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Industry 4.0 in the IBL-LeanLab: Evaluation of Different Emerging Technologies and Elaboration of an Implementation Concept

MASTER'S THESIS

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Dipl.-Ing. Mario Kliendienst

Institut für Industriebetriebslehre und Innovationsforschung

Graz, April 2015

Affidavit

I declare that I have authored this thesis independently, that I have not used other than the declared sources/resources, and that I have explicitly indicated all material which has been quoted either literally or by content from the sources used. The text document uploaded to TUGRAZonline is identical to the present master‘s thesis dissertation.

Date | Signature

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Abstract

At the turn of the century, manufacturing of simple goods was outsourced to emerging low-cost countries. In the short term, this was mutually beneficial, but then it started to include high-tech goods. This is the point when the high-cost countries became concerned because the loss of high-tech good leads to the loss of high-tech manufacturing capability and innovation. To counteract this trend, many countries adopted a high-tech strategy to focus their efforts to bring the high-tech manufacturing back home. As the manufacturing momentum was already moving towards low-cost countries, simple actions would not be enough and in fact a revolution would be necessary. This revolution was called Industry 4.0.

To address this manufacturing revolution, the IBL institute at TU Graz created a test-bed called the LeanLab where new technologies could be tested in a real-world manufacturing environment. This thesis will use the LeanLab as a foundation and will present the research and selection process for the technologies that can provide a foundation for Industry 4.0. These technologies will be scalable and expandable to be applicable for small and medium sized businesses.

As a first step, the concept of Industry 4.0 is described as well as the high tech strategies of Germany and the United States which provide a background and insight on the topic. The LeanLab is then described in its current state as well as ideas for future operation. The next step is the research of available technologies with Industry 4.0 applications within the specific production processes of the LeanLab. After this, an evaluation and selection will be made for four technologies to be installed in the LeanLab. For each technology, a real world system will be presented in detail for installation into the LeanLab. In the end, this thesis can be used as a blueprint for installing the technologies that can help real-world production processes start down the path towards Industry 4.0.

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1 Introduction

At the turn of the 21st century, manufacturing and services in the major industrial nations such as Germany and the United States were rapidly outsourced to low cost countries. The ramifications of these actions is just now being realized as it is very difficult if not impossible to bring this manufacturing back to their origin. The total economic impact of this shift is not just the loss of the manufacturing itself, but also the supply chain and support services. In the 1990's, it was shown that for every job that was outsourced, two jobs were created locally. However this trend ended the following decade as illustrated by the fact that U.S. based multi-national companies added 2,4 million jobs overseas and cut 2,9 million locally. [1]

The impact was not limited to only the loss of jobs. The design and development of high tech products requires close collaboration with manufacturing and if one is outsourced, the other one quickly follows. This means that not only was there a loss of manufacturing, but also a loss of R&D knowledge.

As market leaders outsourced an activity to gain short-term cost advantages, the pressure to compete pushed their competitors to do the same. This further led to the reduction of funding for long term R&D and related employment opportunities diminished. The experienced people changed jobs or moved out of the region, and eventually students shied away from these fields because there were no longer opportunities in the area. This created an erosion of the "commons" which in this context refers to:

> "A foundation for innovation and competitiveness, a commons can include R&D know-how, advanced process development and engineering skills, and manufacturing competencies related to a specific technology."[2]

This loss of commons leads to situations as exemplified by the U.S. where they are no longer capable to produce the technologies that they invented. Through outsourcing, they lost not only knowledge and skills, but also the supplier network, production equipment, and components. [3] Once all of this is lost from a region, it requires a large effort to bring it back.[4]

[1] Pearlstein (2012), Accessed 22 Dec. 2014

[2] Pisano & Shih (2009), Accessed 01 Apr. 2015

[3] Pisano & Shih (2009), Accessed 01 Apr. 2015

[4] PCAST (2012), pp. 7-9, Accessed 25 Nov. 2015

This issue was brought to the forefront by politicians and industry leaders alike as they were both asking "What can we do to bring manufacturing back home?" This is not an easy question to answer especially since high-cost countries have found it increasingly difficult to compete with low cost countries in manufacturing. The governments of Germany and the U.S. have reached fundamentally the same solution: focus on high technology in manufacturing and bring about a revolution in manufacturing. Since the 18th century, there have been three industrial revolutions (Figure 1). The first revolution (Industry 1.0) was brought about when steam and water powered machines were used in manufacturing. The second revolution (Industry 2.0) came in the late 1800s with the first assembly line and mass production. The third industrial revolution (Industry 3.0) was started primarily in the 1970s when electronics and IT were further advance automation. In April 2011, the term Industry 4.0 was coined in reference to a fourth industrial revolution based on the highly integrated use of cyber-physical systems (CPS). This basis of this is not only to connect objects and systems, but also people to create networks that are enterprise-wide value added, dynamic, self-organizing, and can be optimized in real-time by different criteria such as costs, availability, and use of resources.[5]

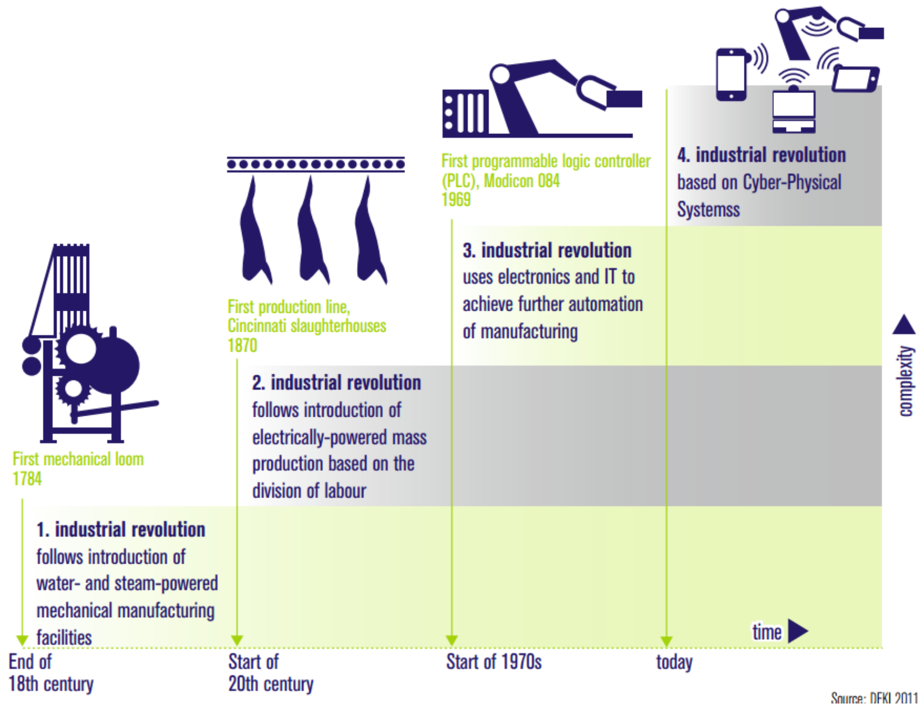

Figure 1: Timeline of Industrial Revolutions[6]

[5] Plattform I4.0 (2014), Accessed 25 Nov. 2014

[6] Acatech (2013), p. 13, Accessed 25 Jan. 2015

1.1 Task

Through multiple meetings and discussions with the thesis supervisor, the following tasks were defined for this thesis:

- General Description of Industry 4.0 with further description of topics as required.
- Description of the Industry 4.0 organizations with a brief description of projects related to this thesis. This is not an all-inclusive selection and is intended to provide a reference for further tasks.
- Describing Advanced Manufacturing Partnership (AMP) and compare to Industry 4.0.
- Describe current state of LeanLab at IBL Institute at TU Graz.
- Describe relevant technologies that have applications within the LeanLab.
- Definition of the analysis process of the technologies and a selection of the 4 technologies.
- Detailed description of the installation of the systems for the 4 selected technologies.
- List the expected outputs of each technology as well as a description of the system, budget costs, and time line.

1.2 Aim of the work

Manufacturing terminology, Industry 4.0, and Advanced Manufacturing Partnership (AMP) will be clearly defined. The current state of the LeanLab will be understood as a reference for future improvements and actions. Technologies related to Industry 4.0 will be categorized, described, and selected based on a criteria to bring about improvements to the LeanLab manufacturing capabilities. Of these technologies, the most promising ones will be selected for further integration within the LeanLab. Each technology will be fully described with an emphasis on the key outputs, cost, and implementation timeline. Each system will also be configured so it seamlessly functions with all other systems as well as possible future systems. The resulting collection of technologies and the process of selection is to be presented in such a way that it could be used as a blueprint for small to medium sized companies to start down the path towards Industry 4.0.

1.3 Procedure

The thesis consists of two main parts: a theory basis of Industry 4.0 and a practical implementation of technologies to achieve the goals of Industry 4.0. Using the Industry 4.0 whitepaper and AMP reports from whitehouse.org, I obtained a first overview of Industry 4.0 and AMP. Whereas the manufacturing terms of Industry 4.0 and AMP can be confusing, I used various reputable internet and literary sources to define them and explain how they relate to each other.

For the practical part of the thesis, I researched the technologies related to Industry 4.0 using the Industry 4.0 whitepaper, the focus areas of AMP, and other emerging technologies from multiple publications and websites. Multiple discussions were held between the stakeholders of the LeanLab to determine the basic requirements and useful outputs. A "short list" of technologies were considered and researched. From this short list, a decision matrix process was created based on several criteria specifically related to the LeanLab. The four technologies with the highest score were selected for implementation in the LeanLab. For each selected technology, a local supplier was found to work with TU Graz to implement the solutions. The main goal of this thesis is to present the four technologies to the IBL Institute for consideration and budget approval with anticipation of full implementation of the systems presented.

2 Industry 4.0

The manufacturing world currently stands at what is being the fourth industrial revolution based on CPS and is the merging of production technology with information technology.[7] This so called Industry 4.0 has a goal to create a "smart factory" which will utilize the Internet of Things, People, Data, and Services in industrial processes (Figure 2). This decentralization of control is a vastly different concept from the well-established centralized control that has been used in manufacturing since the 18th century. The concept of Industry 4.0 has been used as a basis for the high-tech manufacturing strategy for multiple nations. As such, the term represents both a concept and a strategy.

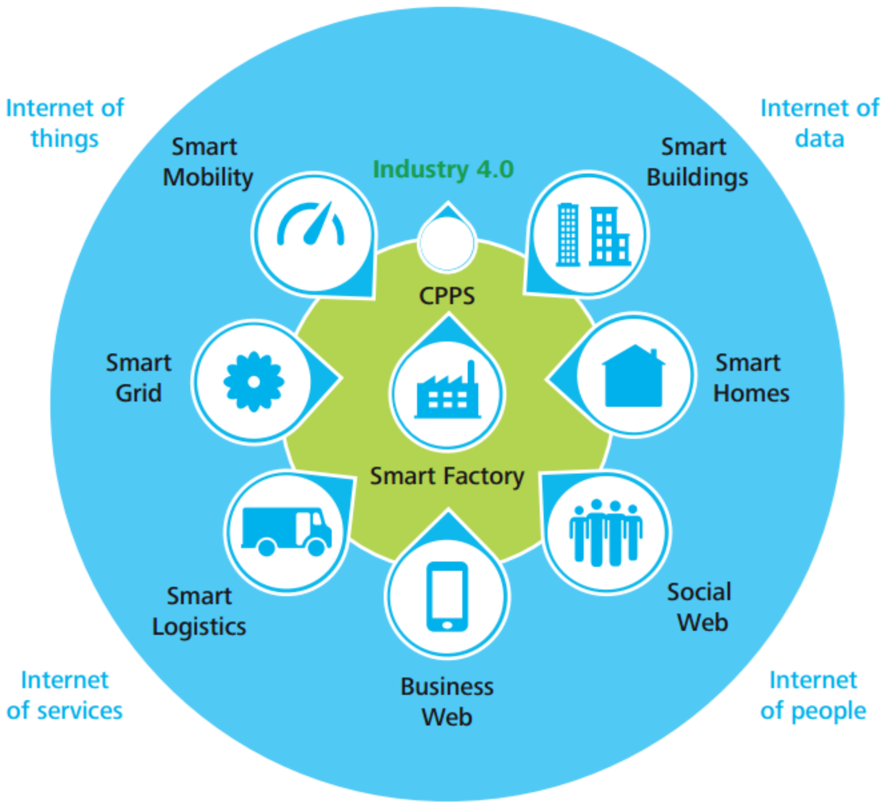

Figure 2: Industry 4.0 Environment[8]

[7] SmartFactoryOWL, n.d., Accessed 29 Dec. 2014

[8] Deloitte AG (2014), p. 4, Accessed 23 Jan. 2015

2.1 Industry 4.0- the Concept

At the heart of Industry 4.0 is the concept of a smart factory and the key part of the smart factory is CPS. Although its roots go back to World War II, the term cyber-physical systems was not actually coined until 2006. CPS is defined as “the integration of computation and physical processes.” This is done through the use of embedded objects which communicate via a network to monitor and control the physical processes. The computational aspect is the link between the monitor and control. The data obtained by monitoring is used to compare the current state to the ideal state and calculate the adjustments needed to reach ideal state. Adjustments are based on computer algorithms and are sent to the physical process as a control.[9] This can be visualized in the following figure:

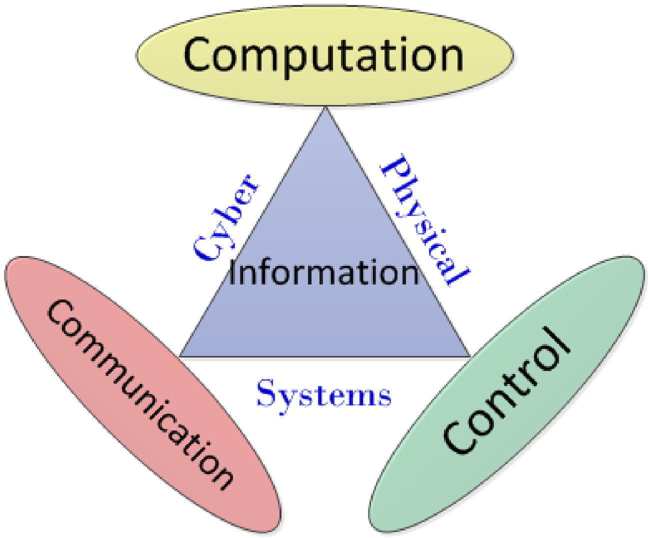

Figure 3: Cyber Physical Systems[10]

In addition to CPS, the Internet of Things (IoT) plays an important role in the creation of the smart factory. IoT is a network of physical objects that is connected to Internet. These physical objects contain embedded technologies that collect and communicate data about the environment around them through the use of sensors and connection to internet. This data can be analyzed and turned into information, knowledge, and wisdom.[11]

From simple interactions such as using a cellular phone to activate a light switch, to complicated systems for autonomous manufacturing, to hospitals long-distance monitoring of

[9] Lee & Seshia (2011), pp. 1-4

[10] Wu & Li (2011), Accessed 22 Jan. 2015

[11] Lee & Seshia (2011), pp. 1-4

devices like pacemakers, IoT applications are diverse and far-reaching.[12] IoT can be considered as a large umbrella under which all connected devices fall. The size of this umbrella is not just growing, but it is exploding as illustrated by the fact that Gartner estimated that there were 2,5 billion IoT connected devices in 2009 and this is expected to increase to 30 billion by 2020. This translates to $1,9 trillion (USD) of total economic value add in 2020 of which manufacturing takes a 15% share ($285 billion USD).[13] IoT is currently at the apex of the Gartner Hype Curve as it is positioned at the "Peak of Enlightenment" with an estimated 5-10 years needed to reach its "Plateau of Productivity".[14] For reference, the Hype Curve can be found in Figure 30 of Appendix E.

The relation between CPS and IoT is not easy to define because they both contain embedded systems that communicate and control physical systems. The difference between the two is a matter of primary focus. As the names imply, cyber-physical systems are focused on 'systems', whereas internet of things are focused on the 'things'. CPS concentrates on a harmonious connection of physical objects with the cyber world and has its roots in manufacturing. IoT is focused on the ubiquitous connection of multiple IoT devices to each other and its current applications are mainly in consumer products. This concept is illustrated in Figure 4.

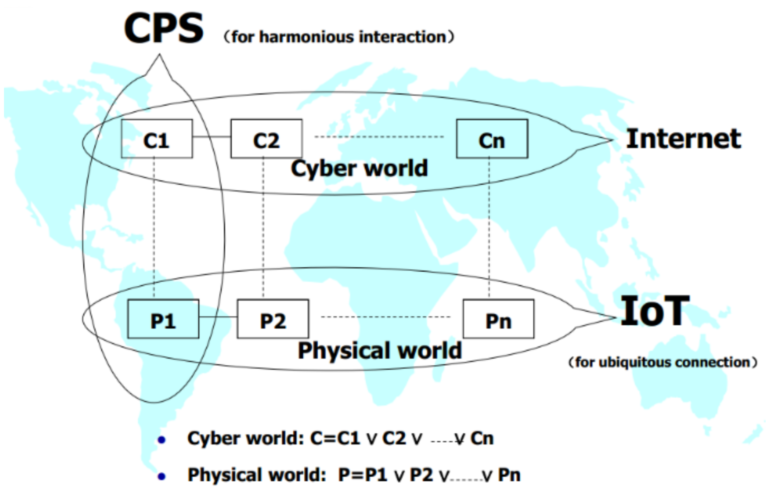

Figure 4: Relation of IoT and CPS[15]

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[12] IBM, n.d., Accessed 05 Dec. 2014

[13] Gartner (2013), Accessed 05 Dec. 2014

[14] Speckund (2014), Accessed 24 Nov. 2014

[15] Chen (2010), p. 10, Accessed 05 Dec. 2014

Another important role in the creation of the smart factory is Internet of Services (IoS). IoS is envisioned as a service on the internet that supplies everything that is needed to use software applications. For example, a device could connect to the service provider via the internet, make the request for the service, the provider would perform the computation, and then send the results to the device. The device would not need the computation software installed nor would it need the computational capabilities. It would only need to be able to transmit the request and receive the response from the service. This intelligence combined with IoT could be utilized to create smart mobility, smart grid, and smart logistics.
Industry 4.0 is a concept that does not just stop with the creation of the smart factory, but rather it expands in scope to include the following four main characteristics:

- Vertical networking of smart production system
- Horizontal integration via a new generation of global value chain networks
- Through-engineering across the entire value chain
- Acceleration through exponential technologies.

