THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF SUPPLY CHAIN AND INFORMATION SYSTEMS

THE CHALLENGES OF APPLYING LEAN PRINCIPLES TO SMART MANUFACTURING

JAMES RUSACK
SPRING 2018

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Management Information Systems
with honors in Supply Chain & Information Systems

Reviewed and approved* by the following:

John Jordan
Professor of Supply Chain & Information Systems
Thesis Supervisor

John Spychalski
Professor of Supply Chain & Information Systems
Honors Adviser

* Signatures are on file in the Schreyer Honors College.

ABSTRACT

This paper seeks to define and evaluate a set of important challenges that companies must solve to effectively implement smart manufacturing with a lean perspective. It is a qualitative analysis utilizing past research papers, business principles, and logic to decide which challenges are the most difficult to solve, as well as providing potential solutions to these problems. These challenges are managing big data and machine learning, managing the data security of the smart factory, implementing new technologies within ERP programs, and managing the data quality of the operation. There is a particular focus on managing data quality and data security as pressing concerns for a lean implementation of smart manufacturing. Additionally, the paper features cultural change as a major strategic element for defeating the technical challenges. Ideally, manufacturing companies will be able to use this paper to evaluate the current risks and benefits of implementing smart manufacturing in their operations while considering a lean perspective and will have a general guide of the areas for additional quantitative research to test the validity of these challenges and solutions.

TABLE OF CONTENTS

LIST OF FIGURES

ACKNOWLEDGEMENTS

I'd like to thank Dr. John Jordan for all of his help with this thesis. Without his oversight, I would have been absolutely lost in writing this paper. He's been an excellent mentor and supervisor! I'd also like to thank Dr. John Spychalski for reading and evaluating my work to ensure it is up to the Schreyer Honors College standards!

Chapter 1

Introduction

Ever since Toyota created efficient manufacturing success with its Toyota Production System (TPS) protocols, lean principles have gained a large bed of support in professional supply chain networks. Many supply chain professionals attribute Toyota's success to their TPS protocols and the lean principles that are used to run this system. Because of this success, lean principles have grown in popularity with businesses, colleges, and supply chain experts. At the same time, smart manufacturing has come up as a new way to improve factory operations and reduce waste. Smart manufacturing refers to the usage of innovative information technologies, like the internet of things, big data, cloud computing, and machine learning to automate and optimize factory processes and entire supply chains. Since lean companies will be looking to implement new technologies to improve their waste levels, it makes sense to look at smart manufacturing as a potential area of improvement for lean manufacturing operations. This raises the question:

What types of challenges will surface when implementing smart manufacturing with a lean methodology in place? And which challenges are the most pressing to solve for effective implementation?

Chapter 2

Research Methodology

To effectively evaluate the challenges in implementing smart manufacturing with a lean perspective, I have reviewed literature in both smart manufacturing and lean methodologies. After learning about the background of these topics, I researched trends of related technologies for each area. Additionally, I will call upon anecdotal evidence from my summer internship at a large manufacturer. I will use this background information to propose a set of challenges that likely need to be met for a useful implementation at a manufacturing facility. I will evaluate the validity of these proposed challenges, their severity, and some basic requirements to get past these challenges, based on further research and qualitative analysis. Due to the cutting-edge nature of these new technologies, I cannot acquire actual implementation data to test my findings quantitatively. Therefore, this essay serves as a qualitative analysis of potential challenges in implementing smart manufacturing with a lean perspective, with strategies and recommendations to attempt to help overcome the challenges. I am hopeful that future research can be employed to test my findings in the real world.

Chapter 3

Motivation for Thesis

In the past, one of the major ways of improving on lean principles was to implement additional technological resources into the manufacturing system. This is effectively exemplified by Toyota's Production System and the technological improvements they made over time (Toyota Motor Corp). Lean is all about improving factory flow and information flow. This is exactly the type of improvement that smart manufacturing and the next generation of industrial revolution could make possible. Smart manufacturing is all about optimizing the flow, costs, and quality of the entire supply chain, so it simply makes sense to implement it with the lean perspective in mind, because lean's goals are similarly aligned. The ability for machines to communicate and share information would be invaluable for making things run smoothly from a manufacturer's perspective. Smart manufacturing could be run even more effectively if it were implemented with the entire supply chain in mind. Information sharing between customer, supplier, and manufacturer would mean improved possibilities for smart manufacturing across the entire supply chain and could result in leaner manufacturing efforts overall.

While smart manufacturing has become a popular topic of discussion in futurism, there is a relative lack of strong research or case studies regarding actually implementing these facilities. Additionally, lean is a proven cost-reduction and value-improvement methodology, with many success stories, and implementing smart manufacturing with the lean perspective has the potential for manufacturing and supply chain success. This combination has a strong potential to reduce energy costs, optimize material usage, and prompt massive supply chain collaboration between manufacturers, suppliers, and customers, allowing for more sustainable and efficient factories and supply chains. This is an exciting, developing topic area due to these possibilities.

This paper seeks to explore a potential set of challenges for manufacturing and relevant computing industries to meet to best implement smart manufacturing with a lean perspective, taking advantage of new technologies, while applying well-understood cost-reduction principles. The proposed set of challenges are based around information system upgrades, edits to business processes, and dealing with cultural and organizational change. There is a particular focus on managing data security and data quality as more challenging problems to solve and making sure to use cultural change principles to ensure a smooth implementation of smart manufacturing.

Chapter 4 Key Definitions

Definition of Lean

According to the Lean Enterprise Institute, the main objective of lean is to maximize customer value while minimizing the waste of an operation. This means creating more value for customers while utilizing fewer resources. “To accomplish this, lean thinking changes the focus of management from optimizing separate technologies, assets, and vertical departments to optimizing the flow of products and services through entire value streams that flow horizontally across technologies, assets, and departments to customers.” (Lean Enterprise Institute 1) Eliminating waste along value streams, instead of focusing on isolated points, creates processes that need less human effort, space, capital and time to make products and services at lower costs and with fewer defects, as compared with traditional business systems. It allows companies to respond to changing customer desires with high variety and quality, low cast, and fast throughput times.

