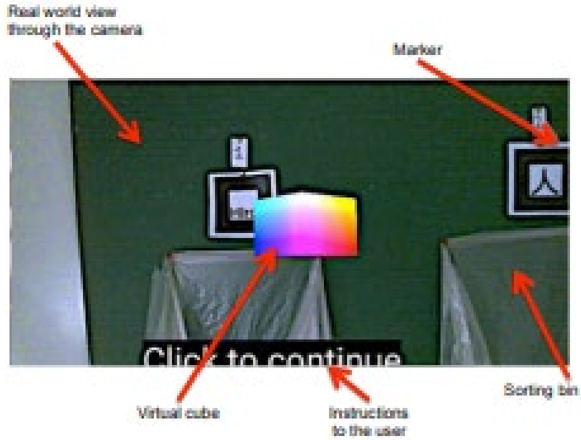

Figure 3: Cube App Display

Figure 3 shows what the person is viewing with the glasses on in trial 3. This display adds an augmented reality element; a virtual box appears on the marker linked to the bin while the user is looking at it.

From this experiment, results were analyzed in 4 categories: preference, ease of use, speed, and error rate.

Preference: The preference was first for the Cube App, then the Display App, and finally the scanner.
Ease of use: All operators ranked trial 3 with the cube App Display as the best ease of use technology.
Speed: The Google Glass apps (trail 3) had the fastest times, but trials 2 had very similar times on speed.
Error rate: Error rate using the Cube app Display (trial 3) had the least errors compared to trials 1 and 2.

Overall, the Case study concludes that using the AR technology with cube app (trial 3) was overall best in preference, ease of use, speed, and error rate.

3.2 Case Study 2: AR Implementations in Paper Making Factory

The following case study uses a paper-making facility to emphasize the use of simulations to create a proper warehouse design and the application of AR for order picking. The focus of this case study is to use warehouse simulation to test different warehouse designs based on a warehouse's demand and fixed order quantities. Further, there is an implementation of AR in order picking processes to help operators load products into storage areas, get real-time information about available stock, navigate operators to the position of requested stock and directly input when products are moved off the shelf (Dimitris 2019).

Warehouse simulation is important for the design of a warehouse because there are many factors that need to be considered before the construction of the warehouse. Forecasted demand would be determined based on the demand from the previous month. Next, the service level is calculated to determine how often products come in and out of the warehouse and at what frequency. Dimensions of the warehouse are recorded to determine the space available for products and optimize the space. Lastly, costs are calculated, and a linear program determines how to maximize the service level and minimize the inventory cost. The statistical analysis shows the capabilities of the warehouse to meet company goals.

Applying this methodology to the paper-making factory results in the data collected in Table 1. The final calculations for the paper-making factory were a 95% service level and 18% inventory costs. Now that the proper calculation was determined, simulations were created to establish the facility's adequate warehouse design.

Table 1: Proposed Solution to meet required Service Level.

Criterion	Unit	Proposed solution
Safety Inventory	Parcels	30185
Average Inventory	Parcels	55010
Inventory Cost	Euro/ Year	179449
Warehouse Size	M^2	1802
Production Quantity (per month)	Parcels	44983

The optimal warehouse design that was chosen can be seen in Figure 4. The final design was based on the warehouse's actual dimensions, and product placement was determined based on FIFO picking and integrating AR into the facility.