The characteristic of vertical networking of the smart production system refers to the use of CPS within the production processes to enable autonomous organization of production. CPS will be integrated not only into production equipment, but also into the products themselves to create “smart products”. These smart products will autonomously organize the functions they need production equipment to provide for their manufacturing. They will be able to react very quickly to changes in demand, stock levels, and faults. The production equipment and smart products will take over the control of their logistics, maintenance, and life cycle management. Resource efficiency is emphasized in the configuration of the smart systems to promote the efficient use of materials, energy, and human resources. All of this combined will lead to a needs-oriented, customer-specific, flexible, and efficient production.[16]

The second characteristic is horizontal integration by means of a new generation of global value chain networks. These new value networks can be optimized in real-time to enable integrated transparency. Since they are deeply integrated, they offer a high level of flexibility to be able to respond to the needs of the network while at the same time allowing for improved global optimization. This is done in a similar way as the smart production by integrating CPS into the system. Inbound logistics, warehousing, production, marketing, sales, and services will all be linked together to create a high level of integration across the entire value chain. This horizontal integration of the customers and business partners creates

[16] Deloitte AG (2014), pp. 1-6, Accessed 23 Jan. 2015

a new business model and will require a new model for cooperation as well as a legal framework for liability and protection of intellectual property.[17]

The third characteristic is the through-engineering and cross-disciplinary approach across the entire value chain and life cycle products. Engineering is seamless integrated for the design, development, and manufacture of new products and services as well as the related production systems for those products. The data will be automatically available in real-time at all stages of a product's life cycle thus creating new and flexible processes to be created during modelling, prototyping, and production. The speed and efficiency of the entire system will be greatly improved.[18]

The last characteristic of Industry 4.0 is the acceleration through exponential technologies. According to Moore's Law, the capacity of microchips, bandwidth, and computational devices all experience exponential growth. It has been shown that these items double in capacity every 18 months.[19] Likewise, Moore's Law also applies to technological advancement and the rapid advancement of previously invented technologies. This can be illustrated by 3D printing, sensor technology, artificial intelligence, robotics, drones, and nano-technology. All of these were invented decades ago, but were limited by the technology of the times. The recent boost in computing power, reduction of cost, and miniaturization of electronics now make all of these technologies suitable for use in production. It is anticipated that many of these technologies will change from their current linear growth to exponential growth.[20]

[17] Deloitte AG (2014), pp. 1-7, Accessed 23 Jan. 2015

[18] Deloitte AG (2014), p. 8, Accessed 23 Jan. 2015

[19] Strickland, Jonathan (2006), pp. 1-2, Accessed 24 Jan. 2015

[20] Deloitte AG (2014), pp. 1-8, Accessed 23 Jan. 2015

The four characteristics of Industry 4.0 build upon each other and are inter-connected. The vertically integrated smart factory will provide a basis for the horizontal value networks while benefitting from the exponential technologies. The horizontal integration of value network will feed the through-engineering which in turn will add to the acceleration of the exponential technologies. This can be visualized in the following figure:

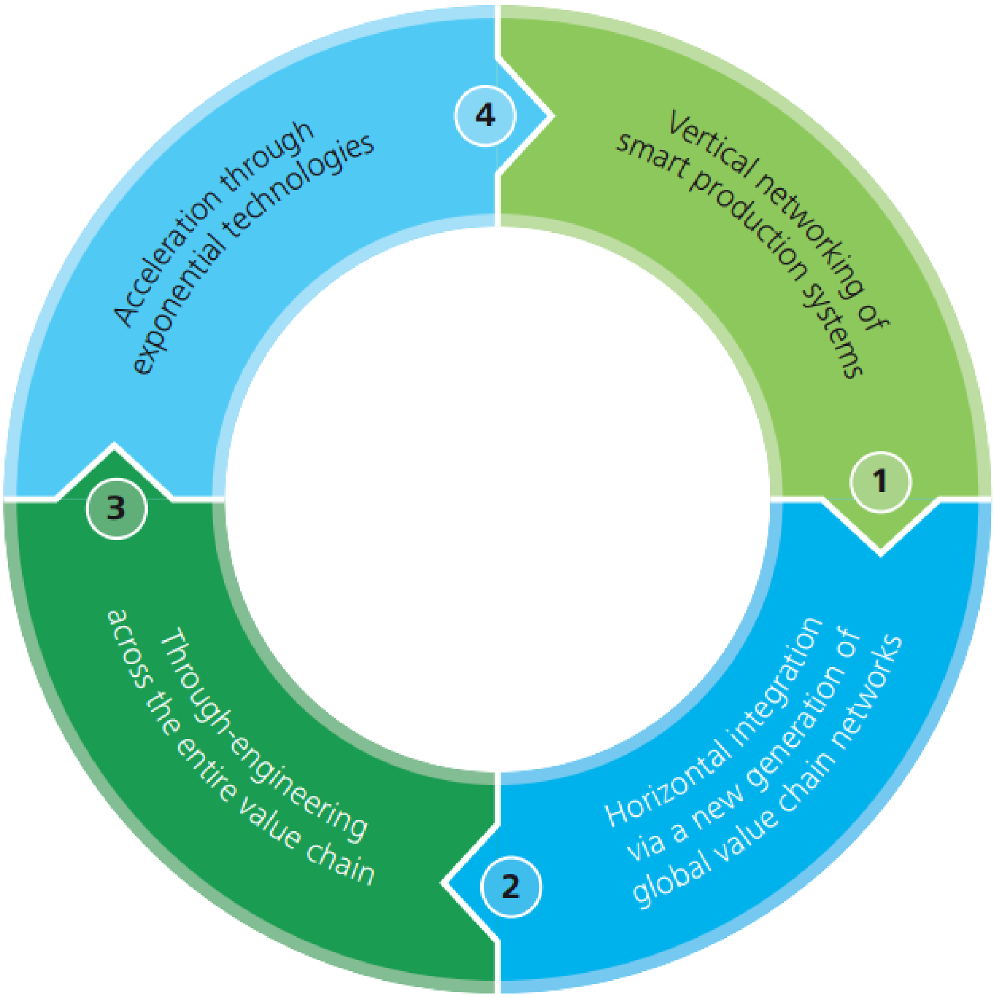

Figure 5: Characteristics of Industry 4.0[21]

2.2 Industry 4.0- Why use it as a Strategy?

As previously discussed, Industry 4.0 is used as a basis for the high tech strategy of multiple governments with German leading the way. Manufacturing is just one part of the country's

[21] Deloitte AG (2014), p. 6, Accessed 23 Jan. 2015

economy, so what led Germany to pursue this strategy? A closer look at the issue will help explain why Germany is focusing on Industry 4.0 to sustain its manufacturing economy.

Historically Germany has been a leader in manufacturing. The "Made in Germany" tag has been a source of national pride as it carries a world-wide reputation of the highest quality and most robust products. At the turn of the century, the landscape of the manufacturing world changed dramatically. In order to cut costs, many companies outsourced manufacturing to low cost countries such as China. From 2001-2010, China created 3,1 while Germany lost 1,8 manufacturing jobs per 100 persons. Further, from 2005-2010, China gained 11,9% while Germany lost 0,5% of Manufacturing GDP 5-year CAGR (Compound Annual Growth Rate).[22]

While the trend of the loss of manufacturing from Germany is certainly a major concern, there are positive aspects as well. The Innovation Index Score (out of 100) for 2010 is much higher for Germany than China, 56,2 vs 45,4 respectively. Germany also far exceeds China in the number of researchers per million of population, 5305 vs 1071 respectively. This shows that Germany already has a foundation of innovation and research that could be utilized to bridge the gap in manufacturing. For further information and comparison between top manufacturing nations, see Figure 31 of Appendix E.[23]

The retirement of the Baby Boom Generation and an aging population is another major area of concern for Germany. The baby boom in Germany reached its peak in 1964 with over 1.3 million births and has been declining since then.[24] Since the peak of the boom was in 1964, the number of births has steadily declined to the point where the overall population has been decreasing for the past two decades. In addition to this decline of population, the Baby Boom Generation is entering into retirement age. This means the number of people of working age (20-65) will decrease from 50 million in 2009 to 43 million in 2030. This is just the beginning as the population will continue to age and the number of people of working age will decrease to 33 million by 2060.[25]

Another issue facing manufacturing in Germany is the fact that high-tech manufacturing requires a higher level of skill versus traditional manufacturing. This is a problem because the children of the Baby Boom Generation achieved a lower average level of education than

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[22] Deloitte (2012), pp. 1-6, Accessed 23 Jan. 2015

[23] Deloitte (2012), pp. 1-6, Accessed 23 Jan. 2015

[24] Destatis (2009), n.d., Accessed 29 Dec. 2014

[25] Destatis (2009), n.d., Accessed 29 Dec. 2014

their parents. Their skill level must be improved in order to meet the demands of high-tech manufacturing. However, this trend was short lived as the enrollment in higher education in 2012 reached record levels surpassing 2,5 million.[26] This is a promising statistic for Germany because its youth is on track to achieve an average level of higher education greater than ever before and this will help compensate for overall reduction in population and retirement of the Baby Boom Generation.

One last area of concern to the manufacturing economy of Germany is the legal and regulatory issues. Germany has a higher average corporate tax rate of 33,0 when compared to China at 25,0 (Figure 31 of Appendix E)[27]. Another disadvantage that Germany faces is related to its legal process for patents and determination of infringement. China has different structure for patents and their court process differs from those in Germany making it difficult to provide sufficient evidence to prove patent infringement. Additionally, the fines for infringement are much lower in China than in Germany.[28] This results in a disadvantage for Germany as it is not on even footing with competing nations.

2.3 Industry 4.0- the Strategy

In 2011, the German government adopted Industry 4.0 as the platform for their Horizon 2020 Strategy. The strategy was formed to provide a means to compete with low cost nations by focusing on high tech manufacturing. Key aspects include the creation of smart factories that are autonomous, flexible, and self-organizing with the outlook set to the year 2020. Whereas Industry 4.0 is the high tech strategy for Germany, the United States has created a similar strategy called Advanced Manufacturing Partnership (AMP) which will be discussed in more detail in later chapters. The primary goal of Industry 4.0 is to be the world leader of Cyber-Physical Production Systems by the year 2020.[29]

Platform Industry 4.0 is the central hub around which several projects are clustered. Figure 6 shows Platform Industry 4.0 and the surrounding cluster of working groups. In order to get a better understanding of how these working groups all fit together, six groups will be

[26] Destatis (2014), Accessed 18 Dec. 2014

[27] Deloitte (2012), pp. 1-6, Accessed 29 Dec. 2014

[28] Goddar (2011), pp. 147-148

[29] VDI Nachrichten (2011), Accessed 29 Dec. 2014

presented: Platform Industry 4.0, it's OWL, AUTONOMIK, SmartFactory KL, Fraunhofer, and Virtual Fort Knox.

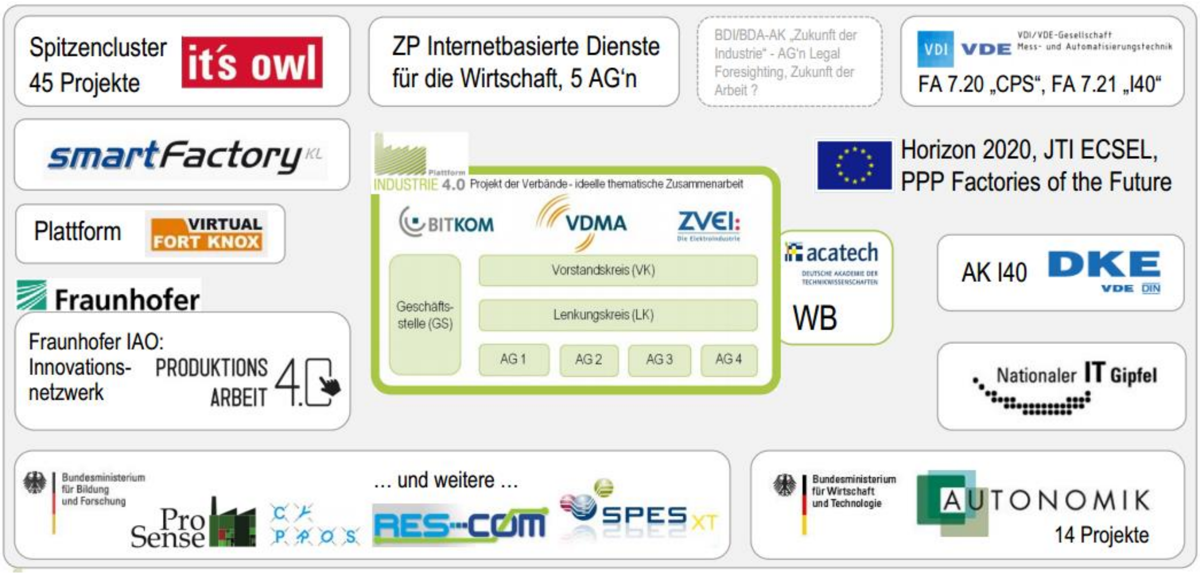

Figure 6: Platform Industry 4.0 and Cluster of Projects[30]

2.3.1 Platform Industry 4.0

Platform Industry 4.0 follows the "future Project Industry 4.0" as the German federal government's action plan for High-Tech Strategy 2020. The main goal is for Germany to be the lead provider for cyber-physical production systems. To accomplish this, the "Working Group Industry 4.0" was created in 2012 by the German Academy of Science and Engineering (Acatech). In 2013, Acatech released their final report with a roadmap for implementation of Platform Industry 4.0 with clear definition of goals, identification of specific results to be achieved, and a timetable for completion.

Platform Industry 4.0 is broken down into three categories: Man, Technology, and Organization. "Man" is the first category which includes four theses and focuses on the need for increased skill level and education, the aging population base, and the human interaction with CPS. "Technology" is the second category and includes nine thesis and focuses on the design of the systems and components, modeling, simulation, self-organization, resource effectiveness & efficiency, and installing a safety culture. "Organization" is the final

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[30] Glatz (2014), Accessed 25 Jan. 2015

category and focuses on value networks, new structures, legal frameworks, and exchange of regional value. [31] A summary of these three categories and 17 theses can be found in Table 1. In collaboration with industry, the following priority research themes were identified for further development from the 17 thesis of Platform Industry 4.0:

1. New business models
2. Framework value networks
3. Automation of value networks
4. Integrating real and virtual worlds
5. Systems engineering
6. Sensor data analysis and derivation of a data-based process control
7. Intelligence, flexibility and changeability
8. A multimodal assistance systems
9. Technology acceptance and work design
10. Radio communication scenarios for Industry 4.0
11. Security & safety
12. Industry 4.0 platform with reference architectures and distributed services.[32]

[31] Plattform I4.0 (2014), pp. 4-6, Accessed 24 Nov. 2014

[32] Plattform I4.0 (2014), pp. 5-6, Accessed 24 Nov. 2014

	#	Theses
Man	1	Various possibilities for a human-oriented design of work organization will emerge, even in the sense of self-organization and autonomy. In particular, opportunities for aging and age-appropriate work design opens up.
	2	Industry 4.0 as socio-technical system which offers the opportunity to expand the range of tasks of the employees to increase their skills and improve their access to knowledge learning resources.
	3	Learning conducive working medium (Learn instruments) and communicable forms of work (Community of Practice), increase the teaching and learning productivity, and create new curricula with an increasingly high proportion of IT competences.
	4	Learning tools - use suitable, conducive to learning artifacts - give the user functionality automatically.
Technology	5	Industry 4.0 systems are easy for the user to understand, intuitive to use, and they are conducive to learning and respond reliably.
	6	Generally accessible solution patterns that allow many stakeholders to design Industry 4.0 systems, implement, and operate (Industry 4.0 by Design).
	7	The networking and customization of products and business processes generates complexity, for example, managed through modeling, simulation, and self-organization. A larger solution space can be analyzed faster and solutions can be found quickly.
	8	The resource effectiveness and efficiency can be continuously planned, implemented, monitored, and optimized independently.
	9	Smart products provide active information and are accessible and identifiable through all life cycle phases.
	10	System components are addressable and identifiable within the means of production. They support the virtual planning of production systems and processes.
	11	New system components have the ability to replace existing systems and are compatibly to take over their functions.
	12	System components offer their functionalities as services to access the others.
	13	A new safety culture leads to trustworthy, resilient, and socially accepted Industry 4.0 systems.
Organization	14	New and established value networks with added value integrated product, production and services, and enable dynamic variation of the division of labor.
	15	Cooperation and competition leads to economically and legally new structures.
	16	System structures and business processes mapped on the valid legal framework; new legal solutions enable new contract models.
	17	Create opportunities for exchange of regional value - even in developing markets.

Table 1- The 17 Theses of Industry 4.0[33]

[33] Plattform I4.0 (2014), p. 4, Accessed 24 Nov. 2014

Further, the Platform Industry 4.0 Working Group created a timetable for the projected completion dates for each of the 12 priority research fields (Table 2).[34] These priority research themes will be described in further detail in a following section based on their relevance to this thesis.

	2015	2018	2025	2035
Horizontal Integration Across Value Networks	Methods for new business models			
	Methods Framework for Value Networks			
	Automation of Value-added Networks			
Continuity of Engineering throughout the Entire Life Cycle	Integration of Real and Virtual Worlds			
	Systems Engineering			
Vertical Integration and Cross-Linked Production Systems	Sensor data analysis and derivation of a data-based process control			
	Intelligence - Flexibility - Changeability			
New Social Work Infrastructure	Multimodal Assistance Systems			
	Technology Acceptance and Work Design			
Continuous Development of Cross-cutting Technologies	Wireless Communication Scenarios for Industry 4.0			
	Security & Safety			
	Industry 4.0 Platform with Reference Architectures and Distributed Services-oriented Architecture			

Table 2- Timetable for 12 Priority Research Fields[35]

[34] Plattform I4.0 (2014), p. 6, Accessed 24 Nov. 2014

[35] Plattform I4.0 (2014), p. 6, Accessed 24 Nov. 2014

Platform Industry 4.0 is officially supported by three industry associations: BITKOM, VDMA, and ZVEI. They are responsible for coordinating the activities of the Platform Industry and reporting on the progress of the cooperation. They also serve as a central link to business, politics, and media. They also provide support to the Working Groups (AG), the Steering Committee (LK), and Executive Circle (VK) while enabling communication to the Specialist Community. [36] The organization, bodies, and relationships are illustrated in Figure 7.