It is important to note that lean is not necessarily possible unless all companies across the business’s value stream are able to optimize processes. Lean cannot be effectively completed unless the suppliers, customers, and other related business partners are considered as part of the overall business’s processes. Managing the intercompany aspects of lean can be challenging, but the increased power of information technologies has the potential to solve this aspect of implementing lean across the entire supply chain.

Basic Lean Implementation

It is important to go over what a lean implementation entails, and the general principles of lean. Lean means approaching problems with a lens of constant improvement. Typically, there is a simple, five-step process for trying to implement a lean perspective in a company.

Figure 1: Lean Implementation Steps

Step one is identifying the value to the customer. This could be identifying anything from product lead time to the price point that is desired. Once all the desired value parameters are figured out, it is important to map out all of the steps and processes that will lead to the creation of that value (Crawford 1). This is where a lean perspective is important, because the goal of this step is to identify all of the steps that do not create value and figure out how to effectively eliminate these wasteful steps. After the wasteful processes have been eliminated, the next goal is to optimize the flow of the entire operation. Ideally, bottlenecks should be reduced or eliminated, and all steps should connect with the fewest number of delays that is possible

(Crawford 1). After the process has been optimized, the next idea is to set up a pull system for product. The customer should be able to request product from the company, and with the lean system in place, the company should be able to respond on time without holding much inventory. This saves significant inventory costs, which can result in a lower cost and higher value for your customer. Finally, step five is to seek perfection. While attaining perfection is impossible, the goal here is to get the company culture engaged with the lean methodologies that have been put into place. People should be constantly seeking to improve aspects of your organization to meet this requirement (Crawford 1).

Definition of Smart Manufacturing

Smart manufacturing is another key term to understand for the purposes of this paper. According to Jay Lee in his "Smart Factory Systems" paper, "The smart factory defines a new approach in multiscale manufacturing by using the most recent IoT and industrial internet technologies, which consist of smart sensors and sensing, computing and predictive analytics, and resilient control technologies. These technologies must be bonded together to acquire, transfer, interpret, and analyze the information, and to control the manufacturing process as intended." (Lee 1)

Smart manufacturing works by gathering additional information about factory operations, using computer technologies to react and analyze the information, automating decision-making for the factory, and ultimately creating more efficiency, reactiveness, and quality control than are possible with current manufacturing operations. Some individuals refer to smart manufacturing as Industry 4.0, or the 4th Industrial Revolution, due to the potential of this new industry to solve

manufacturing problems that humans alone cannot. Smart manufacturing relies on the advancement of technologies in several other industries, including but not limited to:
Big Data, Internet of Things (IoT), Cloud Computing, and ERP Systems.

Definition of Big Data

Big data is computationally analyzing massive sets of data to discover patterns, trends, and associations that would otherwise be unrevealed. (Dictionary.com) Because Smart Manufacturing will be using data generated by sensors and networking devices, which will be recording real-time factory interactions constantly, it will end up creating large data sets of factory and machine information. Big Data analytics and Big Data tools will be instrumental in turning this data into useful knowledge that can be used to change aspects of the factory dynamically and automatically.

Definition of Internet of Things (IoT)

The IoT is the use of computing devices embedded in normal objects, allowing data to be sent and received over the internet. (Dictionary.com) In the case of Smart Manufacturing, these sensors and networking devices would be embedded in machines and areas of the smart manufacturing factory. These physical devices communicate valuable data about the performance of the manufacturing plant while it operates. This is the main driver of the data sets that could be used to help improve the factory operations.

Definition of Cloud Computing

Cloud computing is the concept of using a network of remote servers to store, manage, and process data, rather than a local server or a personal computer. (Dictionary.com) This concept is instrumental to effectively implementing smart manufacturing on a larger scale. Most companies simply do not have the information resources on site to complete the massive processing required for big data calculations. A company providing cloud computing resources would allow for manufacturers to take advantage of mass processing power and storage that would make for easy analysis of data.

Definition of ERP Systems

Enterprise Resource Planning (ERP) systems are software programs designed to centralize data for a business and manage all processes that are required to effectively run a business. (Dictionary.com) This enables all functional areas of the business to be aligned on the information they are using, while allowing each functional area the ability to complete their separate business processes. Typically, these systems run entirely on real-time, centralized information, allowing for relevant decision-making from all interested parties. In terms of smart manufacturing, ERP systems are important to think about because many manufacturing companies use ERP to organize their information and business processes. An effective lean implementation of smart manufacturing should be able to integrate with current ERP offerings or use a new ERP system that includes smart manufacturing compatibility.

Definition of Machine Learning

Machine Learning is “a method of data analysis that automates analytical model building. It is a branch of artificial intelligence based on the idea that systems can learn from data, identify patterns and make decisions with minimal human intervention.” (SAS) This concept is the “smart” in “Smart Manufacturing.” Without machine learning, the data generated, stored, and processed for smart manufacturing decisions would be significantly less useful. The idea is for a computer system to optimize variables and figure out models to generate the best version of a set of parameters that it can change. In this case, it would be provided factory data to train on, given parameters to change, and generate optimized factory and machine settings to provide the best output of the given optimization function. A great machine learning model could maximize the efficiency of factories beyond the conclusions or capabilities of human operators.

Chapter 5

Hypothesized Challenges and Analysis

Challenge 1: Managing Big Data and Machine Learning

The volume of data that companies must manage and process has been exponentially increasing for years. In fact, “90% of the world’s current data has been created and shared in the last two years.” (Science Daily) And this trend is predicted to continue for the foreseeable future. Managing these quantities of data is an industry entirely on its own, with potential for significant value and potential insights.

