How Industrial Internet of Things Enables Engineers to Work Remotely

Christopher Striff, John Takiff, Brandon Drury, Jimmy Algeo, Moummar Nawafleh and Mohamed Awwad
Department of Industrial and Manufacturing Engineering
California Polytechnic State University
San Luis Obispo, CA 93407, USA
cstriff@calpoly.edu, jtakiff@calpoly.edu, bcdrury@calpoly.edu, jmalgeo@calpoly.edu, mnawafle@calpoly.edu, mawwad@calpoly.edu

Abstract

Industrial Internet of Things (IIoT) has enabled many new avenues for industrial engineers to perform their jobs. There used to be a need for an engineer to monitor, analyze, and improve a process manually. The inherent benefit of IIoT applications in industrial settings no longer requires in-person contact. Through the use of sensors, actuators, and data communication networks, businesses can now automate the data collection process to achieve KPIs. With this digital revolution comes the ability to access the data and improve the process from anywhere in the world. While IIoT brings many advantages that may improve a process improvement team's efficiency, it is not without some drawbacks such as security and cost. This paper will explore how IIoT enables remote improvements and how the COVID-19 pandemic has made remote work a fiscal possibility for many businesses.

Keywords
IIoT, Process Improvement, Remote Work, COVID-19

1. Introduction

IIoT systems are sensors, actuators, and data communication software integrated into a singular system. Under the umbrella of data visualization, engineers can completely monitor equipment from a single computer in real-time. In the adolescent stages of the industrial revolution, manufacturing facilities would run machines until a critical failure stopped production. Mechanics would then diagnose the failure and replace the motor, spindle, PLC, etc., to continue production. Current best practices now differ from traditional production as the cost of stopping the manufacturing process from rectifying poor asset management outweighs the financial upkeep IIoT demands. While the upfront costs of Industry 4.0 (mentioned later in the report) deter business leaders from funding next-generation facilities, IoT benefits not only apply to the bottom dollar of the business over time but allow engineers to work from all parts of the globe in national pandemic scenarios.

1.1 Objectives

The objectives of the paper are as follows:

1. Create a hypothetical scenario in which a business could apply IoT to a pre-existing facility
2. Analyze potential technologies within IoT to said business
3. Create a cost-benefit analysis with ROI projection to validate the implementation

2. Literature Review

2.1 RTLS

Real-Time Location Systems (RTLS) use a variety of techniques to track the location of an object. Generally, an RTLS system works by having a locator attached to the object and a series of static trackers or readers that measure the position of the locator. Though there are many types of RTLS, they all aim to improve inventory and asset tracking. Without using an RTLS system, companies are forced to track asset movements and locations manually. This process is prone to errors and is incredibly tedious.

So, what are some of the ways a company can implement RTLS technology into its operation? For small, non-critical items, the best system might be barcodes. Developed in the 1960s, barcode technology is a simple and cheap way of tracking asset locations. If properly configured, barcode scanning machines can automatically scan barcodes alerting other systems of the object's locations. And even without complex automation, barcodes are an easy way to improve manual inventory accuracy and asset tracking as it reduces the likelihood of operator error.

Getting more complex, Radio Frequency Identification (RFID) technology works by locators either actively or passively responding to RF signals received from an RFID reader. Active RFID can read tags at distances over 100m, while passive RFID can read tags at distances up to around 10m (IMPINJ, 2020). The reader can determine which RFID codes are present at a location. A summary of the characteristics of different types of RFID is shown in Figure 1. One key advantage RFID systems bring over barcodes is greater accuracy. While barcodes do require line of sight access to the tag, RFID does not. This means more tags can be read at a much faster pace, and objects can be packed more tightly together while still being accurately tracked (Advantages of RFID vs. Barcodes, 2020).

The downside is that RFID is more expensive than barcodes. While barcodes cost only a few cents to print, a single RFID tag costs at least one dollar and can go as high as 30 (Peak-Ryzex, 2020). A study found that RFID is a cost-effective solution for large suppliers, but for small and medium suppliers, RFID may be cost-ineffective due to upfront costs (Lee & Lee, 2010). This can partially be offset if the companies work with the larger suppliers by having the larger companies subsidize the costs to better integrate with the large companies' distribution system. However, as the technology grows, the costs will decrease, enabling more businesses to benefit from RFID tracking.