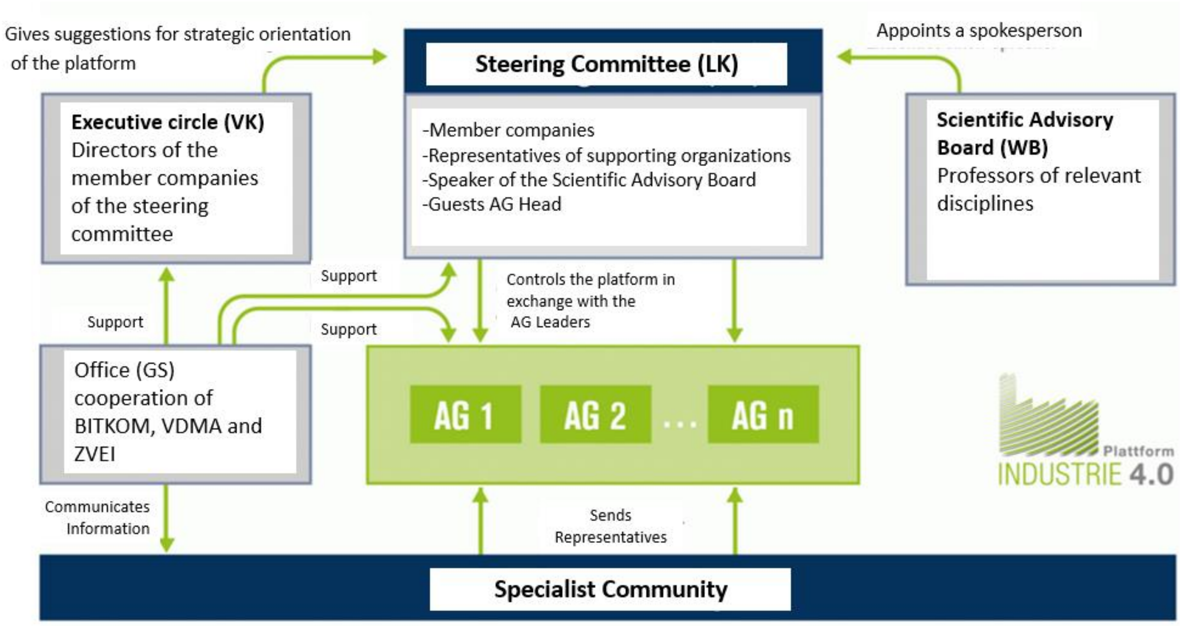

Figure 7: Platform Industry Organization[37]

The first of the three industry associations supporting Platform Industry 4.0 is BITKOM. It is a Federal Association for information technology, telecommunications, and new media. They represent more than 2.200 small and medium sized businesses that employ over 700.000 people with a domestic turnover of €140 billion a year and export high-tech goods and services for an additional €50 billion. This equates to more than 90% of the German ICT (Information and Communications Technology) market.[38]

The second of the three industry associations supporting Platform Industry 4.0 is VDMA. It is a German Engineering Association that represents over 3100 companies with a revenue in

[36] Plattform Industry 4.0, n.d., Accessed 25 Jan. 2015

[37] Plattform Industry 4.0, n.d., Accessed 25 Jan. 2015

[38] BITKOM, n.d., Accessed 23 Jan. 2015

2014 of €212 billion. The members of VDMA come from the field of mechanical engineering related the associated tools and components of process, manufacturing, drive-train and automation engineering, office and information technology, software, and product services.[39]

The third and industry associations coordinating the Platform Industry 4.0 cluster is ZVEI. It is a group that represents the common interests of the electrical industry. They represent 1600 companies which employ 90% of the employees and staff in the electrical industry in Germany and have a revenue in 2012 of €178 billion. Their vision is to shape the framework conditions and common platforms for the growth of the industry.[40]

These three groups working together provide a foundation of ICT (BITKOM), mechanical engineering industry (VDMA), electrical industry (ZVEI). This creates a logical control of Platform Industry 4.0 because not only are all three groups essential to the creation of effective CPS, but they also are the key stake holders in the success of Platform Industry 4.0. Additionally, these groups have the collective competencies and experience to address all 17 themes of Platform Industry 4.0.

2.3.2 It’s OWL

One of the major groups working on Industry 4.0 is a technology network called “it’s OWL” which means Intelligent Technical Systems OstWestfalenLippe. It is an alliance of 174 businesses, universities, and other partners working on 46 research projects with the goal to develop intelligent technical systems.[41]

They have three types of projects: cross-sectional projects, innovation projects, and sustainability initiatives. Cross-sectional projects involve the development of new technologies and methods for intelligent systems from which companies can develop a marketable products. There are five of these types of projects and an example is “Human-machine interaction” where intelligent machines are designed to understand people. A link all of the projects of this type can be found below:

http://www.its-owl.com/projects/cross-sectional-projects/

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[39] VDMA, n.d., Accessed 24 Jan. 2015

[40] ZVEI, n.d., Accessed 25 Jan. 2015

[41] it's OWL, n.d., Accessed 25 Jan. 2015

It's OWL also is working on 33 innovation projects where businesses and research institutes work together to create new products, technologies, and applications. Integral to the process is the utilization of the new technologies and methods developed in the cross-sectional projects. The projects range from the creation of intelligent kneading process for dough to the systems for securing and efficiently handling banknotes. A link to all 33 of the projects of this type can be found below:

http://www.its-owl.com/projects/innovation-projects/

The final type of project is related to sustainability initiatives to ensure projects do not lose momentum once funding has expired. This includes eight projects that also vary in theme. An example of a project of this type is one titled, "Startup Companies" which has a goal to convert promising startup ideas into concrete companies. A link all eight of the sustainability initiatives can be found below:

http://www.its-owl.com/projects/sustainability-initiatives/

2.3.3 AUTONOMIK

AUTONOMIK is a collection of twelve projects funded by the German Federal Ministry of Economics and Energy (BMWI) that are focused on the autonomous, simulation-based systems for small and medium sized enterprises. The major aim is to advance the development and testing of autonomous systems as components of IoT in practical applications.[42] The projects range in theme from autonomous logistics and transport solutions to a RFID-based automotive network to optimize the management of motor-vehicle industry. A link all eight projects can be found below:

http://www.autonomik.de/en/200.php

[42] AUTONOMIK, n.d., Accessed 25 Jan. 2015

2.3.4 SmartFactory KL

The SmartFactory KL was founded as a non-profit association in 2005 to create a network of industrial and research partners to initiate R&D projects ranging from base technologies to the development of marketable products. The main theme is integrate sophisticated information technologies into factory automation. To achieve this, innovative technologies are tested and developed in a realistic manufacturing environment. Projects are developed until the reach industrial feasibility as determined by the interested parties. [43]

The central research and demonstration platform is a hybrid demonstration plant which can produce a product (soap bottle) in a batch size as small as one to exact and customizable customer specifications. The system uses components from different vendors which are flexibly networked and interfaced which requires many levels of both wired and wireless communication. The system is designed to be modular to give a high degree of flexibility to reconfigure process steps or integrate new modules into the system. The plant functions as a demonstration center where individual smart technologies can be tested and experienced inside a functioning system. A link to project is listed below:

http://smartfactory.dfki.uni-kl.de/en/content/demo/technological-demo/plant

2.3.5 Fraunhofer

The Fraunhofer Institute for Industrial Engineering (Fraunhofer IAO) is a research institute that works in close cooperation with the University of Stuttgart and focuses on the topic of technology management. Combined they have a staff of approximately 500 people and 14.000 m^2 of offices, laboratories, and technical installations.

They operate an innovation network that includes multiple Industry 4.0 related topics, and at the heart of this innovation network is an initiative titled “Produktions Arbeit 4.0.” This project is concerned with the future of production work and determination of the role that people will play. The focus is on the development and evaluation of Industry 4.0 applications of relevant technologies and products with research themes in the following categories:

- Applications of mobile devices

[43] SmartFactory KL, n.d., Accessed 25 Jan. 2015

- Intelligent objects
- Flexible capacity use
- User acceptance
- Guidance and rules.[44]

A link to this project can be found below:

https://partner.iao.fraunhofer.de/channel_details.php?&openchannelid=17

2.3.6 Platform Virtual Fort Knox

Platform Virtual Fort Knox is a federative cloud IT (Information Technology) platform which provides the manufacturing industry with production-related IT services. It was initiated by the Fraunhofer Institute for Manufacturing Engineering and Automation IPA and Hewlett-Packard GmbH and was launched to market in October 2013. The aim is to provide flexible and customized IT solutions in an affordable and low-risk way by utilizing highly-automated integration features. Utilizing this platform, the manufacturing industry can rapidly change its IT infrastructure according to the conditions in the global market.

One of the top priorities of the platform is to provide "security by design" meaning it is a built in during the design phase and not added afterwards. This deep integration of security ensures that data is comprehensively protected during all transfer, processing, and storage steps.[45] A link to this project can be found below:

https://www.virtualfortknox.de/nc/en/marketplace/apps.html

2.4 Industry 4.0: A revolution or media hype?

Many comparisons have been made between Industry 4.0 and Computer Integrated Manufacturing (CIM). Conceptually conceived in the 1980's, CIM was predicted to be a revolution of sorts, but has fallen far short of that prediction. CIM is the total control of the production system from a central master computer that essentially removes people from the factory. In doing this, there is a major problem to overcome: what happens when something

[44] Produktionsarbeit 4.0, n.d., Accessed 22 Jan. 2015

[45] Virtual Fort Knox, n.d., Accessed 27 Jan. 2015

occurs that the system designers did not anticipate? Industry 4.0 addresses this issue by utilizing decentralized autonomous systems that communicate with each other with the people not being removed, but rather taking a central role of the value creation process. The focus is on communication and not integration[46].

While Industry 4.0 has made provisions to resolve some of the major problems of CIM, it does not guarantee success. Industry 4.0 is still only a strategy and only time will tell whether or not it is successful. However, there is one key indicator that helps predict success: investment. There is no doubt that financial resources are being allocated to the concept. The United States has committed a total almost 2 billion[47] which is to be matched by industry partners for its high tech strategy and likewise Germany is investing as much as 200 million[48] per year also matched by industry. Huge investments are being made into the field by governments and industry leaders. Due to this, it is more likely to reach a certain level of success in some areas and to have lag or otherwise be unsuccessful in others. The ratio of the two will determine the overall level of success. While only time will tell and nothing is guaranteed, there is certainly reason to be optimistic that Industry 4.0 will be a success.

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[46] Fecht (2013), Accessed 29 Dec. 2014

[47] Whitehouse.gov (2014), Accessed 24 Jan. 2015

[48] Kagermann, Henning, Wahlster, & Helbig (2014), Accessed 25 Nov. 2014

3 Advanced Manufacturing Partnership

Much like Germany, at the turn of the century the U.S. based companies outsourced heavily. The number of manufacturing jobs created per 100 persons from 2001-2010 was a loss of 3,1 for the U.S. While the labor rate for the U.S. is lower than Germany ($35,4/ hour and $46,4/ hour respectively), it is not competitive with China ($2,8/ hour). Also, GDP from manufacturing for the period of 2005-2010 increased only 0,5% for the U.S. while at the same time it increased 11,9% for China. These three indicators clearly show that manufacturing was in fact lost from U.S. to low-cost countries like China and others.[49]

3.1 Background- 2001-2010

It is difficult for the U.S. to retrieve the lost manufacturing due to the much higher labor rate and higher corporate tax rate for the U.S. (39,1%) compared to China (25,0%). This can be seen in the global competitiveness index released by Deloitte in 2013. They estimated that U.S. to be #3 in global competitiveness (China #1 and Germany #2), but in five years the U.S. will fall to #5 due to being passed by both India and Brazil.[50]

Another area of concern related to manufacturing for the U.S. is the ever increasing trade deficit. While the U.S. maintained a negative balance for decades for all manufactured products, they have been able to maintain a positive balance for high-tech products. However after the turn of the century, this too turned negative and has been trending steadily downward since (Figure 8). In fact, in 2010 the deficit reached record levels of 81 billion for high tech products.[51] This is a major concern for the U.S. because the development and manufacturing of high-tech products is an important indicator to greater economic prosperity for a nation and its citizens.[52] Consequently, the loss of this capability has a negative effect on the economic prosperity.

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[49] Deloitte (2012), p. 5, Accessed 02 Dec. 2014

[50] Deloitte (2012), p. 2, Accessed 02 Dec. 2014

[51] PCAST (2011), pp. 3-5, Accessed 24 Nov. 2014

[52] Deloitte (2012), p. 5, Accessed 02 Dec. 2014

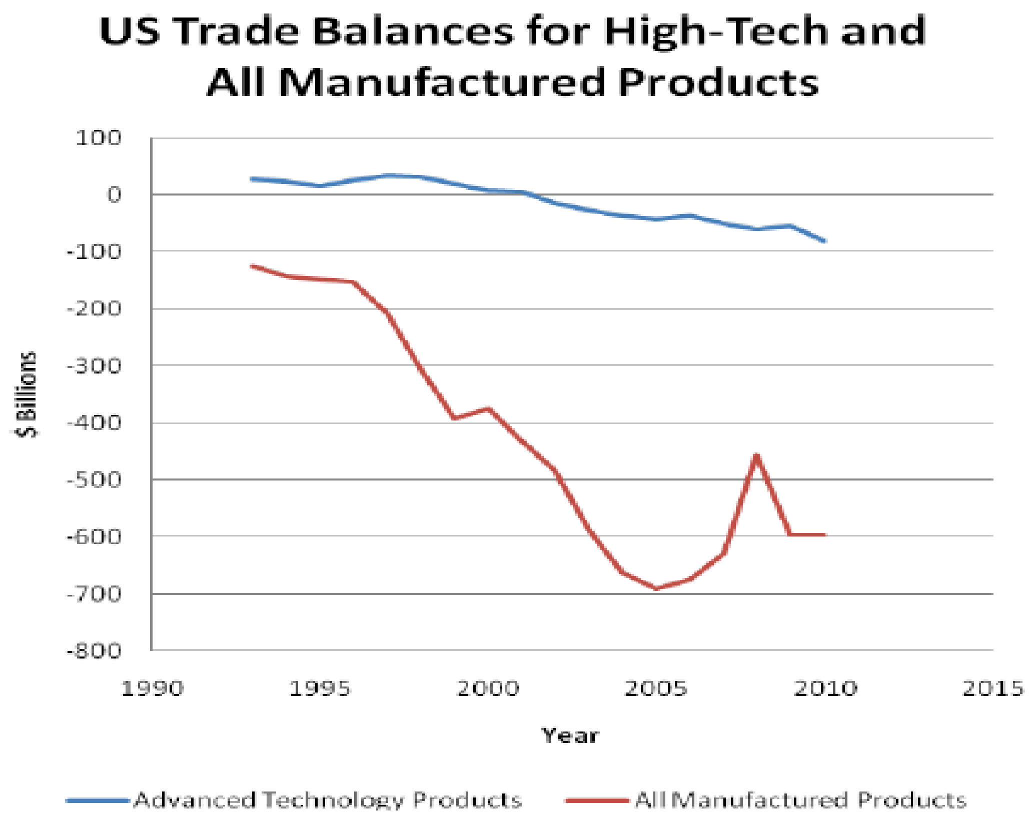

Figure 8: US Trade Balances for High-Tech and All Manufactured Products[53]

However, as bleak as the manufacturing data is for the U.S., there are other indicators that show promise for the U.S. Much like Germany, the U.S. outscored China in the innovation index (U.S.: 57,7, DK: 56,2, China: 45,4). Another positive factor is that the labor productivity is far higher for the U.S. and Germany versus China (68,2, 43,3, and 14,2 respectively).[54] Labor productivity is defined as:

Labor productivity = volume measure of output / measure of input use.[55]

For example, the volume of measure of output is the total number of products produced while the measure of input is the total number of labor hours needed to produce the product. A simple comparison of labor productivity between the U.S. and China yields:

$$68{,}2 / 14{,}2 = 4{,}8.$$

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[53] PCAST (2011), p. 4, Accessed 24 Nov. 2014

[54] Deloitte (2012), p. 4, Accessed 02 Dec. 2014

[55] OECD (2008), p. 5, Accessed 23 Dec. 2014

This means that for an equal amount of products produced, China requires 4,8 times the amount of labor hours to produce them versus the U.S. Whereas this seems like an overwhelming advantage for the U.S., it does not necessarily compensate for the large difference in labor rates between the two countries. If the U.S. uses 1 hour of labor to produce 1 product, then the cost of that product is $35,4 ($35,4 x 1 hour), while China uses 4,8 hours to produce the same product at a cost of $13,44 ($2,8/hour x 4,8 hours). If the labor makes up a high percentage of the total cost to produce the product, then China has the advantage to produce. However, if labor makes up a low percentage of the total cost to produce, then it could be that the U.S. has the advantage. This illustrates that while low-cost countries like China still have the advantage in labor rate, the U.S. can make up some of the difference by further increasing labor productivity.

The U.S. Baby Boom Generation began a decade before Germany and is well into retirement age. While the U.S. still faces a demographic issue, it is far less of a factor than other nations. Figure 9 illustrates this point.[56] In 2050, 20,9% of the U.S. population will be age 65 and over compared to 30,1% for Germany and 26,8% for China. In contrast to Germany which is declining, the population of the U.S. is increasing and projected to expand from 320 million in 2012 to 420 million in 2060.[57] This will help ease the economic effect of the retirement of the Baby Boom Generation.

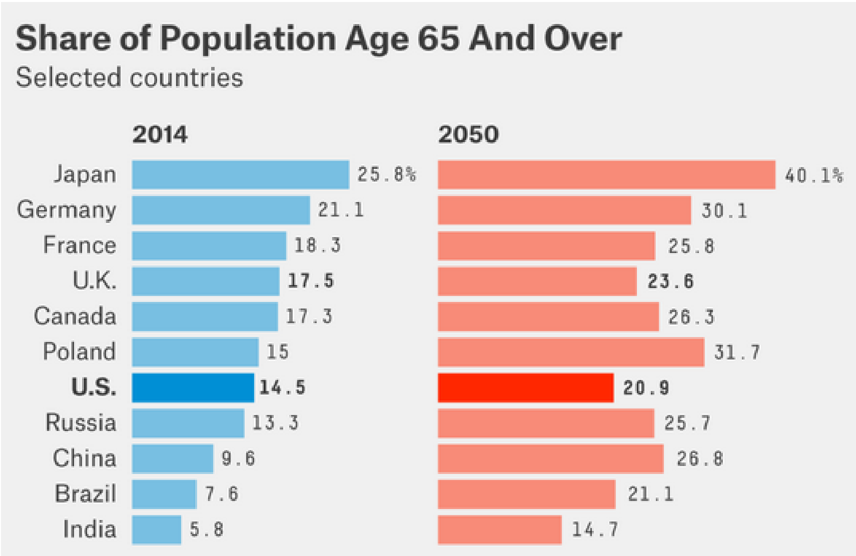

Figure 9: Share of Population Age 65 And Over[58]

[56] Cassleman (2014), Accessed 07 Jan. 2015

[57] Ortman & Colby (2014), p. 1, Accessed 05 Jan. 2015

[58] Cassleman (2014), Accessed 07 Jan. 2015

3.2 AMP- Current State

In June 2011, the President's Council of Advisors on Science and Technology (PCAST) submitted to the President of the U.S. a report titled: "Report to the President on Ensuring American Leadership in Advanced Manufacturing." In this report, the AMP Steering Committed described the importance of advanced manufacturing by stating:

> "A strong advanced manufacturing sector is essential to national security."[59]

They described the business climate in the U.S. as tenuous and stated that companies are reluctant to risk investments in new technologies due to the possibility of market failures and negative connotations that result. Other competitive nations use government incentives to help mitigate the risk. They further stated that the U.S. fell behind in the overall business climate and skilled workforce required for advanced manufacturing.

At the heart of the report, they submitted three main recommendations:

1. Create Advanced Manufacturing Initiative
2. Improve tax policy
3. Support research, education, and workforce training.

Later that same month, President Obama officially launched the Advanced Manufacturing Partnership and created the AMP Steering Committee. In 2012, the AMP Steering Committee built upon the initial report and released "Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing." In this report, they call for a collaboration between the Federal Government, academia, and industry to create a process that efficiently identifies and commercializes the technologies that will fuel the future success of manufacturing. To accomplish this task, they detailed 16 recommendations that fall into three key pillars (Table 3):

1. Enabling Innovation
2. Securing the talent pipeline
3. Improving the business climate.[60]

[59] PCAST (2011), p. iii, Accessed 25 Nov. 2014

[60] PCAST (2012), pp. ix-x, Accessed 25 Nov. 2014

	#	Recommendations
Enabling Innovation	1	Establish a National Advanced Manufacturing Strategy.
	2	Increase R&D Funding in Top Cross-Cutting Technologies
	3	Establish a National Network of Manufacturing Innovation Institutes (MIIs)
	4	Empower Enhanced Industry/ University Collaboration in Advanced Manufacturing Research.
	5	Foster a More Robust Environment for Commercialization of Advanced Manufacturing Technologies.
	6	Establish a National Advanced Manufacturing Portal.
Securing the Talent Pipeline	7	Correct Public Misconceptions About Manufacturing.
	8	Tap the Talent Pool of Returning Veterans.
	9	Invest in Community College Level Education.
	10	The resource effectiveness and efficiency can continuously planned, implemented, monitored and optimized independently.
	11	Enhance Advanced Manufacturing University Programs.
	12	Launch National Manufacturing Fellowships & Internships.
Improve the Business	13	Enact Tax Reform.
	14	Streamline Regulatory Policy.
	15	Improve Trade Policy.
	16	Update Energy Policy.