Implementing sensor technologies for smart manufacturing means even more data for individual companies to manage, and many companies may not have the technological resources to house and manage large quantities of data with ease. The data from all of these sensors could easily surpass the quantities of data that are generated through social network use or other popular internet activities in the near future. For example, Bombardier’s new airplane engine equipped with smart sensors can produce 10000 GB / second, as it is equipped with over 5000 sensors. (Rapolu 1) Processing this quantity of information can be especially difficult to manage for companies without big data analysts and experts on their teams. Companies may need entire teams dedicated to processing data and generating useful insights from all of the gathered information in their sensor networks.

Sensor Data Volumes

Let's imagine that we are a company that wants to implement smart manufacturing in our factory. Before we even start thinking about the specifics of setting up this vast technological project, we need to get an idea of how much additional data our smart manufacturing facility will generate. First, we must make an assumption as to the average data creation rate for a smart sensor in a factory. This is just a guesstimate, and the reality is that this number could be much higher or lower depending on the sensor's application, the business's need for frequency of data ticks, and the sensor's hardware and software design. Let's assume, then, that each smart sensor generates 10 kB of data every second. This is equivalent to 1 MB every 100 seconds. There are 86,400 seconds in a 24-hour day. This means we will generate 864 MB of data every day per sensor, assuming a 24-hour factory uptime. A robust smart manufacturing solution could have hundreds or thousands of these sensors, depending on the factory's size and need for the sensors. This means that hundreds of gigabytes, and potentially even hundreds of terabytes of data will be generated on a daily basis for one smart factory operation. If we want all our company's facilities to be smart manufacturing facilities, this would mean ridiculous quantities of data being generated on a daily basis.

Big Data and Lean

Making sense of these quantities of data will require big data experts, adequate data storage facilities, methods of cleaning out old data, and machine learning models to actually make decisions from the data. This becomes a challenge when you consider that our lean implementation looks to reduce as many costs as possible. The addition of huge amounts of data, adequate storage methods, fast processing resources, and experts in big data and machine learning will add to the expense of implementing our smart factory. Most of the companies I have worked with look at new projects in terms of the proposed return on investment. Because smart manufacturing has a high capital requirement, many companies will be turned off by the risk of undertaking such a project, because the expected returns are not yet based on any real-world studies or tests. While I believe the smart factory has potential for big returns on investment, there is no way for me to prove it, as of yet.

Tradeoff: Data Storage History vs. Expense

This also brings up a major tradeoff between the length of time that factory data is stored vs. the expense of storing and processing that data. For machine learning models to be effective, it is important for training data sets to be large and based around "normality." (SAS Insights) This means that the factory should be recording its normal operational status constantly, for a long period of time, to optimize the machine learning models in a smart factory. This would be key in having accurate models that will reflect the reality of a live factory. However, processing and storing all of this data for long periods of time could quickly become expensive, given the potential data generation rates that I discussed earlier. Therefore, successful and lean smart manufacturing is reliant on the increase in efficiency of data storage and computing power over time.

Luckily, Moore's Law and the remarkable advancement and investment in computing technologies are on our side. Over time, the technical aspects of the big data challenge will naturally become easier to deal with as storage prices drop and computing power gets better.

Additionally, recent cloud computing improvements mean increased accessibility to the computing resources and storage necessary to run a smart factory. Because of this, I believe that the technical aspects of big data and machine learning models have a high potential of being solved in a timely manner. On the other hand, I think the bigger issue with big data will be involving the people management aspects of hiring on multitudes of data analysts and machine learning experts and keeping a lean perspective, with all of these additional points of view to consider.

People Management and Big Data

Setting up a smart factory will require the effective management of data-related experts in IoT, Big Data, and machine learning and experts in supply chain and manufacturing. This is due to a need for two combined areas of expertise. The supply chain experts will have a better idea of the parameters that are important to analyze for a better factory operation. Additionally, they typically manage the lean aspects of manufacturing. They can provide the focus areas and parameters for the machine learning analysts to improve upon and optimize with the smart factory technologies.

It is easy to state that managing these two groups of professionals is important to our implementation of a lean, smart factory, but the reality is that this issue is complex from a management perspective. First, you must consider that people are much more likely to trust other people's insights than the insights provided by machine learning (Druzkowski 1). Supply chain professionals are going to have much more trust and interest in hearing what other supply chain professionals have to say, than to consider the perspectives of those who utilize computers and data for their insights. Computers are simply not as relatable as people (Druzkowski 1). As it is instrumental that the data people and supply chain people work together for a lean operation, companies should consider the importance of strategies to align the two sets of professionals.

Additionally, currently employed supply chain experts may be concerned that this smart factory is a replacement for their traditional role in the company. Would you want to help create a computerized model that eventually destroys your job and career? I know that I would not. Supply chain experts need to feel just as valued as the experts on the technical side of the equation in creating the lean, smart factory, or there may be internal sabotage and turmoil. If an individual felt that their job was threatened, they might work diligently to oppose the smart factory efforts, provide ideas that hurt the operation, or tamper with data inputs into the machine learning models. Companies should be wary of the methods that they advertise these smart factory projects internally, because failure to consider these possibilities could result in an internal power struggle, instead of a strong and lean implementation of the smart factory system.