If companies want even greater tracking accuracy, they could look towards Bluetooth Low Energy (BLE) and Wi-Fi-based tracking systems. Bluetooth and Wi-Fi tracking systems use the Received Signal Strength Indicator (RSSI) method for finding locations. RSSI works by measuring the received signal strength at multiple reader locations to triangulate the locator's position (Vaupel et al., 2010).

Bluetooth and Wi-Fi tracking enables much more precise locating than RFID or barcode. While most RFID and barcode readers are at a static location and can tell if products are present or not, Bluetooth and Wi-Fi tracking regularly report locations that can be combined to show product paths and time spent at different locations.
The accuracy of these systems ranges from 1-15m but is often precise enough to get an accurate picture of a product's path through a facility. Because of the range of technologies and capabilities, the pricing for Bluetooth and Wi-Fi tracking technology varies greatly. A comparison of various types of asset tracking technologies is shown in Figure 2.

	Active RFID	Passive RFID	Battery Assisted Passive (BAP)
Tag Power Source	Internal to tag	Energy transfer from the reader via RF	Tag uses internal power source to power on, and energy transferred from the reader via RF to backscatter
Tag Battery	Yes	No	Yes
Availability of Tag Power	Continuous	Only within the field reader	Only within field of reader
Required Signal Strength from Reader to Tag	Very Low	Very high (must power the tag)	Moderate (does not need to power tag, but must power backscatter)
Available Signal Strength from Tag to Reader	High	Very Low	Moderate
Communication Range	Long Range (100m or more)	Short range (up to 10m)	Moderate Range (upto 100m)
Sensor Capability	Availability continuously monitor and record sensor input	Ability to read and transfer sensor values only when tag is powered by reader	Ability to read and transfer sensor values only when tag receives RF signal from reader

	Asset Tracking Technology	Working Principle	Range	Accuracy	Pros	Cons
Short range asset tracking	**Passive RFID**	Calculates proximity to network of RFID antennas and triangulation of input signals	200 m	NA	▪ Many tag types ▪ No battery ▪ Low cost tags	▪ Higher reader costs ▪ High metal and liquid interference
	Bluetooth Low Energy (BLE)	Calculates proximity to network of Wi-Fi access points and triangulation of input signals	100m	1- 2 m	▪ Low power consumption ▪ Easy to deploy	▪ Battery operated tags ▪ High cost per sq. m (tag, reader)
	Wi-Fi	Calculates proximity to network of Wi-Fi access points and triangulation of input signals	200m	15 m	▪ High data throughput ▪ Fairly large range and accessibility	▪ (In)accuracy battery operated tags ▪ High cost per sq. m (tag, access point)
	Ultra-wide band (UWB)	Measures multiple paths – signal time to receiver and angle of arrival to measure bearing	10-20m	Few cm - 3 dm	▪ Resilient to interference ▪ High accuracy	▪ Shorter range ▪ High cost per sq. m (tag, reader)
Long / Wide range asset tracking	**LPWAN (LoRa, LTE-M, NB-IoT)**	Tracks using GPS and transmitted to LoRA gateway, transmitted to back-end using Wi-Fi / cellular	15000m	Few meters	▪ Zero transmission cost ▪ 10 -15 km range with single gateway	▪ Expensive tags ▪ High battery usage
	Cellular: GSM, LTE, 5G	Tracks using GPS and transmitted to back-end using cellular	Limited by coverage	Few meters	▪ Unlimited range ▪ No gateways required	▪ Expensive tags ▪ High battery usage ▪ High transmission cost
	GPS	Tracks using GPS and transmitted to back-end using Wi-Fi	Limited by coverage	Few meters	▪ Zero transmission cost ▪ Low-battery usage	• No off-the-shelf system available
	Satellite (LPGAN, etc.)	Tracks using GPS and transmitted direct or via gateway to back-end using satellite	+ / - 10000m gateway range	Few meters	• One frequency, modem • Low-battery usage and cost	• Requires line of sight to item begin tracked • Small quota of messages / day

Figure 2: Asset Tracking Technology Short/Long Comparison (Deloitte, 2021)

There are other RTLS technologies available depending on the needs of the situation. While most of the technologies discussed to this point are best used in indoor applications such as a manufacturing environment, others such as GPS and Satellite work better for long-range and outdoor applications. These technologies can be seen in the table below. These technologies' costs vary as some can be affordably found in everyday electronics such as cellphones that have GPS; others might require expensive electronics and integration tools.