Table 3- The 16 Recommendations of AMP-2012[61]

It was noted that the U.S., unlike other leading industrialized countries, did not have a national agency to specifically promote technological innovation in its domestic industries. The U.S. has relied on its strengths of flexibility, ingenuity, vast research universities, and private labs to drive innovation. The AMP Steering Committee stated that this was no longer enough to stay competitive in today's manufacturing environment, and they addressed these as well as other related concerns with the pillar of 'enabling innovation'.

The pillar of enabling innovation focus on the development of a strategy for advanced manufacturing by focusing efforts on the technologies that are key to the competiveness of

[61] PCAST (2012), p. x, Accessed 25 Nov. 2014

U.S. manufacturing. As a first step, the following technologies were identified by the AMP steering committee:

- Advancing Sensing, Measurement, and Process Control
- Advanced Materials Design, Synthesis, and Processing
- Visualization, Informatics, and Digital Manufacturing Technologies
- Sustainable Manufacturing
- Nano-manufacturing
- Flexible Electronics Manufacturing
- Bio-manufacturing and Bioinformatics
- Additive Manufacturing
- Advanced Manufacturing and Testing Equipment
- Industrial Robotics
- Advanced Forming and Joining Technologies[62]

In order to address these key technologies, a National Network for Manufacturing Innovation Institutes (MII) was created. The MIIs serve as a regional innovation hub to develop a defined technology. As of the end of 2014, $2 billion (USD) has been allocated to this and the following five MIIs have been created with three competitions being announced in 2014 (Table 4). The short-term goal it to reach 15 MIIs while long term goal is 45. Two of the MIIs are located at universities (NC State and University of Tennessee), thus establishing an enhanced collaboration between industry and universities.

[62] PCAST (2012), pp. 18-20, Accessed 25 Nov. 2014

Manufacturing Innovation Institutes (MII)	Date of Launch	Location	Government Investment Amount
America Makes (National Additive Manufacturing Innovation	August 2012	Youngstown, Ohio	$30 million
Next Generation Power Electronics Manufacturing Innovation Institute	January 2014	North Carolina State University Raleigh, North Carolina	$70 million
Digital Manufacturing and Design Innovation Institute	February 2014	Chicago, Illinois	$70 million
Lightweight and Modern Metals Manufacturing Innovation Institute	February 2014	Detroit, Michigan	$70 million
Institute for Manufacturing Innovation on Integrated Photonics	Competition announced October 2014	Unknown	$100 million
Smart Manufacturing	Competition announced December 2014	Unknown	$70 million
Flexible Hybrid Electronics	Competition announced December 2014	Unknown	$70 million
Clean Energy Manufacturing Innovation Institute for Composites Materials and Structures	January 2015	University of Tennessee Knoxville, Tennessee	Up to $70 million

Table 4- Manufacturing Innovation Institutes[63]

In order to address recommendation number six, the National Advanced Manufacturing Portal has been created and fully operational. It serves as communication hub for the AMP and MIIs. The Advanced Manufacturing Portal can be found here:

[63] National Advanced Manufacturing Portal (2015), Accessed 05 Dec. 2014

http://www.manufacturing.gov/welcome.html

By successfully creating essentially 8 MII's, a clear strategy to identify and prioritize cross-cutting technologies has been established. Additionally, the collaboration between industry and university has been started and a sizable amount of funds have been allocated. .

The second pillar of the AMPs recommendations is 'Securing the Talent Pipeline'. In order to revitalize the manufacturing capabilities of the U.S., a skilled professional workforce is needed. Unfortunately, in recent years the public misperceives manufacturing work as dull, dirty, and dangerous. According to a report from BOOZ & Company, more than 200 undergraduate students in engineering, science, and mathematics were surveyed, and only 50 percent of the engineering and 20 percent of the math and science students found manufacturing to be an attractive career.[64] This leads to the current situation where the employment opportunities for skilled operators and technicians are increasing at a rate exceeding the availability of qualified candidates as demonstrated by the fact that Siemens has nearly 3500 open jobs in the U.S. requiring Science Technology, Engineering, and Mathematics (STEM) but they have "low expectations of filling many of them."[65] According to Deloitte, in 2012, there were an estimated 600.000 unfilled job openings that require STEM skills.[66] Given this data, it is apparent why this pillar was created.

The first major step to address the talent pipeline was taken in July 2014 when the first legislative reform in 15 years was signed into law to improve the public workforce system. This new law called the Workforce Innovation and Opportunity Act (WIOA) reorganized, simplified, and modernized a federal job training program that has an annual budget of $18 billion (USD). The WIOA addresses essentially all recommendations of securing the talent pipeline pillar.

To address the poor public perception of manufacturing jobs, a National Manufacturing Day was created in 2012. More than 1650 factories opened their doors to more than 50.000 visitors on National Manufacturing Day in 2014 to show the public the good career opportunities that exist in manufacturing.[67] On a local level, there are over 30 active grass-roots campaigns to address the issue of poor perception by as exemplified by the "Dream It.

[64] PCAST (2012), p. 27, Accessed 25 Nov. 2014

[65] PCAST (2012), pp. 27-28, Accessed 25 Nov. 2014

[66] Giffi (2012), p. 2, Accessed 19 Jan. 2015

[67] Mfgday.com, n.d., Accessed 22 Jan. 2015

Do It." initiative. This initiative is championed by the National Manufacturing Institute, but it is managed and implemented at the state level. A link can be found below for a list and link to all current programs:

http://www.themanufacturinginstitute.org/Image/Dream-It-Do-It/Locations/Locations.aspx

In September 2014, it was announced that 270 community colleges would receive $450 million (USD) in grants to strengthen job-driven training partnerships with over 400 employers. This is in addition to over 1.5 billion (USD) funds that was made available since 2011.[68] To further address the issue of apprenticeship, in December 2014, an apprentice program was launched with funding of 100 million with the goal to develop public-private partnerships by implementing innovative high-quality apprentice programs.[69] Dow, Alcoa, and Siemens have launched apprenticeship programs and they created a "playbook" for other companies to use to launch their own. A link to this playbook can be found below:

http://www.themanufacturinginstitute.org/~/media/14B36E1969704C3BADF11A1BE0F21B3D.ashx

In the 2015 State of the Union Address, the U.S. President outlined a plan to make two years of community college free to everyone in the U.S. While this is only a plan at the moment and not a law, it further illustrates the government's commitment to addressing need for improving education in order to create a higher skilled workforce.

The third and final pillar is 'Improving the Business Climate' which includes four recommendations with the first one being enacting tax reform. Currently the corporate tax rate in the U.S. is higher than that of all competing nations. The goal of this recommendation is to 'level the playing field'. To achieve this, the AMP recommended reducing the tax rate for domestic manufacturing, increase the R&D tax credit, and reduce the overall corporate tax rate.

The next part of the final pillar is 'Streamline Regulatory Policy.' The AMP Steering Committee recommended a framework for smarter regulations relating to advanced manufacturing. While excessive regulation can hamper innovation and competitiveness, a well-conceived, science-based, and effectively implemented regulatory system can help protect consumers, workers, and the environment. To achieve this, a robust dialogue between

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[68] Whitehouse.gov (2014), Accessed 22 Jan. 2015

[69] Whitehouse.gov (2014), Accessed 22 Jan. 2015

agencies and businesses should occur before the implementation of new rules. Further, it was recommended that these regulations rely on cost benefit analysis and risk assessments.

The third part of this pillar is to 'Improve the Trade Policy.' Trade policies can have an adverse impact on advanced manufacturing firms in the United States. It was recommended that the U.S. strengthen cooperative, capacity-building initiatives with key trading partners. Additionally, they recommend making the Trans-Atlantic and Investment Partnership (TAIP) a priority to open up free trade between the U.S. and European Union.

These actions 'Improving the Business Climate' pillar have not been as successfully implemented as the ones for the first two pillars. With regards to the tax rate, is has proven to be a highly debated topic whether or not a reduction is the best solution. On one side, if the tax burden is lowered, then companies would be more competitive and profitable in the U.S. However, on the other side, it would remove billions of tax dollars that are budgeted to support multiple programs which includes the AMP. Some small middle ground was reached by increasing the tax deduction for local manufacturing (Domestic Production Activity Deduction) from 6% to 9% in 2012, however the international corporate tax rate was unchanged. The TAIP has stalled and approval vote has been delayed until 2015. In January 2015, the U.S. and Cuba started discussions to restore diplomatic relations, removing sanctions, and opening up trade.[70]

The last part of the pillar is to 'Update Energy Policy' has proven to be more successful. The domestic energy policies has a huge effect on the competitiveness of a manufacture as they are high consumers of energy. This can be addresses by focusing on energy efficiency and conservation, increasing and diversifying domestic energy supplies, increase the speed of development of renewable energy sources, and transition to a low carbon economy. [71] A majority of the progress in this category is due to tax incentives such as the Production Tax Credit (PTC) which reduces federal income taxes for owners of renewable energy projects based on energy produced. Another program is Investment Tax Credit (ITC) which reduces the federal income taxes for companies that invest in renewable energy.[72]

[70] Wroughton & Trotta (2015), Accessed 22 Jan. 2015

[71] PCAST (2012), pp. 40-42, Accessed 25 Nov. 2014

[72] Goodward & Gonzalez (2010), Accessed 22 Jan. 2015

3.3 AMP- The Effect on U.S. Manufacturing

The past 5 years have shown marked improvement for the manufacturing sector in the U.S. Over 700.000 manufacturing jobs have been added and manufacturing is growing at almost twice the rate of the overall economy. This is the longest period of outpacing the economy since the 1960s. In 2013 and 2014, the U.S. was ranked first in a survey of business leaders as a destination for investment. In a separate study, 54% of American manufacturers with operations overseas were considering bringing them back to the U.S. [73] According to the whitehouse.org website:

> "And AMP has been central in getting us here. AMP helped change the dialogue about manufacturing, by elevating the focus on manufacturing's central role in our economy and it's potential. It built on our substantial competitive positioning, and it understood how the knowledge and know-how that comes from making things fuels our pipeline of innovation." [74]

While the GDP for the U.S. is still far less than that of China and India, it is promising for the U.S. since it has a positive trend while China, India, and Brazil are all have a negative trend. The growth in GDP for the U.S., Germany, China, India, and Brazil can be seen in Figure 10.

[73] Pritzker & Zients (2014), Accessed 07 Jan. 2015

[74] Pritzker & Zients (2014), Accessed 07 Jan. 2015

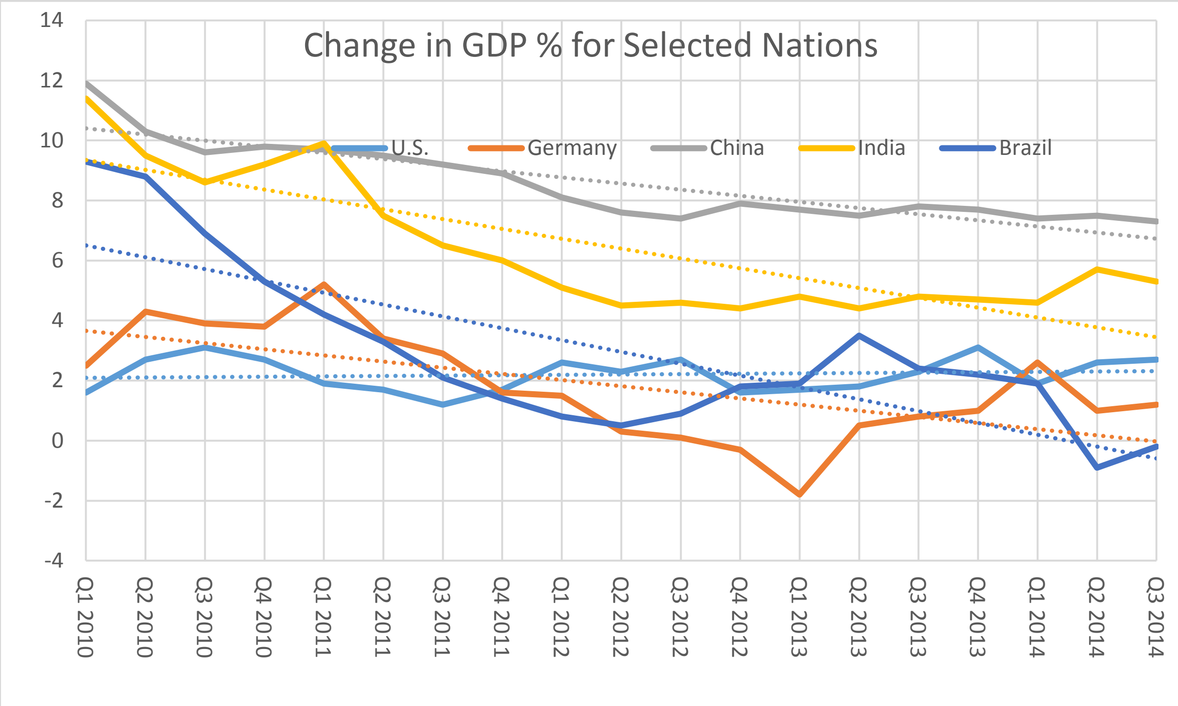

Figure 10: Change in GDP % for Selected Nations[75]

In October 2014, the AMP Steering Committee released a final report titled: "Accelerating U.S. Advanced Manufacturing" where twelve additional recommendations are presented to further support the three key pillars. For reference, these recommendations can be found at the following link:

http://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST/amp20_report_final.pdf

As of the writing of this thesis, there has been no official actions from the U.S. government on these actions. As such, they will not be further discussed in this thesis.

3.4 Comparison of AMP to I4.0

An interesting conclusion can be made when comparing I4.0 to AMP. They both are organized into three similar categories with similar goals. The first comparable categories are 'Securing the Talent Pipeline' (AMP) and 'Man' (I4.0). These both deal with the integration of humans into the manufacturing environment. The main focus for both is to educate the

[75] Trading Economics, n.d., Accessed 09 Jan. 2015

people to obtain the skills required for the high-tech manufacturing of the future. Both have programs to improve the poor image that manufacturing has in the community. I4.0 also takes into account the development of new work organizations that will come with the Smart Factory, while AMP has actions to address the returning military veterans and how to integrate them into high-tech manufacturing.

The second similar categories are Improving Business Climate (AMP) and Organization (I4.0). The common ground for both of these is the idea to put manufacturing locally on equal ground with manufacturing abroad via the trade policy. Additionally, this also involves new structures and legal framework for I4.0. AMP is concerned with the local tax structure, regulatory policy, and energy policy.

The last comparable categories are Enabling Innovation (AMP) and Technology (I4.0). This is where the two strategies differ the most. I4.0 is focused on the manufacturing process itself. It is a dual strategy to be the world leader to supply CPS and Smart Factory technology while at the same time implementing these Smart Factories within its own country. This dual strategy is intended to feed itself and foster continuous and rapid incremental improvement.

AMP is focused on the creation and development of technologies. It provides funds to build a network to assist public-private groups in the creation and development of innovative new technologies. This is evidenced by creation of the eight MIIs that address topics ranging from additive manufacturing to integrated photonics. While there is a MII focused on Smart Manufacturing, it is certainly not the focus as it was neither the first established nor the one with the highest budget.

The two strategies are very indicative of the countries from which they were created. Germany has the reputation of being detail oriented designers and engineers. This can clearly be seen in the up-front focus on the single goal of being the world leader of CPS and a very clear path and timetable being laid out to reach that goal. The U.S. has the reputation of being free-thinking and innovative problem solvers. AMP takes advantage of this by not focusing on one path to improving manufacturing, but rather several independent paths that combined make a stronger manufacturing environment.

Platform Industry 4.0 and AMP do not compete against each other, but instead they complement each other. For example, Industry 4.0 could provide the infrastructure, equipment, and roadmap to install a Smart Factory, while AMP can provide the cutting edge technology consumer product. Both can simultaneously be successful and benefit both countries.

Platform Industry 4.0 is actually more comparable to the Smart Manufacturing Leadership Coalition (SMLC) in the U.S. The SMLC is a non-profit organization with access to $500 million (USD) of U.S. government funding to help businesses overcome the barriers related to the development and installation of smart manufacturing systems. This is achieved through a collaboration of more than 146 companies, institutes, and universities that address issues of R & D, implementation, development of approaches, standards, platforms, and infrastructure to create a system called the Smart Manufacturing (SM) Platform. The SM Platform is a cloud based open architecture system whose goal is to integrate plant level data, simulations, and systems across the entire value stream. [76] A link to the SMLC can be found below.

https://smartmanufacturingcoalition.org/

4 Main Obstacles of Industry 4.0

As is the case with any new idea or concept, Industry 4.0 faces several obstacles. These are based on actual situations that have happened in the past and fears of what might happen in the future. Although there are many obstacles, three of the largest, according to Fraunhofer, are:

1. Technical: Security.
2. Social: Fear of technology replacing humans.
3. Technical: The need for openness and standards.[77]

4.1 Security

One of the major obstacles that Industry 4.0 faces is cyber-security. McAfee, a subsidiary of Intel Corporation, estimated the total worldwide cost of cybercrime was in excess of 400 billion (USD).[78] The total number of detected cybersecurity incidents increased 48% from 2013 to 2014. In fact the compound annual growth rate (CAGR) has increased 66% year over year since 2009.[79]

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[76] SMSLC, n.d., Accessed 28 Jan. 2015

[77] Lucke (2014), Accessed 22 Jan. 2015

[78] McAfee Security (2014), Accessed 24 Jan. 2015

[79] PWC, n.d., Accessed 14 Jan. 2015

2014 was a banner year for high profile cyberattacks. Sony Pictures was hacked and various sensitive data was placed on the internet essentially making it free to the public to view. This included strategic information, employees' personal information, and multiple un-released movies with the most notable being "The Interview." A vulnerability called 'Heartbleed' affected servers, 'Shellshock' affected Unix-y based systems, and even Apple was affected by a security vulnerability called 'goto fail'. In July 2014, it was found that USB devices, such as a thumb drive, have a fundamental flaw that cannot be fixed with software and makes the computer vulnerable to cyberattack when attached.[80]

Due to the high growth in the numbers of IoT devices and the valuable data they contain, McAfee Cyber Security predicts a rapid increase in the number cyberattacks in IoT devices.[81] A study performed by HP found that 70% of IoT devices are vulnerable to attack and averaged 25 vulnerabilities per device tested. HP lists the following as the main causes of the vulnerabilities:

- Insufficient authentication and authorization
- Lack of transport encryption
- Insecure web interface
- Insecure software and firmware.[82]

It is clear that this is security is major obstacle, and as such it addressed directly by the eleventh priority research field of Platform Industry 4.0 called "Safety and Security". This research field considered a prerequisite for functioning of Industry 4.0 systems. Safety is to be designed and deeply integrated into the system from the very beginning and not added after the base of the system is created. Industry 4.0 systems are to be created so they yield the following results:

- Security architectures and policies that meet the safety requirements.
- Methods and tools to analyze and identify security vulnerabilities and risks.
- Deep integration of these methods and tools into all CPS.[83]

In the interest of creating a truly secure Industry 4.0 system, multiple security techniques will be integrated into the system design. Some of the current and widely-know security techniques are sandboxing, whitelisting, and encryption. Sandboxing is the strict limitation

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[80] Paul (2014), Accessed 24 Jan. 2015

[81] McAfee Security (2014), Accessed 24 Jan. 2015

[82] HP (2014), Accessed 24 Jan. 2015

[83] Plattform I4.0 (2014), p. 17, Accessed 24 Nov. 2014

of resources that a particular program can use within a system such as access to memory and processor. Whitelisting is a list or register of entities that are allowed to use a service or access resources. Encryption is the encoding of information using a computer algorithm. In order to decrypt the encoded data, a customized key is required which is specifically assigned to the recipient of the data. With the deep integration of these and other security techniques into Industry 4.0 systems, robust and invulnerable systems can be created to mitigate security risks.[84]

4.2 Fear of Tech Replacing Humans

One of the more popular themes in science fiction is the idea that advanced machines become sentient and take over the world from humans. While this is just fiction, it still is deeply embedded in the conscience of humans. Elon Musk, CEO of SpaceX and Tesla, stated in October 2014 "with artificial intelligence we are summoning the demon."[85] He is so concerned about the issue that he donated $10 million to the Future of Life Institute (FLI), which will fund research with the goal of making artificial intelligence "beneficial to humanity."[86] Even Professor Steven Hawking is worried about the human race being "superseded" by artificial intelligence machines.[87]

The chairman of IG Metall, the largest labor union in Germany, has voiced his concern about the "dark side" of Industry 4.0. He is worried about the new ways to monitor and measure performance and that it could lead to increase in the use temporary workers or on-call workers. He warns that nobody really knows what this move to automation brings and that in the worst case it could cut every other job. He concluded by we must be sure that people shape the technology but are not controlled by it.[88]

A research study by Oxford University concluded that approximately 47% of the U.S. workforce is in the high risk category of being replaced by technology. This includes transportation and logistics, office administration, labor in production, and certain positions in the service industry. It also states that computerization will be limited to low-skill

[84] Marwan (2015), Accessed 02 Feb. 2015

[85] Huffington Post (2014), Accessed 02 Feb. 2015

[86] Alba (2015), Accessed 02 Feb. 2015

[87] ABC News (2014), Accessed 14 Jan. 2015

[88] EurActiv.de (2014), Accessed 16 Jan. 2015

positions, and the least susceptible are positions for which creativity and social skills are important.[89] However there is evidence that even 'creative' jobs will be at risk. In 2012 Narrative Science created an artificial intelligence algorithm that was capable of producing new articles that are indistinguishable from what a human can produce. The service is already being used by multiple respected publishers such as Forbes.[90]

While this is alarming, it does not mean that 47% of people will be without an occupation in the future. It simply implies that the workforce will shift into a new type of labor. This is not new for the human race as exemplified by the mass movement from farming to manufacturing in the U.S. at beginning of the 20th century. It shifted again at the end of the 20th century to the services sector.[91]

Industry 4.0 addresses this concern with the eighth priority research field of Platform Industry 4.0 called "Multimodal Assistance Systems". The main goal of this field is to build new forms of collaborative work with support by intelligent assistance systems while bringing digital learning technologies directly to the workplace. This is to be achieved by:

- Integration of virtual human models to support the simulation of machine processes
- Utilize and maintain knowledge and experience of employees to create a stable system operation
- Creating transparency of the system status to the employees
- Promoting and developing digital education techniques.[92]

4.3 Need for Openness and Standards

One of the most important themes of Industry 4.0 is the networking and integration of several different systems throughout the entire value network. These systems include Enterprise Resource Management (ERP) systems, Manufacturing Execution Systems (MES), Warehouse Management Systems (WMS) and Computerized Maintenance Management Systems (CMMS), Computer Aided Engineering (CAE), PLM (Product Lifecycle

[89] Osborne & Frey (2013), Accessed 14 Jan. 2015

[90] Levy (2012), Accessed 15 Jan. 2015

[91] Urquhart, n.d., Accessed 14 Jan. 2015

[92] Plattform I4.0 (2014), p. 14, Accessed 24 Nov. 2014

Management), and many others. These systems are supplied by multiple providers with different business models. In order for Industry 4.0 to be a success, all of the systems need to utilize a single, common approach as well as the basic structural principles, interfaces, and data as defined by a reference architecture. The reference architecture is a general model that applies to all systems and includes a complete implementation plan and description of the cooperation mechanisms and information exchange process.[93]

The issues are well-known and have been addressed directly by the twelfth priority research field of Platform Industry 4 which is concerned with reference architectures and distributed services-oriented structures. The main goal for this research field is for participating companies to develop products and solutions for Industry 4.0 applications with the following properties for reference architecture:

- Interoperability of products and solutions from different manufacturers
- Presentation of necessary standardization needs.
- Migration path to the future
- No limitation or restrictions to use only existing products.

The goal of the distributed services-oriented architecture is to provide a platform for service based connection of automation and production system with the following features:

- Flexibility through interoperability of services and applications
- Software systems that are easy to install and startup
- Integration of products in the value networks
- Secure and reliable interaction with business processes
- Support of all entities in the value network.[94]

Addressing the issues of openness and standards is actively being addressed by Platform Industry 4.0 and results can already be seen. A prime example of this is the test-bed environment created by the SmartFactory KF project. In this project, equipment from multiple suppliers is linked together using a shared reference architecture to create a fully functional and flexible production line.

[93] Acatech (2013), pp. 39-41, Accessed 24 Jan. 2015

[94] Plattform I4.0 (2014), pp. 18-19, Accessed 24 Nov. 2014

5 LeanLab

The LeanLab is an elective course at TU Graz offered by the IBL Institute. It utilizes an innovative concept of active participation of the students during the course to improve comprehension. Theoretical concepts are presented in a classroom setting in short sessions usually around 1 hour each. After each session, the students and the instructors reconvene in a classroom that is modelled after a real world manufacturing environment. The previously presented concept are re-enforced by the use of practical laboratory exercises. During the exercises, the students work in teams to assemble the product and observe the process. The processes and layout are intentionally not optimized at the beginning state and the students apply the theory concepts to create an improved future state.[95]

This teaching method is called active participation, and is also known as “learning by doing”, “experiential learning”, or “action learning”. It is based on Dale’s Cone of Experience which states that there are two types of learning: passive and active. Passive learning includes verbal receiving and visual receiving and is normal teaching method for most class room environments. Active learning includes participating and doing. The basic theory is that knowledge retention improves greatly when you integrate active learning versus only using passive learning.[96]

5.1 LeanLab Environment

The LeanLab environment includes a classroom that is modelled after a real-world manufacturing space. It is comprised of the tools, equipment, and utilities required to manufacture products (Figure 11). This includes multiple workstations, utility connections, lighting, wireless network capabilities, computer, 3D printing machine, rapid prototype milling machine, specially designed tooling, and multiple hand tools and power tools. The product of the LeanLab is the IBL Scooter (Figure 12).

[95] TU Graz Online, n.d., Accessed 15 Jan. 2015

[96] Edgar (1969)

Figure 11: LeanLab in operation (picture courtesy of TU Graz IBL Institute)

Figure 12: IBL Scooter (picture courtesy of Justin Radke)

5.2 Theories Utilized

The LeanLab course work addresses three major fields in manufacturing: industrial engineering, logistics management, and industrial energy management. It has a special focus on the following topics:

- Lean Production (Lean manufacturing)

- Process observation
- Visual management
- Factory design
- Value stream analysis
- Ergonomics and workplace organization
- Standard operating procedures
- Quality in the assembly process
- Energy efficiency and saving measures
- Supply Chain Management
- Introduction of transformation programs (Change management).

These topics will be described in further detail as required.

5.3 Current State

As part of the LeanLab course, the production process begins in an intentionally un-optimized state and in the end it is presented to the students in an optimized state. For the purposes of the thesis, the optimized state will be called the "current state" and will be used for comparison and further improvement. The LeanLab is for all intents and purposes a simulation test-bed and not necessarily a real production environment. There are no customers, suppliers, or employees. Due to this, there are no systems to handle labor tracking, error tracking, and product lifecycle management. For example, there is no system to keep track of the work hours of the operator. It could be calculated by subtracting the time at the start of working shift from the time at the end of shift and then subtracting any unpaid breaks. Likewise, there is no electronic method to link the data streams such as the operator, work station, time of day, and specific product produced. This makes issues like error tracking and warranty claims very time consuming and inefficient.

The yearly production was defined to be 37.000 units for 270 working days. A work day is 8.0 hours which is composed of 7,5 hours of work and 0,5 hours at lunch.

The Takt time is the time it takes to produce one of the required products based on the customer required quantity and the available time to produce the products.[97] In the case of the LeanLab, the calculation for Takt time is as follows:

Takt time = minutes of production per year/ yearly customer demand

= (270 days * 7,5hours/ day * 60 minutes/ 1 hour)/ 37.000

= 3,2838 minutes = 197 seconds.

Based on this value for the Takt time, the goal for the cycle time was set at 185 seconds. A detailed calculation for Takt time can be found in Table 17 of Appendix B.

The current state utilizes a simple hand assembly process with basic tools. It is organized in to a single piece flow to minimize number of work-in-process items and relies on just-in-time delivery of sub-assemblies from one station to the next. The assembly process starts at Work Station (WS) #1 and continues in sequence to the final station WS #5 (Figure 13). There is no automated processes of any type, and the only human assist devices are a tool support and simple fixtures to hold the product assembly.

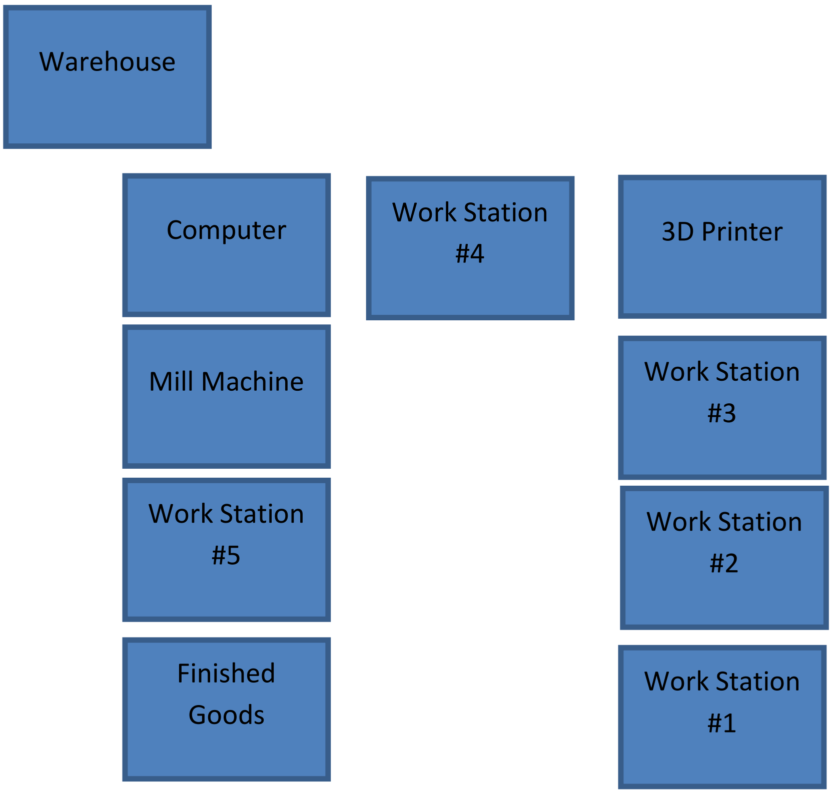

Figure 13: Layout of LeanLab

[97] Ohno (1993), pp. 48-49

5.3.1 *Current Systems*

The production plan is organized and managed by means of a production leveling system also known by its Japanese original term of "heijunka" system. The system levels production by both volume and product mix. The system takes the total volume of orders for a given period and levels them out so the same relative amount and mix is produced each day. The goal of this system is to create a continuous flow of products by utilizing standardized work and a constant cycle time. In order to achieve this, the production line must be flexible enough to produce all variants so that variations in demand for each product can be absorbed into the production plan. This eliminates all the wastes related to fluctuating production.[98]

In the LeanLab, the production leveling is performed by means of a heijunka board. A heijunka board consists of a grid of boxes. The rows represent a product variant and the columns represents a specific period of time such as days or shifts. A color coded card, called a 'heijunka card" is made for each product variant. These heijunka cards are placed in the boxes according to the production plan with the first product being at the top of the column and the last being at the bottom. This creates a visual representation of the upcoming production plan.

At the beginning of each assembly process, the operator pulls the heijunka card that is next in line and assembles the scooter according to that variant. The operator is responsible for identifying the variant and using the proper parts for that variant. The heijunka cards flow through the work stations with the product and they are collected at the end of the process to be re-used.

The inventory of parts and delivery of parts to the work station is managed by a kanban card system which is a core component of the Toyota Production System (TPS). The main functions of the kanban system are:

1. Provide transportation information.
2. Provide production information.
3. Prevent production from using incorrect parts and related unnecessary transport.
4. Serve as a work order which is attached to the goods.

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[98] Shingo (1992), pp. 253-254

5. Prevent defective products by identifying the operation which makes the error.
6. Allow for inventory control and detection of problems.[99]

In the LeanLab application, the parts are placed in storage bins along with a kanban card specific to each part. The kanban card includes the part description, part identification number, and the quantity to be placed in the bin. When the last part in the bin is used, the operator removes the bin and places it in the discharge chute. A warehouse operator makes periodic loops around production to collect the empty bins and to deliver previously filled bins. This process is called a “milk-run”. After the bins are collected, they are taken to the warehouse where they are filled according to the kanban card and delivered during the next milk-run. This creates a “pull” system for parts replenishment.

The kanban card system is not used for all parts. A few parts use a level control system to manage parts delivery. The parts are stacked and there is a strip with green, yellow, and red sections. When the parts are stacked up to the green level, then no parts need to be delivered. When the level is in the yellow, a delivery is necessary and can be filled with the normal milk-run cycle. However, when the level is in the red section, then an emergency delivery is required to prevent a part shortage. It is the responsibility of the milk-run operator to identify the level and take the proper actions for these parts.

Other parts are identified as C-parts and are kept in bulk quantities at the work stations. The milk-run operator is responsible for performing manual inventory checks for these parts and organizing replenishment. This is not a well-established system, as the work stations include enough C-parts for the entire production volume required by the course.

Each work station is assigned a color and everything for that work station utilizes that color. For example, all parts, work instructions, bins, and tools are marked in some way with the work station color. This helps organize the work station and simplifies parts identification and replenishment.

Each bin includes a label that has two separate items to identify the parts. The first is the color of the label which is coordinated with the work station. The second is a single alphabetical letter. By knowing the color and the letter, you can fully identify the part. For example, part “A” with an “Orange” label is a unique product identification. This part is used at the “Orange” work station and belongs in the “A” bin.

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[99] Ohno (1993), pp. 54-57

An andon system is also utilized in the LeanLab for error notification. In the Toyota Production System, the operator is required to stop the process immediately if any problem occurs on the production line due to faulty parts or processes. The purpose of this process is to immediately correct the errors and to prevent the errors from proceeding to the next station. In order to notify management that there is a fault on the line, the operator pushes a button or pulls a cord that activates an alarm which is typically an audio siren and flashing light. When the supervisor notices the alarm, they are responsible to report to the station and correct the fault. An andon board is a visual representation of all the andon lights for an entire work area. The andon board is used by the area's supervisor to be able to monitor all work stations in the area from a central location thus reducing their response time to faults.[100] In the LeanLab, a tower of lights called an "andon tower" is installed at each work station which with a manual switch to activate a red or green light to display status of production. The green light means that everything is normal at the work station. A red light means that there is an issue that cannot be corrected by the operator. After the operator activates the red light, a supervisor goes to the work station as soon as they notice the red light. When the issue is corrected, the red light is shut off and the green light is activated. There is no siren or any other means to notify the supervisor of a problem or fault at the work station, nor is there a data collection system downtime or supervisor response time.

There is no established system to collect data electronically for analysis, reporting, and optimization. For example, cycle time calculations must be made by manual methods such as by counting the total number produced in a day and dividing by the number of work hours in that day. Likewise, scrap data and inventory management are performed in similar method. While the data can be calculated, it is lagging by several hours or even days depending on the frequency of the manual calculations.

5.3.2 Current Production Process

In order to compare to the future state, it is important to describe the current production process. First, the work instructions are printed on paper and posted at each work station. The work instructions use the combination of a detailed description and multiple pictures to convey the parts and techniques necessary for assembly. There is one set of work

[100] Shingo (1992), pp. 43-44

instructions per work station and they are made in a general way to cover all variants. For example, if the scooter requires a green wheel, the work instruction simple states, “Select the proper wheel per the Heijunka card.” The operator must then look at the Heijunka card and decipher that a green wheel is needed.

The assembly process begins at Work Station 1 (WS#1) with the operator being given a Heijunka card. The operator then assembles the scooter according to the work instructions and the variant information of the Heijunka card. The assembly process ends at Work Station 5 (WS #5) where the scooter undergoes a final quality check and is placed in the shipping box.

As previously described, the operator uses the kanban system when they an empty bin and the Andon system when they encounter a problem. When the scooter assembly is complete, the operator passes it and the Heijunka card to the next station. They then begin with the next scooter according to the next Heijunka card.

6 Technology Selection for LeanLab

In order to reach the end goal of selecting four technologies to install in the LeanLab, a process must be used to funnel all the possible technologies into a few categories for consideration and ultimate final selection. The process started with the definition of basic system requirements and useful data outputs. This was combined with the twelve priority research fields and related technologies identified by Platform Industry 4.0. With this information, a "short list" of technologies was created, evaluated, and in the end four specific technologies were selected.

6.1 Basic System Requirements

For the practical part of the thesis, a goal was set to select and install four technologies in the LeanLab to achieve the following general requirements:

1. The systems installed are not to interfere with the production process. The cycle time of 185 seconds must be maintained or improved.
2. The systems must integrate kanban and Heijunka principles where applicable.
3. All new systems must be scalable and expandable.
4. All systems must be able to be integrated all other systems utilizing commonly used interfaces.
5. The timeline for installation and start-up must be less than 90 days.
6. The budget for all technologies combined should be less €40,000.
7. The selected technologies need to be presented as if it is a request for funding and ready to install upon approval. This includes the research of technologies, selection of technologies, full specifications, quotation, and selection of suppliers.

6.2 Useful Data Outputs

Based on discussions with the thesis Supervisor, a list of useful data outputs was created (Table 5). In order not to limit the initial list of technologies being considered, this list was not further developed or prioritized. This will be done during the final selection process.