Proposed Solution to Big Data Challenge

People Management

Solving the people management aspects of the big data challenge is extremely important for companies looking to implement a lean and smart factory. A new strategic change, like introducing smart manufacturing facilities, will require effective cultural change management. According to Sigal Barsade, Ph. D of Management at University of Pennsylvania, it is possible to apply tools and methods to create and manage cultural change in an organization. The first step to culture change is understanding the current culture in the company, by evaluating what your employees believe your organization's current values are. The next step is to "intentionally align culture, strategy, and structure." This means supporting change both structurally and culturally and picking values that align with your business strategy (Barsade 1). Next, an organization needs to have active employee participation in the culture change. Including employees in team meetings about culture, allowing idea submissions, and engaging employees in considering problems and solutions about the changes will mean greater acceptance among peers, employee groups, and the organization as a whole. Finally, communicating the cultural change message and managing the emotional response of employees is the key to unlocking the full power of cultural change. Employees should hear about the culture change frequently, with the usage of "words and actions to convey the vision of the desired future." (Barsade 1) Leaders in the company should be clearly and visibly dedicated to the changes. Managing the employee's emotions is majorly important. Dealing with frustrations, empathizing with employee's struggles, and alleviating any anxiety will do wonders to help bring about effective cultural change.

In the case of implementing smart manufacturing with a lean perspective, interested organizations should consider the base values of lean and smart manufacturing when undergoing their cultural changes. I personally think a strong value system for an organization looking to implement lean principles and smart manufacturing is to have a focus on data-driven, constant improvements. If this message could be effectively communicated, big technology changes could be made to be significantly less scary for the employees in the organization. Smart manufacturing would simply make sense to the supply chain expert, if properly explained and supported with the correct values.

Technical Aspects

Beating the technical aspects of the big data challenge ultimately relies on companies evaluating different storage methods and processing power capabilities in order for their smart factory operation to be truly lean. I believe these aspects are much easier to solve than the people management aspects of the big data challenge. These methods must not sacrifice on quality but must also be cost-averse enough to be efficient and lean. A key tech sector to solve this task is the cloud computing industry. As mentioned in the introduction, cloud computing is the concept of using outside computing and storage methods to process and store private company data. I believe cloud computing resources would help solve this big data and machine learning issue, or perhaps, even a set of smart manufacturing software companies who could offer cloud computing with a focus on machine learning for optimizing the factory. Cloud typically charges based on the actual usage of the computing resources, so it is scalable and requires significantly less capital investment for a company interested in smart manufacturing. However, cloud is not without its issues, like anything else, and I think bringing up cloud means that I should discuss the next challenge of lean smart manufacturing: Data Security.

Challenge 2: Managing Data Security

In general, data security should be a significant concern for all companies, especially those large enough to be a target for cybersecurity attacks. Thycotic released their 2017 "Cyber Security Metrics Report", and the facts tell a story of major security issues across the board, with many companies unable to keep up in the cybersecurity space. For example, "58 percent of companies are failing in their efforts to measure the effectiveness of their cybersecurity investments and performance against best practices." Additionally, "4 out of 5 companies worldwide are not fully satisfied with their cybersecurity metrics." (Thycotic 2) These statistics tell a sad story about the state of data security in companies today, and the report makes the key recommendation that improving data security metrics should be a more significant area of focus for companies. These general data security issues are further exacerbated by implementing a revolutionary technology like smart manufacturing. It is especially difficult to keep information safe in the smart manufacturing space with the need for cloud computing and internet of things devices as main drivers of a successful and lean smart factory.

Data Security and Cloud

Putting information onto the internet means you are allowing anyone and everyone to access that data. Of course, I had always assumed this was only the case with data that I was placing onto social media networks or other public sectors of the internet. Unfortunately, story upon story comes out about the security issues that giant companies experience, even with significant data protection assets.

Take Verizon, for example. Back in July of 2017, Verizon experienced a data breach where up to 6 million customer accounts were compromised. They were using an Amazon Web Services server (cloud computing) to store their information, so you might think that this breach was Amazon's fault. Actually, cloud computing security is a two-way street. The company storing the data secures their facilities physically, ensuring that no tampering of servers or computing resources can be possible. And it is the customer's job to secure virtual machines, applications, and other software-related security issues. (Violino 1) This is where Verizon faltered. A third-party provider of call center operations utilized an AWS server that was improperly configured to allow external access to a customer service database, where personal information of their customers was stored. This means that anyone lucky or patient enough to discover the web address could access this private information with ease. And this type of simple mistake occurs far too frequently in the cloud. "Recent research by cloud security company RedLock's Cloud Infrastructure Security team found that 40 percent of organizations have inadvertently exposed at least one public cloud service due to misconfiguration." (Violino 1) These kind of stories and statistics can scare companies away from the cloud.

Companies should be taking as many precautions as possible in terms of cloud security. Paying attention to important data security metrics should be of the utmost concern to cloud-using organizations. In the area of smart manufacturing, it is especially important to protect stored data, because machine learning models rely on accurate data sets to generate optimal decisions for the factory. If someone were to tamper with these data sets, factory decisions would be made that are actually detrimental to a company's success, instead of solving their problems.

Until these issues are worked out and evaluated, the smart factory may remain a novel idea instead of a useful implementation.

Data Security and Lean

As we know, lean principles work based on effective flow throughout the factory, including information flow. However, this goal is almost entirely opposite that of effective data security. Increased information flow through different computing devices means increased security risk of those transmissions becoming compromised. According to Daniel Newman, in an article on security system complexity and fragmentation, “The more complex [a] system, the harder it is to process and manage all of the alerts or breaches taking place.” Since smart manufacturing relies on multiple layers of data security, between the sensor networks, cloud computing to process the data, and factory control aspects, complexity of this security becomes prohibitively more difficult to manage. After all, layers of security create an obstacle course for hackers, but not one that is insurmountable. “In the end, in-depth security creates more problems for businesses than it does for the hackers themselves.” (Newman 1)

Additionally, for our smart factory to truly be lean, controlling parties of different aspects of the factory must have access to important data to make decisions quickly. But at what point does a lean factory become an internal security risk? Employee access to important factory data poses two distinct security risks: the first is the possibility of this employee selling this data to outside parties, and the second is the possibility of this employee tampering with this data and causing the smart factory to run ineffectively. Competitors may find IoT data about a business’s smart factory operation to be an extremely valuable asset. Gaining access to this data could mean closing the gap on the company’s competitive advantages. And it would be valuable to competitors or other outside parties to sabotage the company’s smart factory operation through data tampering. This could be very detrimental to the success of a smart manufacturing operation. Companies should consider internal data security risks, as well as the typical dangers of hacking, when implementing a lean, smart factory.