Regardless of the RTLS technology selected, they all feed their data to a server of some kind. Some RTLS systems provide software to interface with the server and display the data collected, while others might need a custom solution. Once the data is on the server, though, integration with existing systems such as MRP databases or other enterprise applications is straightforward. And, given the data is on a server, accessing it remotely is simple and can simply slot into a company's existing IT infrastructure for remote work. Using a VPN, any employee can easily and securely access RTLS data from any location with an internet connection.

2.2 Vibration Sensors

Vibrations are a byproduct of many engineering processes found in factories and companies. Measuring vibrations of certain processes and machines have commonly been done manually by an engineer or a manager. However, traditional vibration monitoring systems are associated with limitations such as expensive devices, difficult installation, complex operations, etc. Few of these traditional data tracking devices have built-in remote data transmission and access. An IIoT sensing system can offer the opportunity to change how data is collected. IIoT allows the opportunity to conduct these same measurements remotely by using wireless devices incorporated into the systems themselves. Accelerometers are a great example of the power IIoT has in a real-world example. Accelerometers are commonly used to track condition measuring, motion tracking, and vehicle monitoring (Koene, Viitala & Klar, 2020).

In addition, most handheld smart devices such as smartphones or portable tablets have accelerometers incorporated into their functions. Microelectromechanical systems (MEMS) accelerometers provide precise data tracking with a relatively affordable cost (Koene, Viitala & Klar 2020). A microcomputer combined with a MEMS accelerometer provides the perfect combination to allow engineers to collect data remotely. This combination allows for the system to minimize cost, size, and traffic to the system itself (Meng, Khu, 2020).

Diving into the construction, a USB internet dongle is connected to the MEMS accelerometer to provide 4G communication that can be transmitted via a cloud. A web browser is then created with various alarm functions and a MySQL database to store the cloud data's measurement data. The whole system is powered by a rechargeable solar battery, which avoids cabling work on the systems for installation (Meng, Khu, 2020). . This renders the IIoT vibration device completely portable and remote. A clear visual of how MEMS accelerometers function can be found in Figure 3. This use and construction of MEMS accelerometers yield a cost-effective IIoT measurement system that allows the manager or company to save time and cost associated with manual tracking and installation costs associated with complex wiring and installation.

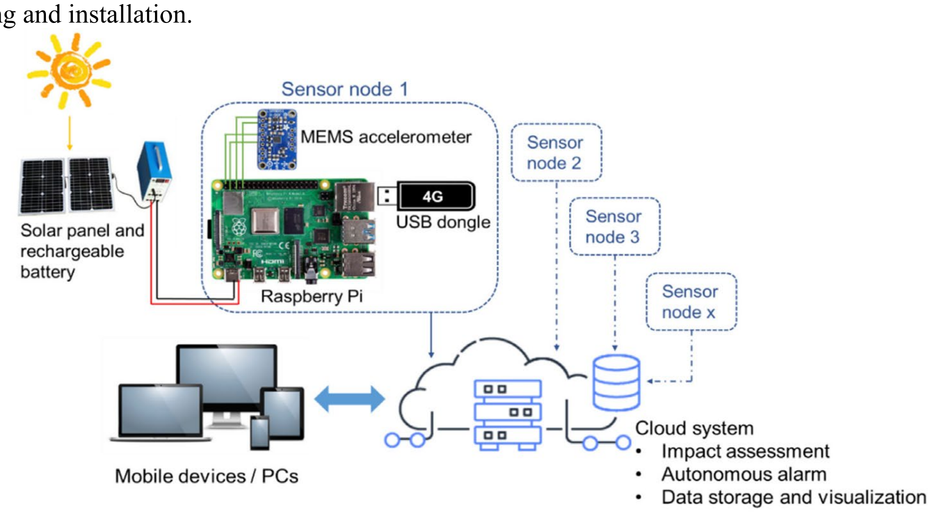


Figure 3: Raspberry Pi use in IOT devices to link sensors and mobile devices

The use of MEMS accelerometers and similar devices poses the question of how these devices can be useful for remote working engineers. With the sudden pandemic affecting many companies and how jobs can be done remotely, MEMS has already seen an impact. These devices are being capitalized on due to their wireless compatibility and their accuracy of two types of measurements: lateral movement and vibration (Koene, Viitala & Klar, 2020). Quality engineers have seen the potential these MEMS accelerometers have in the industry as they have been able to conduct their tasks in the same manner, if not more efficiently, due to the data tracking software on their handheld devices. MEMS accelerometers have the ability to track data consistently throughout the working day, as well as a large, embedded memory in which data is stored during these measurements (Meng, Khu, 2020). With the connection to a web browser, data collected from a working day is stored in this browser for later reference. In the past year, prior to Covid-19, engineers and managers have had the opportunity to experiment with these IIoT devices and have found the benefits of using them for a remote setting. What has been concluded is that the implementation of IIoT, MEMS accelerometers, for example, offers the opportunity for quality engineers to work fully from home (Meng & Khu, 2020).