Description	Useful Applications
Real-time Cycle Time Tracking	Work Load Balancing Operator Efficiency
Historical Cycle Time Tracking	Work Load Balancing
Real-time Inventory, work in process, and finished goods	Supply Chain Management
Real-time Quality Tracking	Scrap Tracking Quality issues tracking Work order management (effects due to scrap) Inventory management (effects due to scrap)
Operator Log-in/ Out at work station	Operator work hours Operator Efficiency Scrap Tracking
Real-time notification of production issues	Improved error resolution time
Data Collection of production issues	Downtime tracking Tracking of Error resolution time Supervisor response time
Real-time work order tracking	Real-time status of individual work order Flexibility to change work order to meet delivery dates
Attribution of all data to each individual scooter	Service, Warranty, and Repair tracking Base Data for analysis of root cause for failures
Digital Heijunka System	Set and manage production plan via computer Automatic generation of work instructions at work station based on variant

Table 5- Useful Data Outputs for LeanLab

6.3 Technology Considered for the LeanLab

As a starting point for selecting technologies for the LeanLab, research was performed to identify technologies that have the capabilities to produce one of the defined useful outputs. These technologies were then evaluated to determine if they fit into one the 12 priority research themes of Platform Industry 4.0. As a final filter, the overall scope of the themes covered by the LeanLab was considered. This significantly reduced the list to the following technologies:

Technology ID	Description	Industry 4.0 Research Theme Addressed
Tech 1	Conventional Sensors	6. Sensor data analysis and derivation of a data-based process control
Tech 2	Human Assist Mechanisms	8. Multimodal Assistance Systems
Tech 3	NFC / RFID	10. Radio communication scenarios for Industry 4.0
Tech 4	Automation	7. Intelligence, flexibility, and changeability
Tech 5	Wearable Tech	8. Multimodal Assistance Systems
Tech 6	Smart Andon	3. Automation of Value Networks
Tech 7	Smart RF	10. Radio communication scenarios for Industry 4.0
Tech 8	Gesture/ Non-contact Control	8. Multimodal Assistance Systems
Tech 9	Smart Inventory Management	3. Automation of Value Networks

Table 6- Technologies considered for LeanLab and Related I4.0 Research Theme

Each of these nine technologies will be presented below with a brief description, possible application in the LeanLab, and a comparison of advantages versus disadvantages specifically related to the LeanLab.

6.3.1 Tech 1: Conventional Sensors

Modern manufacturing is based on data and that data is generated by sensors. A sensor is a device that transmits an impulse that results from a physical stimulus.[101] The impulse from a sensor is decoded into information. This information is analyzed and decisions are made based on certain defined rules. For example, the production of beer is one of the oldest known processes. It dates back to 3400 BC to the Sumerians of ancient Mesopotamia.[102] The key step in the production of beer is the fermentation process. To control the fermentation process, the temperature must be maintained to be within a defined range. If the temperature is too low, the fermentation will be slow and incomplete which will result in

[101] Merriam-Webster, n.d., Accessed 18 Jan. 2015

[102] History.com, n.d., Accessed 08 Jan. 2015

weak and bland beer. If the temperature is too high, the fermentation will be too fast and inefficient resulting in weak and poor tasting beer. To control the process, a sensor is used to determine the temperature and the resulting information is used to control the temperature by regulating a heat exchanger.[103]

Sensors have been created to detect heat, light, flow, level, sound, pressure, pH, conductivity, magnetism, motion, and many other properties. Some sensors are connected directly to the data logging system via cables while others have been coupled with transmitters to communicate the data wirelessly. In an automated production system, this data is used to control a mechanical system that physically controls a process. In the beer brewing process, for example, the system could control the operation of a valve that supplies cold water to the heat exchanger. This is the type of application that will be considered for the LeanLab.

The manufacturing process in the LeanLab currently does not currently use data directly in the production process. It could be applied to create an automatic air temperature regulation system for the LeanLab. First, the portable air conditioner would need to be replaced with a unit installed directly in the window. The window air conditioning unit would need to have the ability to cool the air and to circulate ambient air from outside. Next a temperature control valve would need to be installed on the heating radiator. A temperature sensor could be placed outside the window to detect the outside air temperature, and another sensor could be placed in the center of the work area to detect the real air temperature. Then a temperature regulation system could be created to control and optimize the work area temperature by regulating the air conditioner and heater based on the outside temperature and work area temperature.

The advantages gained by installing this system could be an improved work environment and reduction of electricity costs. The disadvantages are that it does not have a direct link to the assembly process and the cost to install such a system.

6.3.2 Tech 2: Human Assist

One of the main themes in Industry 4.0 is that technology should not replace human operators, but rather technology should help operators perform tasks. This category includes a wide range of technologies ranging from simple fixtures to advanced computerized

[103] Papazian (2014)

systems. In order to further describe this category of technology, three systems will be presented:

- Tool holder
- Surgical Assist Robot
- Concept of real-time and point of use knowledge management system.

The first system is a simple tool holder. There are a wide range of devices available to achieve this function, and in fact the LeanLab already utilizes a type called a spring balancer. A tool holder has several purposes:

- Support the weight of the tool or part. This reduces the physical stress on the operator and it also allows the operator to manipulate parts and tools that would otherwise be too heavy.
- Limit the range of motion of the tool. This eliminates waste movements and increases the speed of the operation.
- Basic positioning of the tool or part. This speeds up the operation by allowing the operator to focus on fine positioning.

The current tool holder's main purpose is to hold the tool up and out of the work area, but also make the tool accessible to the operator when needed. The main problem with this style of device is that in order to use the tool you have to pull against the tool holder itself and it does not assist with alignment of the tool in any way. This can be cumbersome and can be improved with a different type of system such as one that uses spring tension connected to special linkages to manipulate and hold the tool (Figure 14). This system can carry the entire weight of the tool and can hold the tool completely stationary in a wide range of positions. This allows the operator to focus on alignment and proper engagement of the tool.

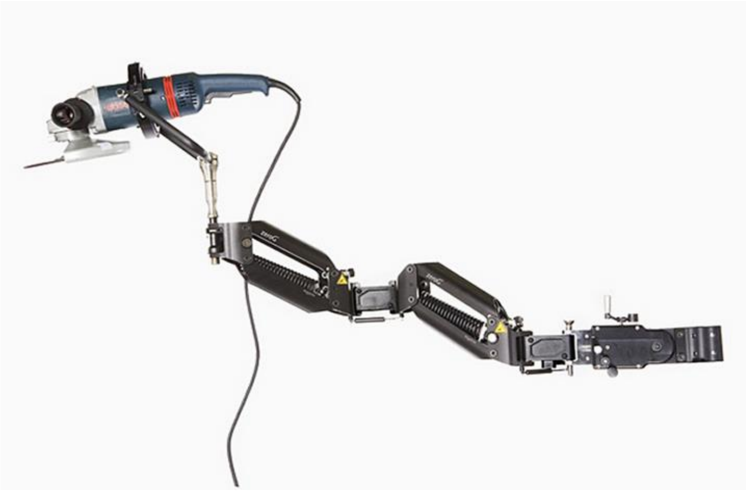

Figure 14: Tool Manipulator[104]

The second type of human assist system considered for the LeanLab is a robotic arm assist. This type of technology falls in between a simple tool holder and a fully automatic robot. These type of robots are utilized in various manufacturing operations and even in the medical field to assist with surgery. It can perform basic functions like holding, positioning, applying pressure, and many others. The robotic arm can assist the operator or the operator can perform the entire operation by controlling the robots.[105]

These type of robots could be utilized in the LeanLab as an interactive part holder. The operator could insert the work piece into a fixture attached to the robot arm, and the robot arm could then hold the work piece and manipulate into optimal position for assembly by the operator.

The third human assist system is not one based on mechanisms or robots, but rather the automated presentation of work related information. As the operator assembles the product, various information is needed such as work instruction, illustrations for assembly, part identification, quality specifications, maintenance, and trouble shooting. This digital system would intuitively present the required information exactly when the operator needs it.

One application of human assist technology in the LeanLab could be an interactive work instruction system based on the parts currently being assembled. For example, a light beam could be installed in front of each part bin. When a part is removed, the light beam is broken

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[104] Equipois, n.d., Accessed 22 Jan. 2015

[105] Kuka, n.d., Accessed 18 Jan. 2015

thus identifying the part currently being used by the operator. The system can then display information is that is specifically related to the part and the assembly process.
The advantages of this type of system is that it eases the strain on the operators and can make it possible it to be performed by people that were previously unqualified. For example, it might make it more appropriate for an elderly employee. The disadvantages are the high cost to install and the high skill level to install and maintain.

6.3.3 Tech 3: RFID

One of the most growing markets in technology is Radio Frequency Identification (RFID). The global market for RFID is expected to grow from $5.6 billion (USD) in 2005 to $21,9 billion (USD) in 2020.[106] RFID is primarily used for identification purposes and has a wide range of applications ranging from asset management, tracking & tracing, production control and Supply Chain Management.
The automotive industry is a heavy user of RFID, and in fact it is a key technology that enables mass customization. Each automobile is affixed with a unique RFID tag that identifies the product and all the specific build details. General Motors integrated a RFID tag into a specially designed “data bolt” that is attached directly to cylinder heads and engine blocks. As the automobile moves through the production steps, the RFID tag wirelessly identifies the product and as such its build details.[107] RFID provides the link between the real world (robots, intelligent machine cells, operators, etc.) and the virtual IT world (build details, production tracking, SSM, etc.). Because of this link, Siemens considers RFID to be the basis for Industry 4.0. [108]
The basic principles of RFID are not complex. A microchip with an antenna, called a transponder or tag, enters into the range of a reader. The reader is a device with one or more antennas that can read data off of the transponder and transfer it to a computer. This data can then be analyzed and used in a way that creates value for the business.[109]
There are many types of RFID systems and there is no standard out-of-the box system that fits all applications. This is due to the fact that the components have a wide range of

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[106] Statista, n.d., Accessed 11 Jan. 2015

[107] De Paula (2013), Accessed 02 Feb. 2015

[108] Weinländer, n.d., Accessed 11 Jan. 2015

[109] Violino (2005), pp. 1-3, Accessed 11 Jan. 2015

capabilities and limitations. In order to prevent technical issues, is important to select the components specifically for the exact application.

There are two basic categories of RFID systems: passive and active. Passive systems do not have a power source and function by using the magnetic field created by the reader to generate its signal. The reader uses a power source to create a magnetic field. This magnetic field then induces a current in the antenna of the transponder. The transponder's microchip uses this current to generate a magnetic field with a series of pulses based on its stored data. The reader receives the pulses and is converted into pulses of current via induction. The reader then interprets these pulses into data.

Since the passive system's transponder relies on the magnetic field to generate power, the strength of the magnetic field is important. The greater the distance between the reader and the transponder, the weaker the magnetic field and lower the amount of current induced. When the current falls a certain point, the signal of the transponder ceases to function because it does not have enough current for the microchip to operate. For this reason the passive system are limited to a maximum of 6 meters. Since the passive transponder does not have a battery, they are relatively inexpensive and typically cost in the range of $0,20 to $0,40 USD.

An active system includes a power source with the transponder and when it is in range of the magnetic field, it uses its power source send a signal back to the reader. Because it uses its own power source, the strength of the magnetic field required to activate it signal is far lower than that of the passive system. Due to this, the range can be upwards of 100 meters and costs $10-$50 USD each.[110]

Another important characteristic of an RIFD system is the frequency. Table 7 lists the main frequencies and a summary of the basic information as well as listing typical applications. In general, the low frequency waves can penetrate walls, but cannot go through metal. As such should not be used on metal parts where the tag needs to be read through the material. Ultra high frequency waves generally require the use of an active transponder, whereas low and high frequency are more applicable to passive transponders.[111]

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[110] Violino (2005), p. 2, Accessed 11 Jan. 2015

[111] Violino (2005), p. 3, Accessed 11 Jan. 2015

Band	LF Low Frequency	HF High Frequency	UHF Ultra High Frequency	Microwave
Frequency	30–300kHz	3–30MHz	300 MHz–3GHz	2–30 GHz
Typical RFID Frequencies	125-134 kHz	13,56 MHz	433 MHz or 865- 956 MHz 2.45 GHz	2,45 GHz
Approximate read range	less than 0,5 m	Up to 1,5 m	433 MHz = up to 100 m 865- 956 MHz = 0,5 - 5 m 2.45 GHz	Up to 10m
Typical data transfer rate	less than 1 kilobit per second (kbit/s)	Approximately 25 kbit/s	433- 956 MHz = 30 kbit/s 2,45 GHz= 100 kbit/s	Up to 100 kbit/s
Characteristics	Short-range, low data transfer rate, penetrates water but not metal.	Higher ranges, reasonable data rate (similar to GSM phone), penetrates water but not metal	Long ranges, high data transfer rate, concurrent read of <100 items, cannot penetrate water or metals	Long range, high data transfer rate, cannot penetrate water or metal
Typical Use	Animal ID Car immobilizer	Smart Labels Contact-less travel cards Access & Security	Specialist animal tracking Logistics	Moving vehicle toll

Table 7- RFID Frequencies and Related General Information[112]

The advantages of installing a RFID system is that it can provide a basis for automatic identification of parts and can track those parts throughout the entire process. This allows data to be collected for analysis that otherwise is not available. The technology is well established and easy to install without assistance from other institutes at TU Graz. The disadvantages are the complexity in the design of the system, cost is at the limit of the project budget, and high skill level required to commission.

[112] Ward (2006), Accessed 16 Jan. 2015

6.3.4 Tech 4: Automation

Whereas the automation has existed for decades, it is constantly evolving and improving. The recent miniaturization and capacity increase of electronics have enabled automation to grow. The three main types of automation utilized in manufacturing are:

- Fixed automation
- Programmable automation
- Flexible automation.

Fixed automation is an automated production that is not changeable due to the equipment configurations and typically produces a high volume product. Programmable automation can changed and can produce batches of products. In between two different batches, a reprogramming and changeover of tooling must occur. Flexible automation is an advanced version of programmable automation where the reprogramming and changeover can be done automatically.[113] Of these types, the most related to Industry 4.0 is flexible automation and it will be the only one considered for possible installation in the LeanLab.

A sample system for flexible automation installation in the LeanLab could be the use of a robotic arm at each work station. The robotic arm could be configured to perform all the tasks as described in the work instructions. The movement of the sub-assemblies from one station to next could be performed by an automated conveyor system. The robotic arms and controls could be placed in front of the work station where the operator currently stands during the assembly process so as not to interfere with the parts replenishment process.

The delivery of parts to the work stations could be performed by a robotic arm that is integrated into the parts delivery cart. The robotic arm could select the bins from the warehouse and place them in a central space of the milk run cart. An automated drive system could be installed on the parts delivery cart to enable it to move along the delivery path. The modified parts delivery cart could then perform the process of part replenishment just like a normal human operator.

The advantages of this technology is high quality product and high production rate. The disadvantages are the extremely high cost and long commissioning time. The scope of this project would be so large that it would need to be split into multiple pieces and multiple institutes would need to be involved.

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[113] Encyclopedia Britannica, n.d., p. 6, Accessed 18 Jan. 2015

6.3.5 Tech 5: Wearable Tech

The miniaturization of technology has led to rapid growth in technology that is worn on the body or clothes. This type of device is called "wearable tech" and by 2017 the estimated market for wearable tech is projected to be $20 billion (USD).[114] Examples of this technology are the smartwatch, google glass, and fitness trackers.

The newest version of these devices include an array of sensors including accelerometers, GPS antenna, NFC (Near Field Communication), vibration sensor, visible and infrared light sensors, temperature sensors, Bluetooth antennas, and many others. In 2014, a special version of operating software called "Android Wear" was released specifically for wearable tech.

Google Glass is one of the most known wearable technologies. It has the form of glasses and includes many of the features of a typical smart phone including making phone calls, sending SMS and emails, speech recognition, internet browsing, calendar, touchpad, GPS navigation, and many others. What makes Google Glass stand out from other wearable devices is its display called an Optical Head Mounted Display (OHMD). Google Glass can project a semi-transparent image directly to the eye that can only be seen by the user and not by others. This coupled with the ability to take pictures and photos sparked a public concern about the invasion of privacy.[115] While consumer sales for Google Glass ended in January 2015, a new model featuring more powerful Intel processors is being created and will focus specifically on the health industry and manufacturing.[116]

While this technology would be a good fit for the LeanLab especially since it is being re-focused on manufacturing, there is already a project at the IBL Institute of TU Graz that uses Google Glass in the LeanLab. Therefore, it will not be taken into consideration for this project. Instead, a smart watch will be considered for the LeanLab as it has a wide range of functionality. The operator could wear a smart watch and simplify multiple tasks and eliminate paper by digitally signing documents using NFC. Their health could be monitored using the pulse functions and the data could be used to estimate the stress load during the assembly process. The smartwatch could be used to scroll through digital work instructions using gestures as detected by the accelerometer or by simply swiping the screen.

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[114] Sabhlok (2013), Accessed 18 Jan. 2015

[115] Strickland (2012), Accessed 19 Jan. 2015

[116] Parsons (2014), Accessed 18 Jan. 2015

The advantages of this could be improved operator efficiency through stress load management, reduced paperwork, and improved work environment by eliminating paper clutter. The disadvantages are that is it not an established technology in manufacturing and there will be very little ‘off the shelf’ applications. This will lead to high cost, long lead time for developing applications, and it will require a high skill level to set-up and manage the system.

6.3.6 Tech 6: Smart Andon

While the LeanLab currently includes a basic andon system, it does not include an andon board, nor does it include a data collection system for downtime and errors. An andon board is a collection of all the andon lights for the entire process in one place. The supervisor and managers can get a quick overview of the status of the entire production line and can optimize the production line accordingly.

Since the first use the andon systems, their capabilities have been expanded to include automatic data collection. For example, when an error occurs at the work station and the operator activates the red light and automatically the time of day of the error is recorded in a database. Likewise, when the error is corrected and the green light is activated, the time of day is recorded in the database and a calculation is made to determine the amount of downtime attributed to the fault. The software packages also include various automatic and customizable reporting tools for visualization of this data.

Modern andon systems also include modules for notification of errors. Many factories are too large for the supervisor or manager to see all the andon lights from one location. To solve this problem, a software package can be configured to send an email or SMS to the responsible persons in the case of a fault at the work station. This reduces response time and adds a layer of transparency to the process.

The advantages for this system are the relatively low cost and ease of implementation. The technology is well established, easily expandable. The main disadvantage of this system is that it requires equipment form a third party to link to other systems such as the RFID system. This introduces an extra interface and possible source for errors that would not be necessary if it was included in a fully integrated system.

6.3.7 Tech 7: Smart RF

A recent technological breakthrough in wireless communication is Bluetooth Low Energy (BLE) also known as Bluetooth 4.0. This advancement greatly reduced the amount of energy required to actively transfer data wirelessly. This low energy requirement enabled the creation of active sensors powered by a small coin-cell battery. The active sensor can send and receive data continuously for years while using only a single battery.

The first mainstream application of this technology was by Apple's in 2013 when it released its iBeacon for the Apple based devices. The iBeacon is a location service technology built into Apple's device operating system called "iOS". A BLE enabled iBeacon device sends out a continuous BLE signal. When a device running iOS enters the signal range of the iBeacon, the iOS device detects the BLE signal and can use it to define the location of the iBeacon.[117] This technology is not just limited to Apple's iOS as Android 4.3 and above was adapted to utilize it as well.[118] In fact, BLE 4.2 was released in December 2014, and it has the added feature of being able to access the internet through a gateway device utilizing Low-power IP (IP6LoWPAN). This means the device is no longer handcuffed to a mobile device, and now it can connect via Wifi directly to the internet.[119] This opens up the technology for use anywhere Wifi is available. This means the data can easily be collected on computers and placed in databases.