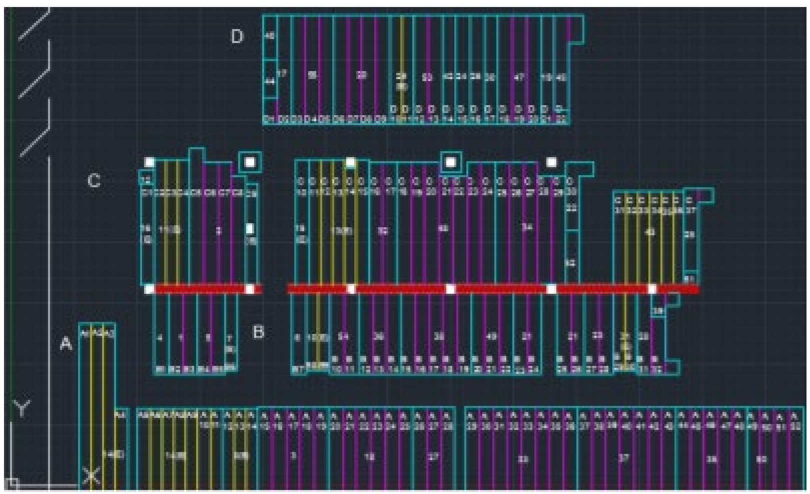

Figure 4: Selected Warehouse Design

AR for order picking was chosen to give operators direct access to the inventory database, the ability to easily upload where products were placed in the facility, and help navigate them through the facility to find their product. Each location and product within the warehouse had a QR code attached to properly identify where the objects were placed and what object was associated with that position. Operators would receive an order on this device and be told where it can be located in the warehouse. Each time an item was loaded or unloaded from the location two barcodes would be scanned to update the system in real-time: one barcode identifying the product and a second barcode identifying the position. This allowed for faster order picking and less time wasted inputting data into the system at a desktop.

3.3 Case Study 3: Cloud-Based Augmented Reality Remote Maintenance Through Shop-Floor Monitoring: A Product-Service System Approach

In this case study, researchers delve into the potential impact of using a cloud-based augmented reality platform called $CARM^2$-PSS to increase the reliability of the shop floor maintenance system and the return of investments (Mourtzis et al. 2017). Maintenance comprises 60-70% of total production costs, providing preventative, condition-based preventative, and corrective procedures that guarantee the product's quality. The platform $CARM^2$-PSS is developed in the cloud and is comprised of two primary services: a monitoring service and the AR remote maintenance service. $CARM^2$-PSS was created for "condition-based preventative maintenance procedures" using smart algorithms and augmented reality and smart algorithms. Besides, the proposed platform is designed to function as a product-oriented product-service system.

To demonstrate the qualities of the CARM^2-PSS, it was used in a real-life industrial problem where a production plant from the white-goods industry and involving an equipment manufacturer (which has a specific department offering maintenance service). The equipment manufacturer previously communicated with the production plant through phone calls or a text to inform then about performing a maintenance procedure, the maintenance department would then be informed on the maintenance issue and deploy an expert to go on site to diagnose the problem and physically fix it in the production plant. In order to reduce maintenance time, cost, and travel, the company decided to apply the CARM^2-PSS system to their plant. Once the shop floor monitoring system was installed, it continuously received data from the machine tools, analyzing them and calculating the status of each tool. The function and results of the implementation of the CARM^2-PSS System are seen in Figure 5.