The engineers are given access to the specific accelerometer, and they can diagnose an issue and evaluate the system remotely throughout the day. IIoT, focusing on the measurement of vibrations, can be conducted remotely in the same level of detail as compared to an engineer gathering data manually, in-person (Meng, Khu, 2020). Although this experiment was concluded prior to Covid-19, the principles are still applicable, and the opportunity to capitalize on IIoT is now.

2.3 COVID-19 and Remote Work

When the COVID-19 shutdowns hit in March 2020, companies had to scramble to ensure that operations could continue while the employees worked remotely (Chitgari et al., 2020). Luckily for companies that were already at I3.0/I4.0 standards, the existing technology made it easy for workers to share documents, data, and ideas. A study from the National Bureau of Economic Research found that about half of all workers were working remotely. This study was conducted in April and May, so the numbers could have increased as we saw spikes in cases. Of the study participants, around 35% of them had recently switched to remote work, while 37% still commuted to their workplaces. Some companies needed on-site activity to operate, so that 37% probably accounts for these types of workers. In-person employees' necessity could stem from the labor needed in the production process, the lack of technology needed to conduct remote work, or a combination of factors.

Although the pandemic brought a lot of challenges to companies needing to adapt, it also ushered in a technological evolution out of necessity. Automation is one such example of forced development pursued by companies that need to keep up with or recover from the pandemic. Other affected areas include increased flexibility in supply chains, decreased interest in consumer IIoT devices, the increased importance of remote asset access, and increased utilization of track and trace solutions. Remote asset access is crucial progress towards IIoT that companies need to follow because of COVID. Even without remote work, being able to see what is happening on the production floor from their office is a step closer to I4.0.

Unfortunately, the pandemic's negative impacts have limited company resources and counteracted the implementation of IIoT and pandemic necessary technology, especially in smaller companies. The largest factor that companies need to decrease is their costs. Furthermore, implementation of IIoT technology is a big company decision that is also usually expensive. Therefore, some companies are approaching the pandemic with retrofit solutions. These system adaptations do not provide as many benefits, but they are easily installed without removing the legacy systems.

Overall, COVID has adversely affected all companies and forced them to inherit a system that enables normal company operations while adhering to the safety and remote work guidelines. However, this forced progression coincides with IIoT goals that companies were already pursuing. An interconnected technology that provides quality assurance and detailed daily operations without requiring a visit to the factory floor is a necessity for the pandemic and I4.0.

3. Methods

3.1 SLO Aerospace

Cal Poly's motto is Learn By Doing. While COVID has placed restrictions on our ability to work together in person, we decided to create a hypothetical scenario to demonstrate the benefits of the various technologies covered. Our hypothetical company is called SLO Aerospace. It is a company of around 300 employees with one large facility located in San Luis Obispo. They manufacture aircraft parts with specific performance requirements. They have a few assembly lines scattered throughout the facilities, and some conveyors connect different areas. They are looking to embrace new IIOT technologies to improve their operations and the quality of their products.

3.2 RTLS

For a company of this size, let's say they introduce an active inventory tracking system. The system will probably cost them between $10-100k. This includes trackers installed in the ceiling, a number of tags to attach to products, and the backend server to process and store the data. Let's also assume the system chooses to go with all the software for the company's needs, and they don't need to develop any proprietary software.

One of the immediate benefits the company would see is an accurate picture of how their parts are flowing through the factor. And it would be a literal picture. RTLS systems can create heatmaps where products spend most of their time identifying chokepoints in operation very simply. This gives the continuous improvement team a clear target for their efforts to gain the maximum benefit.