For a smart factory to be effective in security and also lean, it must remain inexpensive but protective, which is an additional challenge for all tech parties involved. Considering all of the above problems with security and a lean operation, there may need to be additional security resources and investments to ensure a safer smart factory operation. However, we need to consider that investment in security should consider the optimal level of security to be a comfortable level of cost, convenience, and risk level. As Professor John Jordan states frequently in his MIS 446 class here at Penn State, “You could be 100% safe from mugging by never leaving a heavily locked apartment.” But realistically speaking, this is not going to be an enjoyable, convenient, or inexpensive way to live your life. Striking the balance between cost, convenience, and risk level is going to be key to creating an effective lean implementation of a smart manufacturing facility.

Data Security and IoT

Many security issues have come out with the Internet of Things. According to “A Survey on the Internet of Things Security,” “Sensor nodes have many varieties and high heterogeneity. They have generally simple structure and processor. These make them could not have complex security protection capability.” (Zhao, Kai, and Lina Ge 3) Additionally, this paper brings up issues around the contradiction between security and cost, stating that if sensor cost is too low, the large number of low performance sensors would reduce the security of the whole network. (Zhao, Kai, and Lina Ge 3) High performance nodes would increase security, but at an increased network maintenance cost. Additionally, the processing power of these sensors would be relatively low to maintain a lean smart factory, lowering the potential power of encryption algorithms and security authentication. (Zhao, Kai, and Lina Ge 4) And these are just the security issues with the sensor technologies themselves.

Many more security concerns come up when attempting to manage a network implementation of these sensors, as there may be network interchanges where data transfers are less secure than others. If these nodes are hacked, then data quality for the smart factory operation becomes a major issue to consider, as well, which we will talk about in a later section on data quality issues.

Proposed Solution to Data Security Issues

Unfortunately, the data security issues of implementing smart manufacturing with a lean perspective are one of the most important challenges mentioned in this paper. There is no easy answer here, because attackers are always finding new angles and opportunities to perform malicious deeds. It's going to take a lot of strategy, planning, and cooperation between sensor manufacturers, cloud providers, and interested companies to figure out better methods of managing security, while keeping costs at a reasonable level to enable a lean implementation. Until these issues are worked out, companies should be wary of the information security risks of implementing the smart factory.

Challenge 3: Integrating ERP with New Technologies

Assuming that the company has the information storage capacity and processing capability for large quantities of data, they must also have an ERP system that can integrate with outside modules. As it stands, modern ERP implementations like SAP and Oracle are huge undertakings and are mostly standardized. This means that a smart manufacturing module would be new, and therefore, difficult to support with a centralized ERP system. A smart manufacturing system would require a strong integration with current ERP offerings to be effective and easy to use, especially when approaching with a lean methodology. Lean is about information and factory flow, and proper integration strategy would certainly help with the flow of information to different decision-makers for the factory. Many common complaints from companies regarding ERP systems is that they are largely “one size fits all” programs. These programs have limited configurability, and if a company wants the popular ERP systems to have new functionality, it can take serious software development resources on the company’s payroll to get there. The other issue here is that lean is about always looking for constant improvement and change, and ERP is extremely difficult to change, in general.

Anecdote: ERP Problems at Large Manufacturing Plant

This past summer I interned in the supply chain management department of a large engineer-to-order based manufacturing plant. This manufacturer utilized an implementation of a popular ERP system to handle most of its business processes. One major issue with this company’s implementation was that it completely disallowed automatic data pulls from its ERP system for security purposes. This meant that all the users at the local branch were required to use one-off downloads of system information into Excel to process any information they needed. Because of this, decisions could not be made off of real-time information, and many users experienced miscommunication issues and distrust of the ERP system as a whole. I believe making automatic and updated data pulls available increases the chances of an ERP system allowing lean principles to come to fruition, especially when considering the importance of information flow with lean.

Additionally, since this local plant was engineer-to-order based, they rely heavily on proper scheduling to run manufacturing processes efficiently. The current system for scheduling is based on one woman's decisions, who is quite skilled at her job. She takes a look at the basic schematic designed by the engineer, decides about how long that order will take to make based on her previous factory experience, and then schedules the orders optimally based on her understanding of what will take longer to make. While I was amazed at how effectively this factory ran, given its reliance on human intuition, I also came to the realization that this company is not using their ERP system and computing power to its full potential. If this woman, or any of the other skilled workers were to leave the company, its factory operation would suffer significant losses without any real plans for recovery. The company was aware of these issues, but they cited their ERP implementation as being largely incompatible with their ETO business. I recommended a stronger, more permanent method of ETO scheduling while I was interning there, but I ran into issues with figuring out an appropriate method of integrating any programs with the current ERP implementation. I simply did not have much experience with implementing these complex systems and would have needed significant professional assistance to actually accomplish this task. Implementing ERP and considering new technologies at the same time can be a challenge, and I learned it firsthand at this internship.

Proposed Solution to ERP Integration with Smart Manufacturing

This is another challenge that will require cooperation between multiple industries to solve for the vast majority of companies. In this case, IoT device manufacturers, cloud providers, and ERP system developers will need to figure out the best ways to handle integration with smart manufacturing technologies. Manufacturing companies with coding resources may be able to overcome this challenge with ingenuity in software development, but for smaller manufacturers, they may require established smart manufacturing solutions with available integrations for common ERP programs. Luckily it seems that IoT integration is a focus area for some major ERP developers. For example, SAP offers IoT modules to connect people, things, and businesses together (See Figure Below). The robustness of their solution in terms of implementing a smart factory with a lean methodology is not yet assured, but it is definitely a move in the right direction for ERP and smart manufacturing. I have hope that more of the ERP industry will see this IoT trend as an opportunity to improve the value of their software offerings.