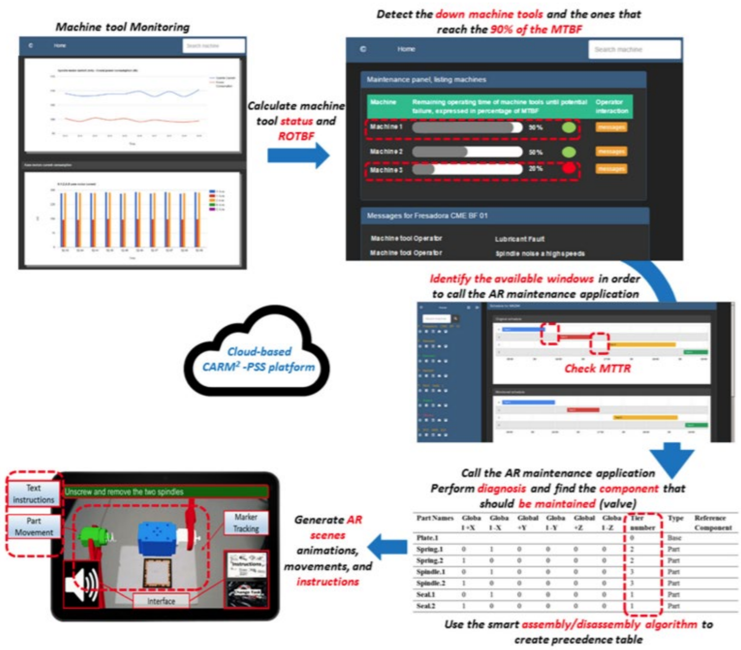

Fig. 7 Application of the CARM^2-PSS platform

Figure 5: End function/results of CARM^2-PSS system

Through the new CARM^2-PSS system, the end-user can oversee and manage the shop floor, performing both accurate and fast condition-based preventative maintenance using the AR remote maintenance service. This service can diagnose maintenance problems and create automated AR scenes using a "smart assembly/disassembly precedence algorithm" to produce an AR application that can be sent directly to the on-site machine operator or technician. Some of the main benefits of this approach are that the procedure for maintenance is remote, automated, and condition-based, which reduces the cost and time required in maintenance procedures. It can also increase the system's usability by allowing technicians to perform high-quality maintenance procedures easily and efficiently. This platform is easy to use and can be applied throughout the manufacturing industry in any area where a company wants to improve monitoring in quality testing. In short, this product can increase machine reliability, provide accurate remote maintenance, and increase the productivity of operations.

3.4 Case Study 4: Applications of Augmented Reality in Virtual Training

The following case study focuses on the application of augmented reality in virtual training (Hořejší 2015). Augmented reality originated to assist military pilots in navigating poor visibility and allowing soldiers to visualize tactical data. By providing a window of clarity in vague circumstances, augmented reality has proven to be an effective tool. Augmented reality is not only limited to military purposes as it has the potential to be applied to manufacturing environments. Logistics, layout planning and prototyping, and virtual or augmented training are examples of where augmented reality can be applied.

Augmented reality applies 2D instructions with a virtual 3D object via cheap "smart devices." Smart devices include ordinary tablets and smartphone devices. Thus, the implementation of augmented reality is inexpensive and easy. It is important to note, however, that specialized see-through glasses adds more costs. In 2014, the Pick-By-Vision solution was in its testing phase in SAP, Knapp, and Ubimax (Figure 6). The concept behind the solution was to reduce time in placing and delivering items to or from the warehouse. A stock keeper would wear specialized glasses displaying the assigned task and instructions. The stock keeper would follow the instructions based on proximity and utilization. When the stock keeper moves the item to the desired location, the item is scanned through a barcode, and the status of the item is changed in the company's ERP database.

Figure 6: Testing Phase of Pick-By-Vision

There are several cases that augmented reality can be applied to, including, but not limited to, capturing the scene, scene recognition, scene procession, and scene display. By capturing the scene, the user can see the surrounding environment in real-time or the time of a prior event. Scene recognition is configured using markers that highlight a scene's characteristic elements, which creates a 3D model. Scene recognition is complimented with scene procession, which transforms 3D videos, 2D pictures, and other media forms. Finally, the scene display shows the complete event on the smart device.

In this case study, 20 volunteer participants were asked to assemble a gully trap, as seen in Figure 7. On average, it took participants 5 to 7 minutes to learn how to assemble the gully trap and 12 attempts on average to assemble the gully trap without instructions. In the second phase of the experiment, 20 new volunteer participants assembled the gully trap with augmented reality using Unifeye Design, a software tool. On average, the participants were able to assemble the gully trap in 2 minutes 55 seconds after 10 attempts. The type of camera used in the experiment demonstrated that the marker used for scene recognition could easily be lost if the resolution is low. Additionally, if the camera is used for a long duration of time, the accuracy may decrease. To accommodate worker activity, it is recommended to use a camera with auto-focus. Another obstacle the designers faced in the experiment is the limited capacity of the Unified Design. Further studies should base their designs with these obstacles in mind and the goal of developing a user-friendly interface that can easily create a database with text instructions.