There are other areas that the RTLS system could be integrated. Perhaps, the company wants to see how the materials are being routed through the facility. The tags could be attached to materials when they are received and tracked all the way to when they are installed in the product. Taking data like this could identify materials that spend longer on shelves versus materials that go straight to the assembly line. This could heavily improve material storage and retrieval operations if the plant was to rearrange its storage locations if, for example, commonly used parts needed to be constantly moved from one end of the factory to the other while less used materials are unnecessarily taking up shelf space near where they are needed. RTLS also enables teams further down the line to see when their upstream parts should arrive. For example, suppose the wing team at SLO Aerospace knows the aileron team is experiencing delays. In that case, they could 5S their workspace or assign workers to help other areas of the manufacturing environment while receiving updates about the delayed upstream product.

Lastly, the company can track whatever assets it wants. If it has vehicles, an RTLS system can show the paths they take and where they are parked. This could help the company improve its routing algorithm or place supplies for the vehicles' operators, so they spend less time searching for tools. RTLS also helps with loss prevention. If the company has limited high-cost tools that move frequently, they could track the tools and know if they were improperly removed from their designated location or facility. Large asset loss can significantly decrease with an RTLS system.

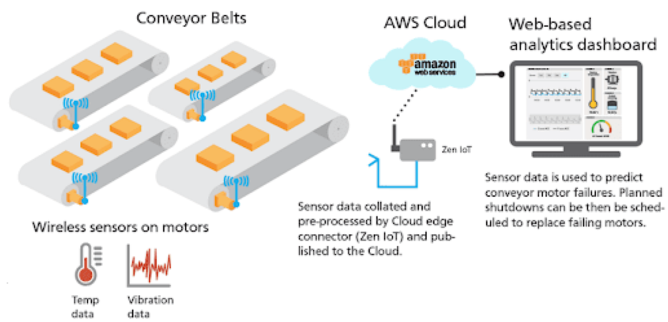
One of the great benefits is that this technology can be operated remotely. Managers are no longer required to personally inspect and report production rates. They are also no longer responsible for monitoring one specific facility as RTLS can be operated remotely, enabling teams to be physically separated but still working together.
Remote process improvement is also possible with RTLS. Historically, most process improvement or process monitoring required being present to time workers and monitoring the process. With RTLS, the process can operate independently while data is being collected. Then, it can be analyzed anywhere, and areas for improvement can be identified. Teams of continuous improvement engineers can work remotely to design solutions to the identified problems and then monitor the improvements after the improvement has been deployed.

RTLS at a company like our hypothetical SLO Aerospace will not alone lead to a direct improvement. Rather RTLS needs to be seen as an available tool for multiple people to benefit from. It can help the materials teams efficiently move raw materials. It can help employees working on the product by alerting them of delays. It can help a company track its most valuable material assets. And most importantly, in the context of this paper, it enables work to be conducted remotely. Teams of improvement engineers and managers alike can continue their work but from the safety of another location.

3.3 Preventative Maintenance

SLO Aerospace conveyors and assembly lines are partially autonomous with human interaction for QA testing purposes. The conveyors run on servo motors that operate around 40% speed throughout the workday. Servo motors are notorious for failing due to shorts that draw too much power from the electrical grid. As a result of an unforeseen failure, the production is bottlenecked, and maintenance staff is called in to fix the problem.

By installing current, temperature, and tachometer sensors within the conveyor system, engineers can monitor the



motors from anywhere in the world to schedule preventive maintenance during non-production hours.

Figure 4: Integrating sensors into conveyor belts

Figure 4 shows an industry use case where temperature and vibration data is streamed to the cloud using Amazon's AWS platform. In SLO Aerospace's example, a popular provider like Amazon Web Services or Microsoft Azure would be purchased to decrease the initial investment compared to other companies like Splunk, as pre-built dashboards and user-friendly interfaces assist engineers with overall setup time.

Ideally, an engineer would log into a secure network of sensors placed on various servos within the facility to monitor power draw, shaft RPM, and temperature from the internal bearing. When a component operates outside of the threshold, engineers would then place a maintenance request to replace or fix the motor before critical failure. To automate the process further, SLO Aerospace programs the data communication network to send automated emails daily with the following parameters:

Conveyor 1 - Servo #:

{ Bearing Temp High/ Low : Yesterday's High/Low/Average : Within Tolerance Yes/No }

{ Shaft RPM High/Low : Within Tolerance Yes/No }

{ Power Draw High/Low/Average : Amperage High : Within Tolerance Yes/No }

The above email format is common in the industry to quickly diagnose capital assets' health at a glance and are used to send repair requests when equipment is not within tolerances. By investing in the large upfront cost of installing sensors, transmitting them to a data communication network, and analyzing them via the cloud or edge computing, engineers can capitalize on lowering overhead costs by working remotely.