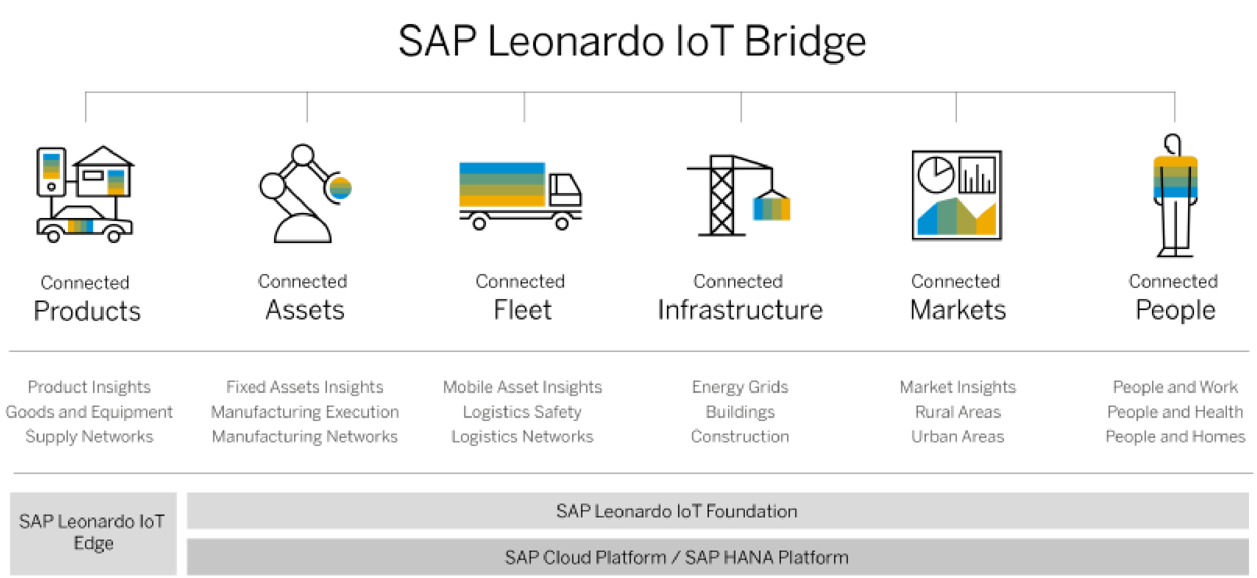

Figure 2: SAP IoT Offerings

Challenge 4: Maintaining Data Quality

Data quality is a top technology issue for many companies. An Experian report states that 88% of companies see a direct effect of poor data quality on their bottom line, losing 12% of their potential revenue on average. Companies often struggle with keeping customer data up-to-date and cannot keep databases clean of duplicate and obsolete information. These problems are further exacerbated by the usage of big data technologies. The addition of more data and data types means additional strain on the business's information networks. In the case of smart manufacturing and a lean implementation, the problem becomes even more complex.

Traditionally speaking, many companies rely on transactional and relational databases, which can struggle to keep pace with the volume of data collected and disparity of different information systems that are used to collect it. Sensor data from smart manufacturing would exacerbate these issues, because of the sheer volume of data that it would produce and the difficulty of integrating this quantity and variety data into typical database structures in a smooth manner. Once data is entered incorrectly, it can become pervasive throughout all of the processing and analysis steps of the business's information systems. This can become a total nightmare to clean up, if it is sent through too many of these processes. If data quality becomes an issue with the sensor data for a smart factory, then the factory itself would be making decisions based on obsolete or poor sets of data. Similarly to poor data security, poor data quality could throw off the optimization function of machine learning models, meaning the smart factory would be making decisions that hurt the manufacturing operation's performance.

Sensors on Sensors

Relying on sensors to transmit data about the factory raises additional questions about maintaining the health of these sensors. After all, the health of the factory is constantly being measured by the sensors. But this raises the question: what is measuring the health of the sensors that are measuring aspects of the factory? How can we trust the data quality of sensors, if we are not measuring how accurately those sensors are working? Perhaps the answer is that we need sensors to measure how well the sensors are performing. Do we then need sensors to measure the sensors that are measuring the sensors? This starts to get confusing, and I think additional research should be done as to the reliability of IoT sensors for manufacturing processes, as well as the potential need for sensor networks monitoring the health of the sensors in the factory. If we do need additional sensors to monitor the factory's operations, then the cost of maintaining data quality could become higher than the potential returns from the smart factory.

Real-Time Decisions and Quality

An additional issue to consider is the need for the smart factory to be a real-time operation, especially when considering a lean methodology. The idea is that a real-time information based smart factory would become leaner than one that relies on past data. It would be capable of reacting to changes in business parameters quickly and make changes to the factory's operation, which is the whole point of undergoing this technological change. However, this raises additional concerns for data quality, because there should be an evaluation of the validity of sensor data being input into these models. It is a bad idea to blindly input data into a model that is making decisions for a company's supply chain. This becomes an issue for a lean operation, because both speed of flow and quality of input data enable a lean operation. A balance must be struck between cost and quality, and it is up to each company's individual operation to decide where that lies.

Data Quality and Data Security

If the organization has struggles with keeping data secure, then data quality will naturally suffer as a result of this, as well. As previously stated, any data tampering will cause problems that eventually effect the machine learning models and their accuracy. Any accuracy deficiencies will result in poor factory decisions being made. This is why data security is key to allowing data quality to be maintained. Look at the previous data security section for further information on keeping data secure in a smart manufacturing operation.