Another application of these beacons is to help people navigate inside buildings. For example, San Francisco International Airport installed over 500 beacons to help disabled people navigate through the airport.[120] Japan Airlines also uses the beacon technology at the Tokyo Haneda Airport. The airline's staff was equipped with smartphones which allowed the company to locate staff members and assign specific tasks to them. They also utilized the technology to send offers and product information to customers. American Airlines and Virgin Atlantic are both testing beacons for similar applications.[121]

Of all the many beacon applications already in existence, one of the most far-reaching is its application in retail stores. Macy's, a major department retail store in the U.S., deployed the

[117] Apple, n.d., Accessed 10 Jan. 2015

[118] Hern (2014), Accessed 16 Jan. 2015

[119] Bluetooth.org, n.d., Accessed 10 Jan. 2015

[120] Fingas, n.d., Accessed 11 Jan. 2015

[121] Reddy (2014), Accessed 10 Nov. 2014

beacon technology in nearly 800 stores. There are two main uses of the beacons identified by Macy's that made it an attractive technology for their business. The first of which is to send push notifications for coupons and advertisements to customers in the area of the product. The notifications are customized to each user based on past purchases and in-store behavior. This also can be used to create interactive shopping experience by offering videos, reviews, and other related information about the products in close proximity to the user in real-time (Figure 15).

Figure 15: Beacon use real-time interactive shopping experience[122]

Figure 15 was taken from a video published on a beacon manufacture's website. A link to the interactive site is below:

http://estimote.com/#

The second main use for beacon technology is the offline big data application of real-time data directly from the customer about how they interact with the store. The customer's movement is tracked through the store and this data stored offline. It is analyzed and used to identify patterns of purchaser personas which in turn is utilized to increases sales with product placement techniques and even architectural layout.

The main concern for most people using this technology is the invasion of personal privacy. While this is certainly an issue, it is ultimately the decision of the user whether or not to

[122] Estimote, n.d., Accessed 25 Jan. 2015

allow it. The beacon technology uses a multiple step verification process to obtain consent by the user to collect this location-based data and to send push notifications.[123]

Since its creation, the beacon hardware has been expanded. They now can be configured to include temperature sensors, accelerometers, and other sensors. The thickness of the beacon has also reduced down to as low as 5 millimeters. These were developed to be used to work in an environment like described in Macy's case with one additional function. Instead of placing the beacon on a wall or inside a lightbulb fixture, they are placed on a display product such as shoes. When a shopper picks up the shoe to look at it, the accelerometer detects the movement and sends the information to a device. The device can then be configured to display detailed product information. The overall interactive experience is similar to the beacon without the sensors with one major difference: it does not rely on the shopper using their own personal device. It reduces the concern for the invasion of privacy. A disadvantage for this technology for the retail store is that they need to supply the display screen and also allocate floor space for it.

6.3.8 Tech 8: Gesture / Non-contact Control Devices

According to Gartner's 2015 Hype Curve for Emerging Technology (Figure 30 of Appendix E), gesture control is in the slope of enlightenment phase with and in the range of 2-5 years from the plateau of productivity. Additionally, Gartner defines gesture control as:

> "the ability of a computer system to recognize and interpret movements of the human body in order to interact with and control a computer system without direct physical contact."[124]

The main objective of gesture control devices is to improve the usability of a system and it is primarily used as an input function. Typical applications are to help physically-impaired people interact with computers. The most widely known device utilizing this technology is Microsoft's Kinect camera. The Kinect camera includes a RGB camera, depth sensor, and multiple microphones. It can track up to six people at one time with 25 skeletal joints per person and supports facial recognition and voice recognition. It can be used to control the

[123] Wallace (2014), Accessed 11 Jan. 2015

[124] Gartner, n.d., Accessed 19 Jan. 2015

entire user interface with voice and gesture commands and also to play specially developed games.[125]

Siemens has utilized this technology to improve employee safety at a nuclear plant. In such a facility, there are areas where employees need to maintain exposure to radiation to a standard known as ALARA (As Low As Reasonable Achievable). In order to minimize the operators time in these areas, they use the Kinect Camera to control human avatars to simulate the desired activity inside a 3-D model of the nuclear plant. They can obtain accurate time estimates and then optimize the size of the crew in order to minimize the duration and exposure related to the activity.[126]

In the LeanLab, this technology could be used to allow the operator to interact with the work instructions. For example, the system could be configured so that when the operator moves both arms from right to left in unison, then the page of the work instruction being displayed advanced to the next page. The system could also track the movements of the operator so they can be analyzed and optimized to improve cycle time and operator strain.

The advantages of the system are that the hardware is inexpensive and relatively robust compared to other emerging technologies. The disadvantages of the system is that custom software is required and this will have a long lead time and be expensive to develop. Additionally, there is already a project on this topic in the pipeline for the LeanLab.

6.3.9 Tech 9: Smart Supply Chain Management

One of the major themes of Industry 4.0 is the automation of value networks. One aspect is the horizontal integration of Supply Chain Management (SCM). The processes and activities of SCM should be organized and designed to utilize relationships and dependencies to achieve a global optimum.[127] In order to address this theme, an evaluation and selection for a basic supplier strategy is necessary. There are four main sourcing strategies for any given inventory item:

- Sole: only one supplier exists and therefore must be used.
- Multiple: several suppliers exist and several are used.
- Single: several suppliers exist, but only one is exclusively used.

[125] Microsoft, n.d., Accessed 22 Jan. 2015

[126] Kinect for Windows Team (2013), Accessed 19 Jan. 2015

[127] Plattform I4.0 (2014), pp. 8-10, Accessed 24 Nov. 2014

- Dual: two or more suppliers exist, but only two are used.

In order to select a strategy, the parts required by production process must be considered. The product produced in the LeanLab is a scooter composed of simple parts such as bolts, springs, foam bicycle grips, and standard wheels. These parts are mass produced and can be supplied by multiple sources. This eliminates the sole supplier strategy. Since the availability of the parts is high, the possibility of disruption to these parts is low. Due to this, the best strategy to yield the theoretical maximum profit is to select a single source supplier as illustrated in Figure 16.

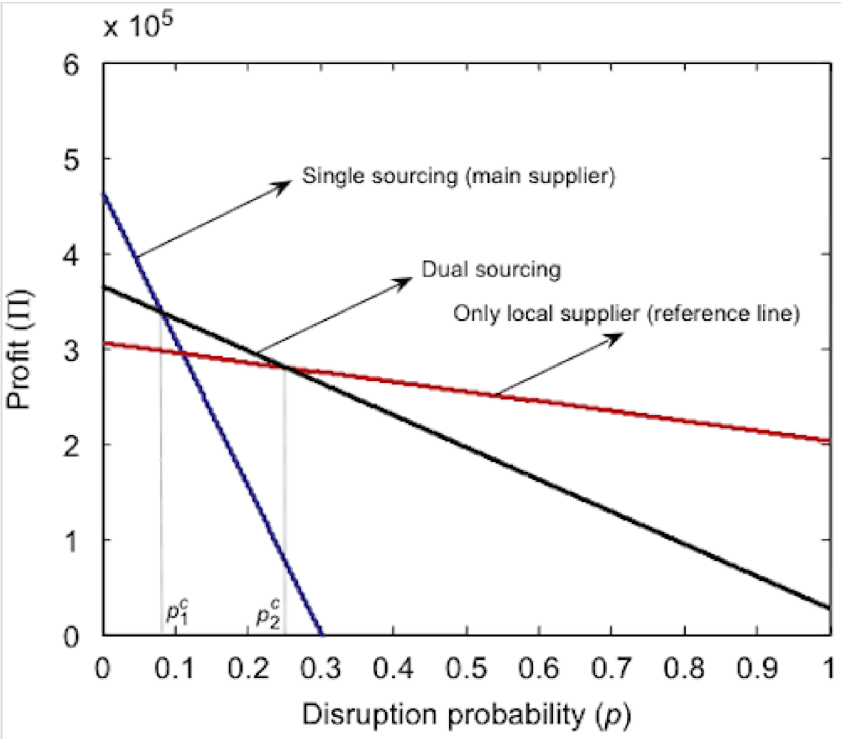

Figure 16: Profit versus Disruption Probability[128]

Implementation of a single source supplier strategy is not an easy task to accomplish because it is not just the integration of a new technology into factory, but also it is an integration of a supplier-partner. This requires a strong working relationship between the factory and supplier built on trust and mutual benefit. The factory cannot allow their real-time production data to fall into the hands of its competitors, and it is the responsibility of the supplier to protect this data.

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[128] Dumke (2011), Accessed 19 Jan. 2015

Another major concern when selecting a single-source supplier is that the company introduces a risk that is difficult to manage. For example, in 1998 Ford had to shut down production for three of the Fiesta and Puma plants in Cologne and Dagenham because of a shortage of door and trunk latches due to a computer glitch at its single source supplier for these parts. This shutdown led to a lost production of 7,000 vehicles.[129]

While the risks are high, the benefits are also high. In fact, even after the incident at that caused the shutdown, Ford continued using the single source supplier concept. As they stated:

> "If you look at industry as a whole, this way of supplying is very common and the instances of what has just happened are very rare. We will be reviewing our approach to see if there is a better method, but I think history has shown that it's a sound business method overall."[130]

The topic of SCM is currently included within the scope of the LeanLab, but it could be expanded to include a simulated single-source supplier partnership. This partnership could be based on the supply of a small group of parts limited to inventory management and logistics. This would provide a starting point for the topic in the LeanLab that can be further developed.

The advantages of this system are that it would introduce a major thesis of Industry 4.0 to the LeanLab. The theory of instruction could be expanded by including a cost payback calculation and a risk analysis for selecting a single source supplier. Since the system would be entirely theoretical, the disadvantage is that there is no real need for a supply of these parts and it will be difficult to integrate into the current scope of the LeanLab.

[129] Professional Engineering (1998)

[130] Professional Engineering (1998)

6.4 Selection Process for Technology

In order to select the technologies to be installed in the LeanLab, a decision matrix methodology was utilized as defined by the American Society of Quality (ASQ).[131] The three main parts of the decision matrix are:

- Evaluation criteria
- Weight of the criteria
- Score for each technology.

The evaluation criteria were determined to be:

- Level of Productivity Improvement
- Level of Quality Improvement
- Investment amount
- Required skill level to operate
- Time to implement
- Technical feasibility
- Not already in pipe line.

The scoring system used was the following:

4= Excellent (best in class)

3= Good (exceeds requirements)

2=Fair (meets basic requirements)

1= Poor (meets minimum requirements)

0= (does not meet all requirements).

The score was multiplied by the weight for each evaluation factor. A summation was made for each technology and the top four overall scores were selected. All these factors were considered and the decision matrix was completed (Table 8). The result is the selection of the following four technologies:

Tech 3: NFC/ RFID

Tech 6: Smart Production Control

Tech 7: Smart RF

Tech 9: Smart Inventory Management.

[131] American Society of Quality, n.d., Accessed 10 Jan. 2015

Tech 3 and Tech 7 fit into the Platform Industry 4.0 priority research field of "Radio communication for Industry 4.0 scenarios." This research field addresses the exchange of data between the stationary and mobile components of CPS. Specifically these technologies utilize the current and future potentials of wired and wireless communication technologies within the production process. The goal of this research field is to achieve a standardized basic solution which are cross-industry applicable with interoperability, scalability, and cost sensitivity.[132]

[132] Plattform I4.0 (2014), p. 16, Accessed 24 Nov. 2014

Evaluation Factor	Weight	Tech 1		Tech 2		Tech 3		Tech 4		Tech 5		Tech 6		Tech 7		Tech 8		Tech 9	
		Score	Sum	Score	Sum	Score	Sum	Score	Sum	Score	Sum	Score	Sum	Score	Sum	Score	Sum	Score	Sum
Productivity Improvement	10	3	30	4	40	4	40	4	40	4	40	3	30	4	40	4	40	4	40
Quality Improvement	5	3	15	4	20	4	20	4	20	3	15	3	15	3	15	3	15	3	15
Investment	20	2	40	4	80	3	60	0	0	3	60	4	80	4	80	4	80	4	80
Newness of technology	10	1	10	2	20	3	30	3	30	4	40	3	30	4	40	4	40	4	40
Required Skill level	10	4	40	4	40	3	30	1	10	3	30	2	20	3	30	2	20	4	40
Ease of implementation	15	4	60	3	45	4	60	1	15	4	60	4	60	3	45	2	30	4	60
Technical feasibility	15	4	60	4	60	4	60	4	60	4	60	4	60	4	60	4	60	4	60
Already in Pipeline	15	0	0	3	45	4	60	4	60	0	0	4	60	4	60	0	0	3	45
Total	100	255		350		**360**		235		305		**355**		**370**		285		**380**	

Tech 1: Conventional Sensors
Tech 2: Human Assist Mechanisms
Tech 3: NFC/ RFID
Tech 4: Automation
Tech 5: Wearable Tech
Tech 6: Smart Andon
Tech 7: Smart RF
Tech 8: Gesture/ Non-contact Control
Tech 9: Smart Inventory Management

Table 8- Decision Matrix for Technology Selection

Tech 6 and 9 both fit into the theme of "Automation of value networks." This field is focused on the stages of a value chain that are automatically performed in the "digital" world. Tech 6 specifically addresses the goal of creating easily applicable, integratable, autonomous modules. Tech 9 addresses design and organization of relationships and dependencies in order to achieve a global optimum. [133]

6.4.1 System #1: RFID

RFID was selected and will provide a technology base for the LeanLab. This is a complicated system which was designed conceptually from the ground up with a close collaboration of an experienced RFID specialist. It utilizes concepts of kanban for inventory control and Heijunka for planning. It uses the planning data to create a system to display version specific work instructions. It includes an architecture that has the capability of expansion and integration with other systems. The system will consist of a network of readers, RFID tags, RFID antennas, database, displays, and software package with graphic user interface.

In order to provide a starting point for the design of the system, nine use cases were developed specifically for the RFID system. As the system is not to increase the cycle time and are to be as invisible to the operator as possible. To achieve this, the use cases are based on operator actions and the RFID system was designed around them. All of the use cases can be found in Appendix A, and a simplified use case will be presented below to illustrate the design process:

Use Case 1: Smart Timing

Goals:

- Automatic collection of basic production data.
- Automatic operator clock in/out at work station
- Specific Work Instruction for Variant being processed during exact cycle.

[133] Plattform I4.0 (2014), p. 9, Accessed 24 Nov. 2014

Process for Operator:

Step 1: Grab the first part according to the work instructions- Front Fork (Item #7). This starts a new cycle.

Step 2: Assemble according to the work instructions at WS #1. Place any empty parts bins in the discharge chute.

Step 3: When finished, move the assembly to the next work station.

The steps were evaluated and compared to the Useful Outputs for the LeanLab (Table 5) to determine which outputs could be linked to the actions. The following illustrates the same assembly process for the operator and the actions occurring that in the background by the RFID system are described below:

Step 1 Grab the first part according to the work instructions- Front Fork (Item #7). A RFID tag is previously attached to the Front Fork (Figure 17) and coded with variant information according to the Heijunka system. The RFID reader will be placed so that when the Front Fork enters the working space, it is automatically scanned. The operator will not need to change the way they assemble the scooter in any way.

This RFID scan will trigger the following actions in the background:

- Display the work instruction based on the variant required.
- Start the cycle time clock.
- Assign the date and time of start to the scooter.
- Assign the work station number and operator to the scooter.
- Remove the parts to be used during this step from inventory and place them in WIP.

Step 2: Assemble the scooter according to the work instructions. When a part bin is empty, it is placed in the discharge chute. A RFID tag will be attached to the backside of the label of the part bin (Figure 17) which will allow it to be automatically scanned when it enters the working space in route to being placed in the discharge chute. This will trigger the following actions in the background:

- Notification to warehouse that 1 bin of parts is needed according to the kanban requirements.
- Comparison of real usage to calculated usage. This is like a miniature inventory check that is constantly being performed. When there is a discrepancy, a notice will be sent to warehouse.

Step 3: When the assembly is complete, move the product to the next station. When the product is moved to the next station, it will automatically scan the RFID tag because the reader will be in the natural path to the next station. This will trigger the following actions in the background:

- Stop the cycle time clock.
- Calculate and display the cycle time for that product.
- Send a signal to the andon system to increase production count by 1.

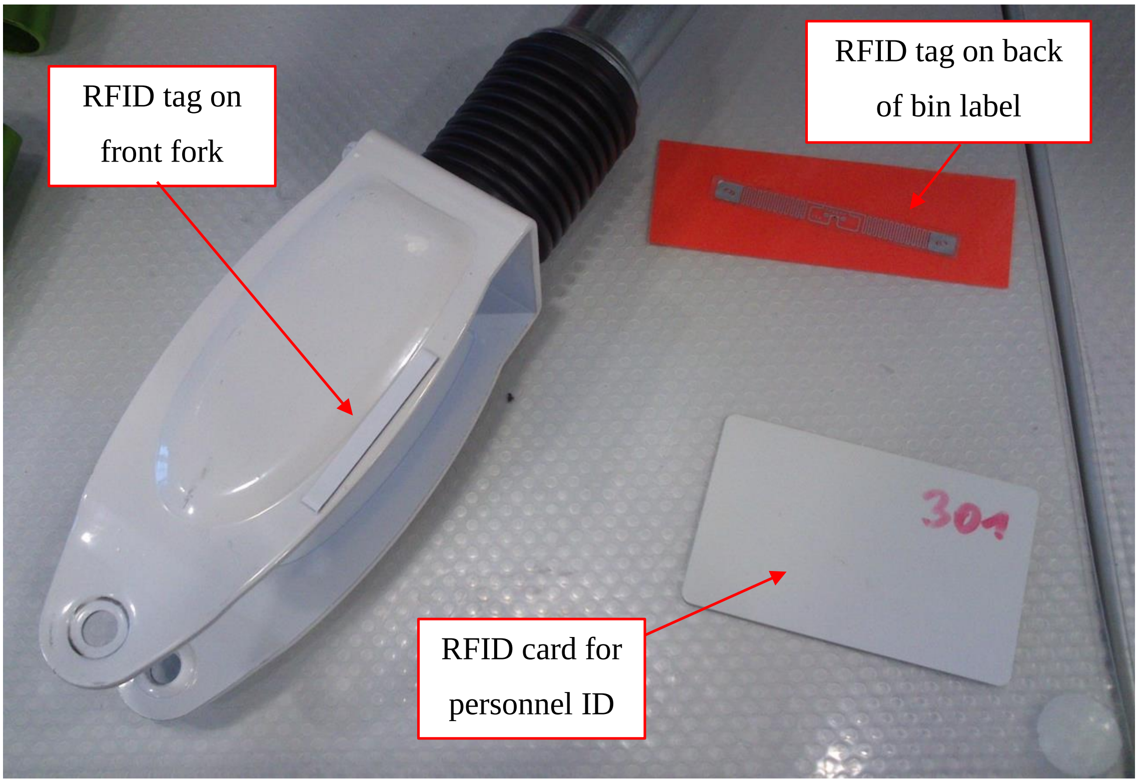

Figure 17: RFID Tags for LeanLab Application

Many other processes were taken into account in a similar manner including scrap management, supervisor reaction time, supervisor problem correction time, and many others. In order to organize all the use cases and equivalent components of the RFID system, a BPMN (Business Process Model and Notation) was created. The BPMN represents how the operators, supervisors, and RFID system interact with each other, and also how the RFID system will interact with the other systems to be installed such as the andon system. See Figure 28 & 29 of Appendix E for the BPMN.