While the aforementioned example of placing sensors on conveyor systems works within data communication spaces - other modern machines that collect data also have built-in sensors that are IoT compatible—choosing between older machines and placing sensors from third parties to send data to could have marginal benefits to purchasing new equipment that has sensors within the machine itself. The cost of a new machine versus an older one and setting it up to extract useful information is relatively even, so companies should look to other methods of analysis when choosing between pre-owned or new equipment.

4. Data Collection

Due to the nature of the example, a hypothetical scenario was difficult to collect meaningful data. To remedy this, SLO Aerospace projected the Maintenance and Quality Assurance departmental costs for the next five years.

Table 1 shows the breakdown of anticipated costs in two scenarios: one with and without IoT implementation for RTLS and Preventative Maintenance applications. From there, the engineers were able to calculate the potential savings and ROI in both instances.

Projected Year	Maintenance Cost (non-IOT)	Maintenance Cost (IOT)	Quality Assurance (non-IOT)	Quality Asssurance (with IOT)	Potential Savings	ROI
Year 0	$ -	$ 60,000.00	$ -	$ 70,000.00	$ (130,000.00)	$ -
Year 1	$ 82,000.00	$ 129,340.00	$ 94,091.00	$ 140,590.00	$ (93,839.00)	$ (223,839.00)
Year 2	$ 92,072.00	$ 70,640.00	$ 148,220.00	$ 75,032.00	$ 94,620.00	$ (129,219.00)
Year 3	$ 81,455.00	$ 58,200.00	$ 188,000.00	$ 100,327.00	$ 110,928.00	$ (18,291.00)
Year 4	$ 88,035.00	$ 72,340.00	$ 198,206.00	$ 122,340.00	$ 91,561.00	$ 73,270.00
Year 5	$ 109,450.00	$ 69,840.00	$ 142,989.00	$ 82,560.00	$ 100,039.00	**$ 173,309.00**
Totals:	$ 453,012.00	$ 460,360.00	$ 771,506.00	$ 590,849.00	**$ 180,657.00**	

Table 1: SLO Aerospace Departmental Costs by Year

After crunching the numbers, the engineers were quickly able to determine that the IoT implementation within the facility was a net benefit to the company after 5 years, with a projected savings of $180,000. The engineers were quick to include that the data provided was still a projection, but the margin of error was small enough to present to executive leadership for approval of the project.

In the presentation, the engineers included Table 1, Figures 5, 6 and 7 as justification for the project. In the meeting, engineers noted that year 1's maintenance and QA costs were higher than non-IoT costs due to the training and learning curve that the employees would incur in the first year of use. They also included that because the IOT devices were able to be accessed remotely, maintenance and engineering staff alike could monitor the facility from home if need be.

5. Results and Discussion

SLO Aerospace's executive team realized that the engineering department had grown considerably over the past few years, and installing the IoT system would not only lower overall maintenance and QA department costs but allow some engineers to work remotely.

Given the current state of the COVID-19 pandemic and the uncertainty of when business operations would return to normal, the executive team funded the project to prevent production halts in the future. Leaders demanded, however, that the data communication network selected includes state-of-the-art user authentication software, and all affected departments be trained immediately to the new style of work.