Data Quality and Cultural Change

Besides technical changes, maintaining proper data quality is also a challenge of creating a culture that values quality data. If employees have a strong focus on keeping data records clean, optimizing the way information is pulled in, and maintaining strong practices for data quality, then implementing a smart factory will be significantly easier and leaner. Making decisions based on quality data should be a value instilled in every employee from the first day they join the organization. If this is the case, then people will be focused on looking into data quality health much more regularly than an organization that does not consider the effects of culture change on data quality health. And again, data quality has a direct impact on the effectiveness of the analysis that goes into processing factory decisions in smart manufacturing, so having this type of culture would be a major advantage.

Proposed Solution to Data Quality Issues

Many data quality issues could be solved by figuring out whether there are actually data quality issues in the company's systems at all. This paper seeks out potential challenges, but they are not necessarily always present in all situations for manufacturing companies. I propose the usage of a simulated smart factory relying on the physical sensor data in the factory. This would allow interested companies to test out the decisions that the factory might make based on the input data that's being generated by the factory's real run-time. If the decisions seem to make sense, or would improve factory operations, then it makes sense to fully implement the smart factory.

I also recommend the usage of incremental implementation. It is not necessary for a company to drop millions of dollars on simply trying out an entire smart factory. They could run tests on a smaller part of their overall manufacturing operation to work out bugs in the system, before actually implementing the overall system on a larger scale. This would allow the business to have a better idea of the potential return on investment of a smart manufacturing operation, without having to invest nearly as many resources. Data quality is definitely a strong issue to consider when implementing a lean smart factory, but there are far more tools to deal with data quality than something like data security.

Chapter 6

Discussion

Significance of Findings

This paper is significant in evaluating the current state of implementing smart manufacturing with a focus on a lean implementation. If companies were to ignore costs in implementing a smart factory, many of the challenges I brought up would be solved with ease. However, that's simply not a realistic possibility for most companies. The main point is to provide interested companies an idea of the tradeoffs that they will be making between cost, quality, security, usability, and efficiency of a smart manufacturing implementation, and that making a system that actually saves them money will take more work and capital than is anticipated by the average paper focused on futurism. In particular, data quality and data security are the two number one concerns that I have identified in this paper, and these areas should absolutely be approached with additional research specific to operating a smart factory.

Questioning Findings

I recognize that it is possible that some of the findings of this paper could be less serious than I have indicated. Technology and manufacturing industries are most likely working hard on some of these issues and may understand more details about the specifics of solving the challenges that I have identified in this paper. Due to the nature and scope of this paper, I thought it important to note the issues and tradeoffs that I think are pressing in the area of lean smart manufacturing. Companies should be asking themselves if they can actually save money from implementing this type of system, with the current technology environment. If I were running a company, I would want to look into these issues further and develop more specific research on each one of them, before deciding if smart manufacturing is worth the investment in its current state. Additionally, the set of challenges that I have developed is not necessarily an exhaustive list of problem areas for lean smart manufacturing. There can always be unforeseen circumstances when undergoing any new technology changes, especially one like smart manufacturing that relies so heavily on technological improvements in numerous dynamic industries.

Chapter 7

Conclusion

In conclusion, this paper has identified and evaluated four separate challenges that manufacturing companies with a lean methodology should evaluate and attempt to solve before implementing smart manufacturing. The four challenges are: Managing Big Data and Machine Learning, Managing Data Security, Maintaining Data Quality, and Integrating ERP with New Technologies. The main considerations in these challenges are maintaining quality, efficiency, and security of the factory operations while also considering the cost implications of improving these factors. Additionally, considering the impact of cultural aspects on these challenges is relevant. Most companies should start with working on the people-related challenges of implementing a lean, smart manufacturing operation before tackling the technical aspects of the challenges. I think that, of these challenges, Data Quality and Data Security stand out as particularly pressing issues to solve before a company can consider a smart manufacturing implementation, due to their potential to destroy all effectiveness of the technologies that a smart factory utilizes. All of these challenges will require significant technology industry coordination and cooperation for smart factory adoption to take off with lean manufacturing companies worldwide.

Final Perspective

The scope of this paper is wide and attempts to provide an overview of general challenges with applying lean principles to smart manufacturing. I simply did not have access to the data to dive deep into any one of these challenges. I think the main point of this paper is to identify areas for further research and evaluation in this specific area of using lean methodology on a smart manufacturing operation. In particular, I believe there is an opportunity to research the effectiveness of simulating smart factory decisions in measuring the quality of implementing those decisions in the world, the optimal number of sensors to measure the health of sensors in a smart manufacturing implementation, and more specific cost-benefit evaluations of smart manufacturing operations based upon the tradeoffs that I have identified with each of the challenges. This paper is designed to open the door to further research that can provide quantitative answers to the qualitative questions that I have raised. I have strong hope that the various technology industries related to smart manufacturing will meet these challenges in the coming years, because smart manufacturing and lean principles have a lot of combined potential for supply chain improvements.

BIBLIOGRAPHY

"2017 State of Cybersecurity Metrics Annual Report | Cybersecurity Reports." *Thycotic*, Thycotic, Jan. 2017, thycotic.com/resources/cybersecurity-metrics-report-2017/.

Barsade, Sigal. "Five Steps for Managing Culture Change." *Wharton - University of Pennsylvania*, University of Pennsylvania, Sept. 2014, executiveeducation.wharton.upenn.edu/thought-leadership/wharton-at-work/2014/09/managing-culture-change.

"Big Data, for Better or Worse: 90% of World's Data Generated over Last Two Years." *ScienceDaily*, ScienceDaily, 22 May 2013, www.sciencedaily.com/releases/2013/05/130522085217.htm.