Figure 7: Gully Trap Design

4. Results and Discussion

AR is adaptable. It can be applied to various needs within a company. By using AR technology to their advantage, companies can become more efficient and competitive. The long-term effects AR can bring into the workplace will benefit the company by increasing work productivity, reducing the error rate, and saving time. The four case studies explored in this paper demonstrate that augmented reality can be applied to several functions. Case 1 explored AR's application in the four main areas of warehouse operations: receiving, storing, picking, and shipping. By simplifying the user experience, workers can work faster with lower error rates. Case 2 describes how operators can navigate AR devices' assistance, which will present real-time data from the company's inventory database. This can result in a decrease of order picking time and time wasted inputting data into the system at a desktop. Case 3 discusses how the CARM^2-PSS system can improve operations by reducing maintenance costs and time. The CARM^2-PSS system is simple to use and applicable in various fields in the manufacturing industry aimed to monitor quality testing. Finally, Case 4 introduces how AR can be used for virtual training, which can reduce the time it takes to train workers and develop new instructional procedures.

In addition to adaptability, AR can be inexpensive. Additional costs are dependent on the type of display used. As previously stated, displays are sorted into three categories: head-mounted displays (HMD), handheld displays, and spatial displays. Ordinary tablets and smartphones are categorized as handheld displays, have the capability to use AR software, and are least costly compared to specialized AR equipment.

4.1 Future Steps

Three future steps are identified in this paper: data visualization implementation for supply chain decisions, inventory management, and virtual training. First, Cloud-based AR systems for manufacturing sites could be used to automate and help provide logistical support regarding inventory movement and maintenance. Second, AR devices could assist in inventory management by instructing facility operators to use an HMD along with AR technology to improve the overall error rate that pickers made and time spent during the picking operation. Third, AR could be utilized in training employees with new equipment. By further integrating the software with a mobile application it can help streamline the training process and provide employee progress to management.

5. Conclusion

Augmented reality can be used in supply chain management to improve warehouse and manufacturing operations in various ways, as seen through the results of the case studies and in prior research. As seen through the case studies, AR technology is quite versatile and can increase productivity throughout supply chains. More specifically, AR technology has been used in the past to increase efficiency in receiving, storing, picking, and shipping processes. AR is also used to forecast demand accurately, designate warehouse layouts and order-picking processes, to diagnose maintenance problems in manufacturing equipment. And lastly, to increase the effectiveness of training employees. Through the case studies and literature review, it is apparent that the applications of augmented reality throughout supply chains have a big potential to change the way they are operated. These improvements can save companies time, reduce costs, reduce error rates, and promote a highly efficient production environment.

References

Bagassi, Sara, Francesca De Crescenzio, and Sergio Piastra. "Augmented reality technology selection based on integrated QFD-AHP model." International Journal on Interactive Design and Manufacturing (IJIDeM) 14.1 (2020): 285-294.

Carmigniani, J., Furht, B., Anisetti, M. *et al.* Augmented reality technologies, systems and applications. *Multimed Tools Appl* **51,** 341–377 (2011). https://doi-org.ezproxy.lib.calpoly.edu/10.1007/s11042-010-0660-6

Dimitris , Mourtzis, et al., *Warehouse Design and Operation using Augmented Reality technology: A Papermaking Industry Case Study, Procedia CIRP*, vol. 79, ISSN 2212-8271, 2019.

Hořejší, Petr. "Augmented reality system for virtual training of parts assembly." *Procedia Engineering* 100 (2015): 699-706.

Edwards, Roy. "NHS Pilots Augmented Reality (AR) for Inventory Management ." *Enterprise Times*, 12 Sept. 2019, www.enterprisetimes.co.uk/2019/09/13/nhs-pilots-augmented-reality-ar-for-inventory-management/.

Joshi, Naveen. "4 Ways the Supply Chain Industry Will Use Augmented Reality." *Application Development*, 3 July 2018, www.allerin.com/blog/4-ways-the-supply-chain-industry-will-use-augmented-reality.

Mazareanu, E. "Supply Chain: Investments in AR/VR 2019." *Statista*, 21 Jan. 2020, www.statista.com/statistics/953201/global-supply-chain-ar-vr-investment/.

Mealy, Paul. "The History of Virtual and Augmented Reality." *Dummies*, Wiley Brand, 2020, www.dummies.com/software/the-history-of-virtual-and-augmented-reality/.