5.1 Graphical Results

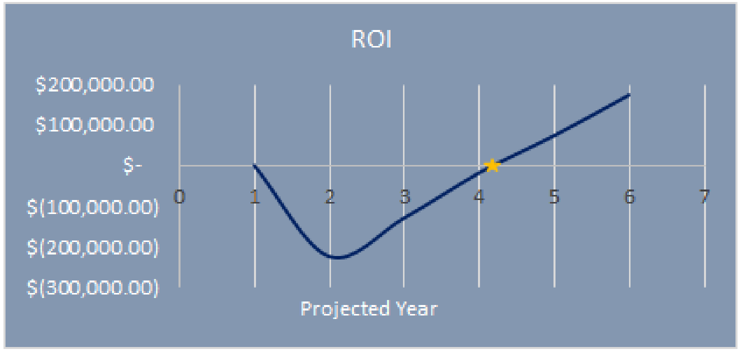


Figure 5: ROI for IoT Implementation

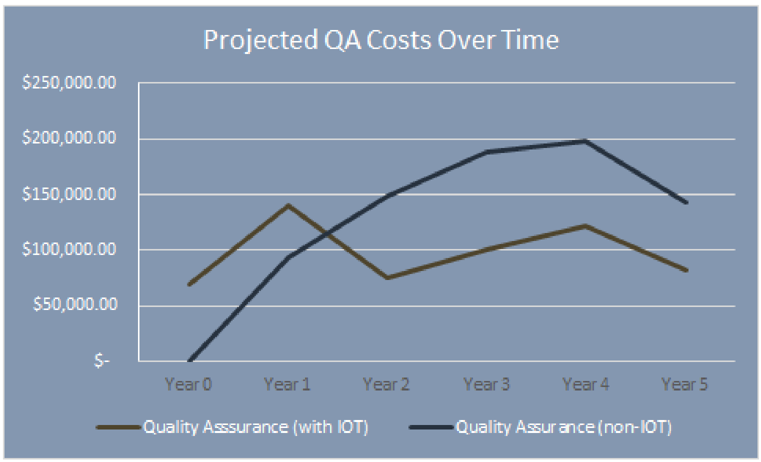


Figure 6: Projected Quality Assurance Department Costs with and without IoT Implementation

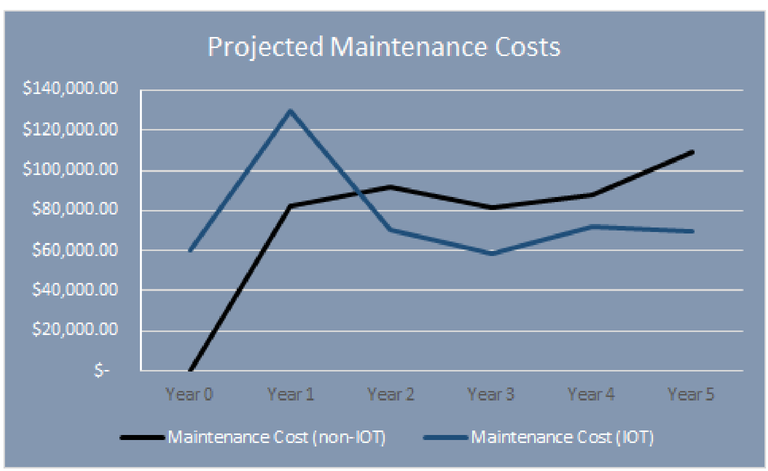


Figure 7: Projected Maintenance Department Costs with and without IoT Implementation

6. Conclusion

In conclusion, the COVID-19 pandemic has only accelerated the transition to an IIoT integrated work environment. Companies now have begun to realize the importance of incorporating IIoT in their business for the benefits they offer. With the push from COVID-19, industries inch closer towards "Industry 4.0", which relies heavily on IIoT, autonomous systems, and machine learning.

In the example of SLO Aerospace, the engineers were able to identify issues within the current facility and propose an effective solution to senior leadership. From there, the executives noticed that not only could the technology save the business's bottom line but prevent facility shutdown from global pandemics. Engineers can now securely log into the facility data communication network and make adjustments to critical assets from their home's comfort. While a mass-scale implementation plan like SLO Aerospace is not feasible for some production facilities, engineers should carefully examine IoT benefits and compare the potential outcomes to propose accurate savings models to the business.

References

Advantages of RFID vs Barcodes. 8 2 2020. Web Site. 2 2020. <https://www.abr.com/advantages-of-rfid-vs-barcodes/>.

Chitgari, H., Carroll, J., Derickson, G., McRory, S., Tremaine, K., & Awwad, M. (2020, January). A cross-industry study identifying enabling factors of supply chains that successfully responded to covid-19. *In Proceedings of the International Conference on Industrial Engineering and Operations Management.*

Deloitte. (2021). Types of asset tracking technologies. Retrieved from https://bit.ly/3nuScrB

Hadley, William B. "The Impact of Covid-19 on the Internet of Things – Now and beyond the Great Lockdown: Part 1." *IoT Analytics*, Available: iot-analytics.com/the-impact-of-covid-19-on-the-internet-of-things/., 16 Apr. 2020.

Koene, Ivar., Viitala, Raine., Klar, Ville., "IoT Connected Device for Vibration Analysis and Measurement." *Science Direct,* Available: https://www.sciencedirect.com/science/article/pii/S2468067220300171, Apr. 2020.