Crawford, Mark. "5 Lean Principles Every Engineer Should Know." *ASME.org*, Mar. 2016, www.asme.org/engineering-topics/articles/manufacturing-design/5-lean-principles-every-should-know.

Druzkowski, Marcin. "Ten Useful Tips for Starting a New Machine Learning Project at Your Company." *Ocado Technology*, 6 June 2017, www.ocadotechnology.com/blog/ten-useful-tips-for-starting-a-new-machine-learning-project-at-your-company/.

Lee, Jay. "Smart Factory Systems." *Informatik-Spektrum*, vol. 38, no. 3, Sept. 2015, pp. 230–235., doi:10.1007/s00287-015-0891-z.

"Machine Learning: What It Is and Why It Matters." *Machine Learning | SAS*, SAS, www.sas.com/en_us/insights/analytics/machine-learning.html.

Newman, Daniel. "Complex and Fragmented Systems Are the Enemy to Security." *Futurum*, 6 Nov. 2017, futurumresearch.com/complex-fragmented-systems-enemy-security/.

Rapolu, Bhoopathi. “Internet Of Aircraft Things: An Industry Set To Be Transformed.” *Connected Aerospace Content from Aviation Week*, AviationWeek, 18 Jan. 2016, aviationweek.com/connected-aerospace/internet-aircraft-things-industry-set-be-transformed.

TOYOTA MOTOR. “Toyota Global Site | Production System.” *Toyota Motor Corporation Global Website*, Toyota Motor Corporation, www.toyota-global.com/company/vision_philosophy/toyota_production_system/.

Violino, Bob. “The Dirty Dozen: 12 Top Cloud Security Threats for 2018.” *CSO Online*, CSO Online, 5 Jan. 2018, www.csoonline.com/article/3043030/security/12-top-cloud-security-threats-for-2018.html.

“What Is Lean?” *Lean.org*, Lean Enterprise Institute, www.lean.org/WhatsLean/.

Zhao, Kai, and Lina Ge. “A Survey on the Internet of Things Security.” *2013 Ninth International Conference on Computational Intelligence and Security*, 2013, doi:10.1109/cis.2013.145.

ACADEMIC VITA

JAMES RUSACK

EDUCATION AND HONORS

The Pennsylvania State University | Schreyer Honors College
University Park, PA
The Smeal College of Business
Graduation: May 2018
Bachelor of Science in Management Information Systems

WORK EXPERIENCE

Rockwell Automation
Richland Center, WI
Materials Analyst Internship
May 2017 – Aug 2017

- Creating standardized tools and reports to support decision-making processes for the Production Floor Management Team
- Assisting with Excel-based projects with a focus on scheduling improvements, resulting in a 40% reduction in regular overtime levels
- Providing strategic guidance for future manufacturing scheduling software through research and analysis of current market offerings
- Developing user friendly technical solutions to achieve the requirements and goals of the Materials Team

Dun and Bradstreet
Center Valley, PA
Competitive Intelligence and Strategy Analyst Internship
Jun 2016 – Aug 2016

- Analyzing primary research to distill key insights to senior leadership with a focus on increasing accessibility to information
- Organizing department intranet and SharePoint sites for ease of use, increased access, and general visual appeal
- Creating competitor business profiles using primary and secondary sources to support the sales team in competitive sales situations
- Gained important foundational communications, analysis, and computational skills by completing variety of projects

Business Development Internship
Jun 2015 – Aug 2015

- Compiling and examining customer data to create a "look-a-like" model to increase sales outreach success rates by 20%
- Extrapolating findings and connecting with businesses to support the D&B sales team with potential leads and prospects

Giant Food Stores
Bethlehem, PA
Cashier
Jul 2013 – Aug 2014

- Cashiering, bagging groceries, gathering shopping carts, cleaning floors, managing returned goods, assisting customers directly

Kumon Learning Center
Bethlehem, PA

Tutor / Instructor
Aug 2012 – Jul 2013
- Tutoring K-12 children in reading and mathematics and providing feedback on students' progress in a fast-paced environment
- Grading quizzes, tests, and homework sheets to identify concepts that the student needs to understand better

CLUBS AND PARTICIPATION

Penn State Ski Club
University Park, PA
Member
Aug 2015 – Present
- Participating in meetings, hosting and attending club social events, and discussing future ski trip plans
- Joining the club and travelling for recreational ski weekends with destinations ranging from Killington, Vermont to Tremblant, Canada

Penn State Video Game Club
University Park, PA
Member
Aug 2015 – Present
- Attending bi-weekly meetings, club social events, and participating in Video Game Club tournaments for specific games
- Enjoying Video Game Club game nights where members meet up and play games like Super Smash Brothers or Mario Kart

Apollo THON
University Park, PA
Member
Aug 2015 – Present
- Participating in THON event, attending club meetings, joining club for fundraising efforts, and discussing future club events
- Hosting canning weekends in my hometown of Bethlehem, including housing people, providing meals, and supplying transportation

Students Organizing the Multiple Arts
University Park, PA
Member
Aug 2015 – Present
- Providing and discussing ideas for new events, plans, and fundraisers like a collaborative art project with multiple artists and art forms
- Supporting members in specific art endeavors by attending individual concerts, art shows, and photography projects

AWARDS, SKILLS & INTERESTS

- **Awards:** Penn State Academic Excellence Scholarship, Penn State Provost Award Scholarship, Dean's List (Fall 2014 – Spring 2016)
- **Skills:** Microsoft Office (Word, Excel, PowerPoint, SharePoint, Access), Tableau, Gephi, Basics of C++, CRM software, UML, MySQL, BPMN, ProjectLibre / MS Project, Statistical analysis, Reaper, Multi-media editing, Computer hardware assembly
- **Interests:** Making music, improvisation on guitar and piano, tech news, artificial intelligence, internet of things, machine learning, Rocket League, skiing, attending musical concerts, playing video games, supporting Penn State football, and watching soccer