Mengoli, Maura, et al. "Spatial Augmented Reality: an Application for Human Work in Smart Manufacturing Environment." Department of Industrial Engineering and Mathematical Science, Polytechnic University of Marche, 15 Nov. 2018.

Mourtzis, Dimitris, et al. "Cloud-Based Augmented Reality Remote Maintenance Through Shop-Floor Monitoring: A Product-Service System Approach." *Journal of Manufacturing Science and Engineering*, vol. 139, no. 6, 2017, doi:10.1115/1.4035721.

Romaine, Ed. "15 Statistics That Show the Importance of Same-Day Delivery." *Conveyco*, Conveyco, 17 Nov. 2020, www.conveyco.com/delivery-statistics/.

Stoltz, Marie-Hélène, et al. Augmented Reality in Warehouse Operations: Opportunities and Barriers. 18 Oct. 2017, www.sciencedirect.com/science/article/pii/S2405896317324291.

"US20130044042A1 - Wearable Device with Input and Output Structures." Google Patents, Google, patents.google.com/patent/US20130044042A1/en.

"Warehouse Management, Supply Chain 24/7." *Companies: Warehouse Management*, Supply Chain 24/7, 2020, www.supplychain247.com/companies/category/wms.

Yadav, Niteesh. "Understanding Display Techniques in Augmented Reality." *Medium*, Prototypr, 6 Jan. 2019, blog.prototypr.io/understanding-display-techniques-in-augmented-reality-c258b911b5c9.

Biographies

Angela Colabella is a senior at California Polytechnic State University, San Luis Obispo. In June 2021, she will be graduating with a BS in Industrial Engineering with a minor in Italian Studies. She will continue her education next year at University of California, Berkeley, pursuing a Master's degree in Industrial Engineering & Operations Research. She previously has worked as a software applications tester for Boeing in their Global Services department. After graduation, she hopes to pursue a career working in supply chain management.

Collette Lee is currently a senior at California Polytechnic State University, San Luis Obispo, majoring in Industrial Engineering and minoring in statistics with a passion for lean manufacturing, process improvement, problem solving, and data storytelling. She will be graduating in June 2021 and has prior experience working in the sheet metal industry as a technician assistant and security consulting as a data entry specialist. Post-graduation, she hopes to work on continuous improvement.

Lane Pledger is a fourth-year Industrial Engineering student at Cal Poly San Luis Obispo. He will be graduating in the spring of 2021. Lane is currently applying for master's programs in Industrial Engineering. He has internship experience at Greenlee and Tempo Communications for two summers. After graduation, he hopes to pursue a career in manufacturing in either the aerospace or automotive industries.

Monique Cendejas is a fourth-year Industrial Engineering student at Cal Poly San Luis Obispo who will be graduating in March 2021 and is currently searching for a position after graduation. She has experience in Supply Chain through her internship with Moog Inc in Torrance, California. She hopes to continue working in the Supply Chain post-graduation.

Vikrant Mannemela is currently a fourth-year Industrial Engineering student at California Polytechnic State University, San Luis Obispo. He will be graduating in June 2021 and is expected to start a Master's in Engineering Management program in September 2021. Vikrant has interests in data analytics and process improvement and plans to further work in those fields post-graduation.

Mohamed Awwad is an Assistant Professor in the Department of Industrial and Manufacturing Engineering at California Polytechnic State University (Cal Poly), San Luis Obispo, CA. He received his Ph.D. and MS degrees in Industrial Engineering from the University of Central Florida, Orlando, FL, USA. Additionally, he holds MS and B.S. degrees in Mechanical Engineering from Cairo University, Egypt. Before joining Cal Poly, San Luis Obispo, Dr. Awwad held several teaching and research positions at the State University of New York at Buffalo (SUNY Buffalo), the University of Missouri, Florida Polytechnic University, and the University of Central Florida. His research and teaching interests include applied operations research, logistics & supply chain, blockchain technology, distribution center design, unconventional logistics systems design, and OR applications in healthcare and the military.