Rock, Daniel, Ozimek, Adam, Brynjolfsson, Erik, Horton, John J, TuYe, Hong-Yi, & Sharma, Garima. 2020, COVID-19 and Remote Work: An Early Look at US Data. https://doi.org/10.3386/w27344,

Buchanan, Nicholas D, Aslaner, David M, Adelstein, Jeremy, MacKenzie, Duncan M, Wold, Loren E, & Gorr, Matthew W. (2021). Remote Work During the COVID-19 Pandemic: Making the Best of It. Physiology (Bethesda, Md.), 36(1), 2–4. https://doi.org/10.1152/physiol.00035.2020

In Lee, Byoung-Chan Lee. "An investment evaluation of supply chain RFID technologies: A normative modeling approach." *International Journal of Production Economics* 125.2 (2010): 313-323. Web Page. 2 2020. <https://www.sciencedirect.com/science/article/pii/S0925527310000551>.

Jackson, Henry. "IoT News - IoT Market Growth Will Slow down Due to the COVID-19 Pandemic and the Limited Take-up of LPWA Solutions." *IoT Business News*, Available: iotbusinessnews.com/2021/02/25/20654-iot-market-growth-will-slow-down-due-to-the-covid-19-pandemic-and-the-limited-take-up-of-lpwa-solutions/., 25 Feb. 2021.

Meng, Quihan., Zhu, Songye., "Developing IoT Sensing System for Construction-Induced Vibration Monitoring and Impact Assessment." *MDPI,* Available: https://www.mdpi.com/1424-8220/20/21/6120/htm, October 2020.

Peak-Ryzex. *RFID vs Barced Comparison Advantages Disadvantages*. 21 11 2019. Blog. 2 2020. <https://www.peak-ryzex.com/blog/rfid-vs-barcode-comparison-advantages-disadvantages/#:~:text=Cost%20Comparison,more%20expensive%20than%20barcode%20scanners.>.

IMPINJ. *Types of RFID System*. n.d. Web Page. 2 2020. https://bit.ly/2PKzZbA

Vaupel, T., Seitz, J., Kiefer, F., Haimerl, S., & Thielecke, J. (2010). Wi-Fi positioning: System considerations and device calibration. *2010 International Conference on Indoor Positioning and Indoor Navigation*. doi:10.1109/IPIN.2010.5646207

Biographies

Christopher Striff is a fourth-year California Polytechnic State University student pursuing his bachelor's in industrial engineering. He will earn his degree in June of 2021 and continue his education in the workspace as a Reliability Engineer employed by Lockheed Martin. Within this role, he will manage IIoT networks operating in government classified areas to achieve operational milestones to continue production of the F-35 fighter jet. Currently, he works closely with Radiology Associates in a senior project capacity to improve the procurement process of non-medical supplies by automating communication between requestor and approver. His team will implement a new procurement system by June 2021 with the goal to automate approval workflow, achieving a 0% rework rate.

John Takiff is a fourth-year industrial engineering student at Cal Poly, expecting to graduate in the spring of 2021. After graduation, he will be joining Deloitte Consulting in San Diego as an application and program analyst. His professional experience comes from working with Electronic Theatre Controls as a Manufacturing Engineering co-op and a senior project working in Cal Poly's PolyGAIT laboratory developing solutions integrating Real-Time Location Tracking technologies.

Brandon Drury is a fourth-year industrial engineering student at Cal Poly, expecting to graduate in the spring of 2021. He will be starting his career near San Francisco as a sales engineer for Trane Technologies. He is currently working on a senior project with SLOPD in which the objective is to improve the rates at which the homeless population receives assistance in San Luis Obispo.

Jimmy Algeo is a fourth-year Industrial engineering student at Cal Poly who will be graduating in Spring 2021. His professional experience comes from his senior project with Lam Research, where he assisted in the standardization of business process documents and the implementation of a global operating management system (OMS).

Moummar Nawafleh is a fourth-year Industrial Engineering student at Cal Poly, expecting to graduate in the spring of 2021. Moummar was born and raised in Jordan and hopes to use his IE background in starting his own business back in Jordan, after he completes a Masters of Science in Entrepreneurship and Innovation from the University of Southern California. He is currently working on a senior project with Cisco on finding a way to improve their reverse logistics operation.

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 M.S. degrees in Industrial Engineering from the University of Central Florida, Orlando, FL, USA. Additionally, he holds M.S. 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.