The BPMN was discussed extensively with the RFID specialist in order to "design in" the key features of RFID to fit the needs of the LeanLab. Based on the BPMN, the hardware was selected and the preliminary design of software for the system was created. The hardware layout can be seen in (Figure 18) and includes the following hardware:

- RFID antennas- quantity: 6
- RFID readers- quantity: 2
- Portable RFID reader- quantity: 1
- RFID tags- quantity: 315
- RFID Personnel ID Cards- quantity: 50
- NFC Stickers- quantity: 100.

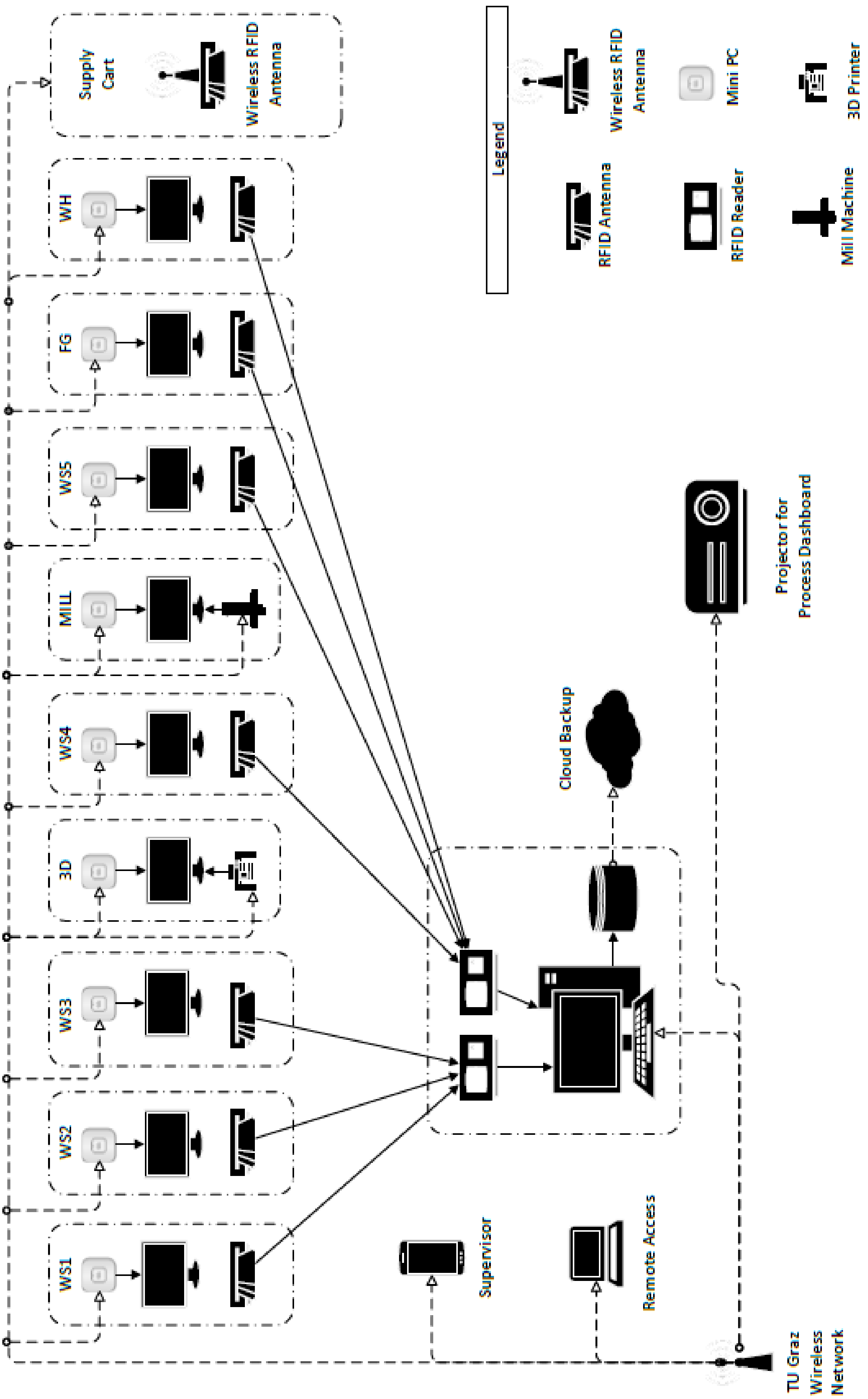

Figure 18: Basic RFID Layout

In addition to the data collection and interaction with the andon system, there will be an integrated system to display the work instructions and other important information at each work station and warehouse via a LCD display. A monitor will be attached to each work station. Each monitor will include an inexpensive mini-pc to give it access the internet via a standard web browser. The work stations will be assigned a specific IP address and the work instructions will be pushed to that IP address according to the requirements of the Heijunka system. The product information will be assigned to the individual scooter via the RFID tag and it will be accessed when it is scanned at the work station. This will allow the work instruction for the exact product variant to be displayed as it is needed.

Other information will be displayed on the screen based on production counts, cycle times, rejects, quality issues, and goals (Figure 19). There will be a management dashboard screen that displays a quick overview of the key process indicators (Figure 20). Once the system is set-up, multiple screens can be created and displayed according to the needs of the LeanLab.

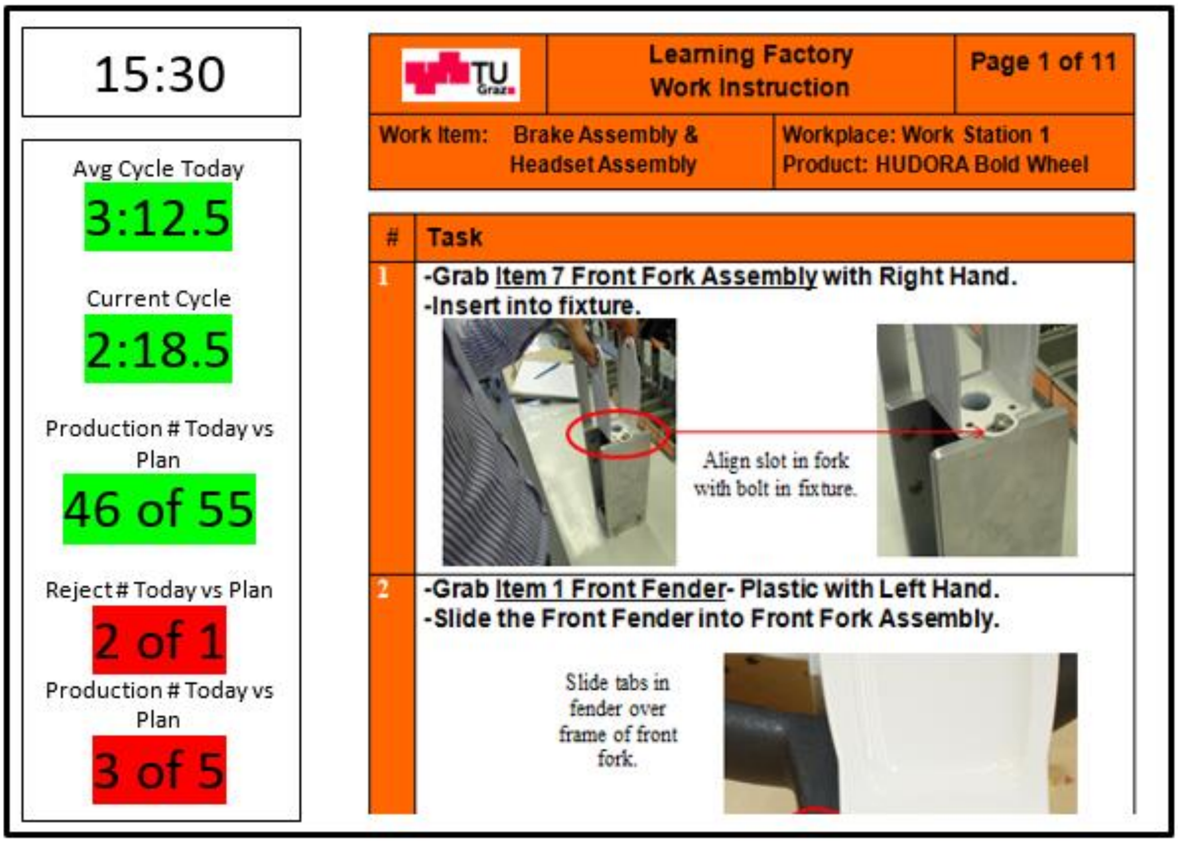

Figure 19: Display Screen at Work Station

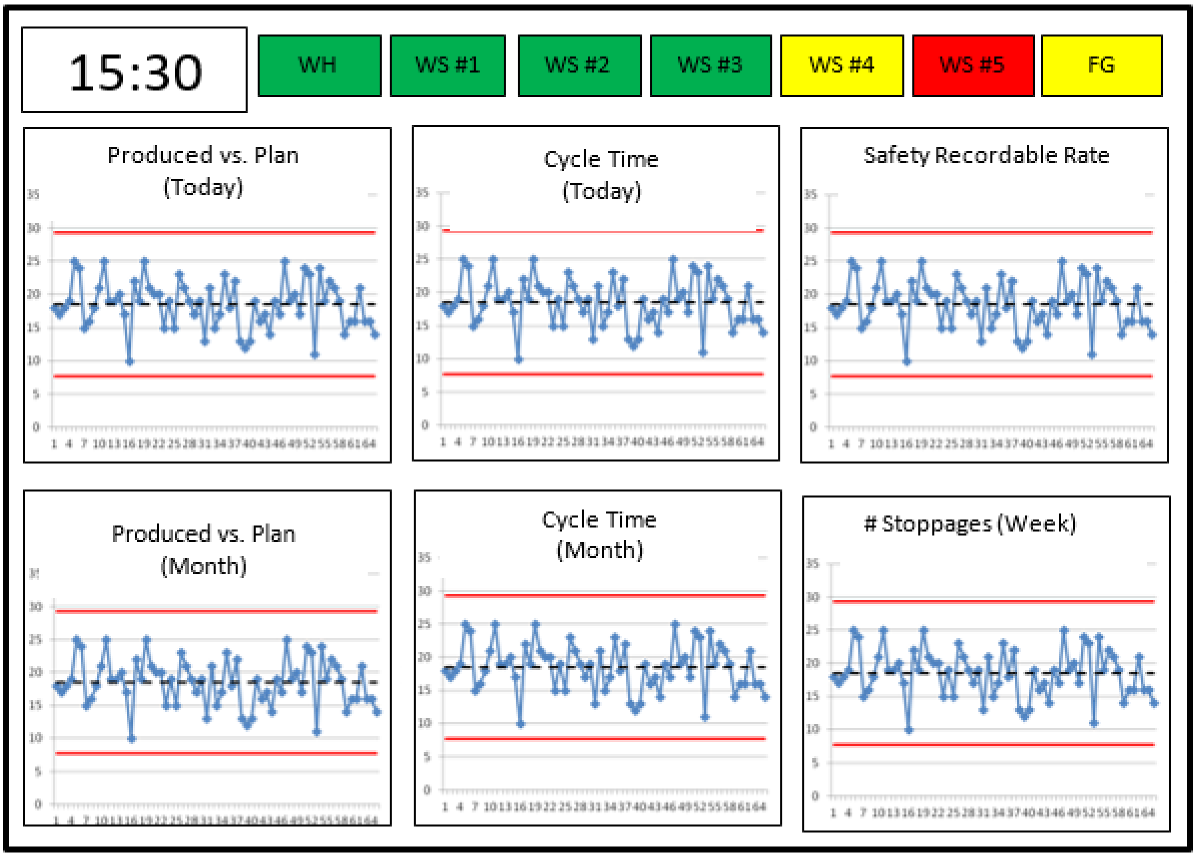

Figure 20: Management Dashboard Screen

As the scope and timeline were determined to be at the limits of project definition, it was decided that to take a three staged approach to the installation of the RFID system. The goals of the use cases were grouped together based on their overall scope as seen below and illustrated in Figure 21:

- Stage 1- needs within the LeanLab.
- Stage 2- addresses the interaction with suppliers.
- Stage 3- addresses the product life cycle.

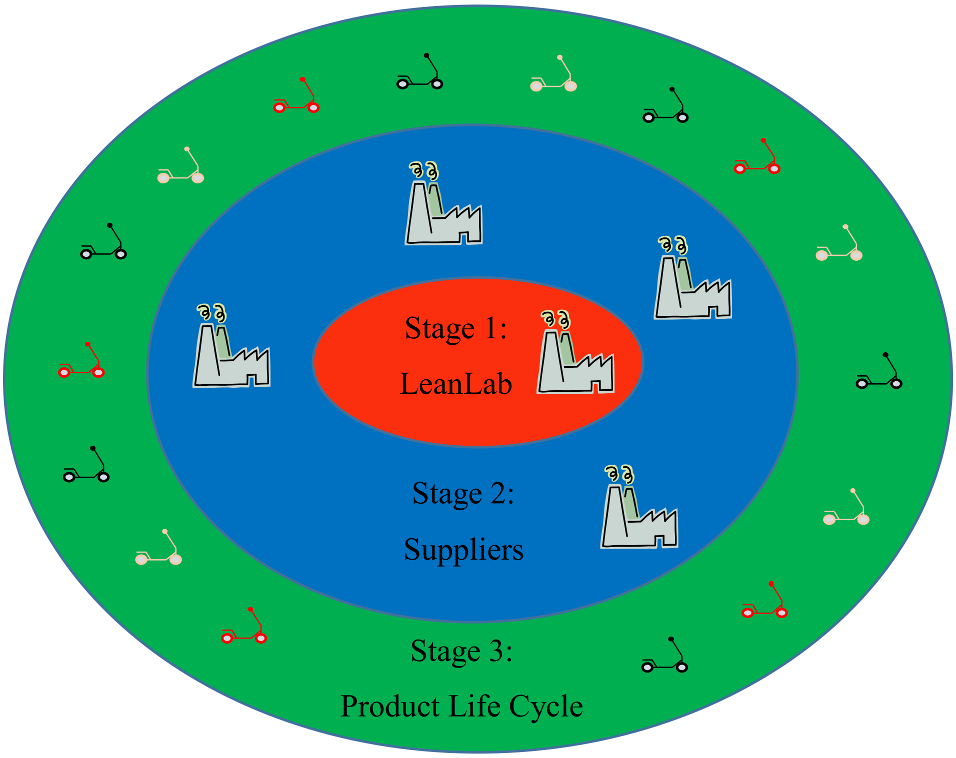

Figure 21: Scope of the 3 Stages

The stages were quoted individually to provide all the equipment, software, and set-up needed to accomplish the goals required by the use cases that they address. The RFID specialist submitted an un-negotiated quotation for each stage. The stages build upon each other and as such must be installed in sequential order. This means that in order to install Stage 2, you must first complete Stage 1. See Table 9 for the budgetary quotation for each stage. For a detailed quotation and for supplier contact information, see Table 12 and Table 13 of Appendix A. With regards to the quotation, the amounts are unaltered and as received from the supplier. They have not been negotiated nor have any special considerations been made for cooperation with TU Graz.

Stage	Use Cases Addressed	Quotation (EUR)	Notes
Stage 1	Use Case 1	23.806,00	Does not include connection to 3D printer or CNC
	Use Case 4		
Stage 2	Use Case 2	23.059,00	
	Use Case 3		
Stage 3	Use Case 5	14.790,00	Includes connection to 3D printer & CNC

Table 9- Budgetary Quote for RFID System

6.4.2 System #2: Smart Andon

The Smart Andon system integrates three sub-systems into one package: andon light system, software package, and wireless communication system. All three sub-systems include their own functionality and benefits. Together they form a simple, intuitive, and robust production monitoring and reporting system.

The first sub-system is the light tower which is comprised of several tiers of lights which are individually activated with a manual switch. Each color represents a pre-defined condition at the workstation and they can be individually activated. The lights are low-power consuming LED with a randomized flashing pattern to prevent the acclimatization effect.

The second sub-system is production data tracking software. This is a computerized system that has three main modules: observation, production order, and reporting. The observation module displays the current production data and production status for each work station[134]. On the main screen, there will be a box as illustrated in Figure 22 for each work station. This will allow each workstation to be displayed on one screen thus allowing the responsible person to observe all stations simultaneously. This is similar in concept and application to the andon boards in the Toyota Manufacturing System.[135]

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[134] Werma Signaltechnik (2014), p. 45, Accessed 10 Jan. 2015

[135] Shingo (1992), pp. 43-43

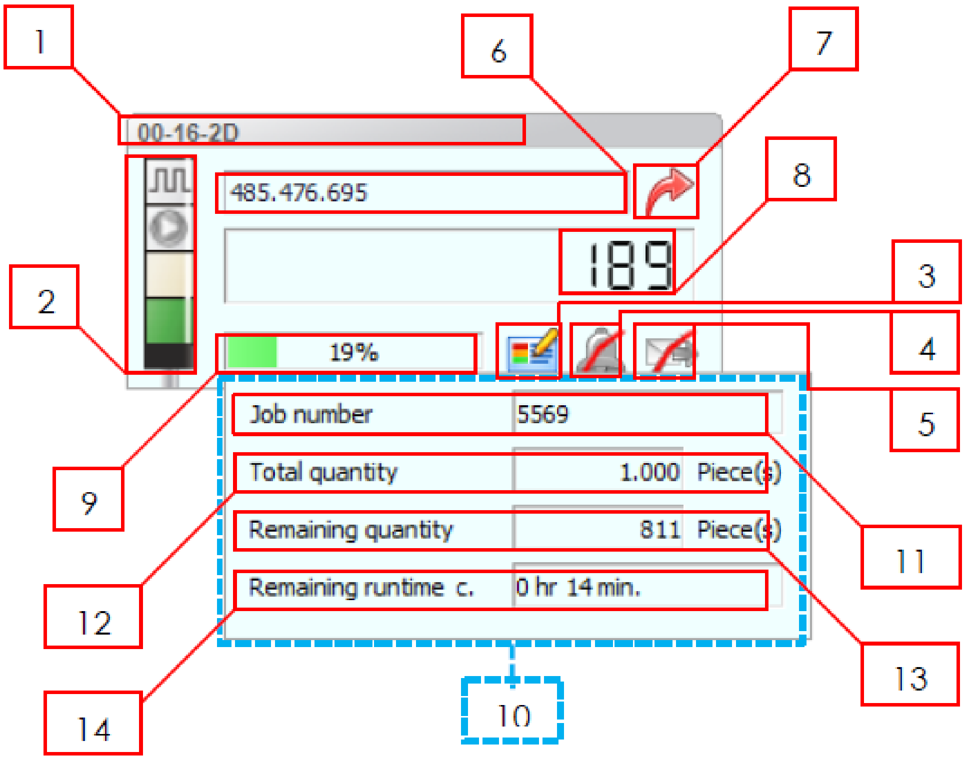

Figure 22: Observation Screen[136]

1. WIN slave performance name
2. Status depiction
3. Edit WIN slave performance configuration
4. Set up the status change message
5. Set up the status transmission
6. Displays the running job
7. Jump to Job Module
8. Current quantity
9. Fulfilment level of the job
10. Mouse over function for job details
11. Job number
12. Total quantity of the job
13. Remaining quantity of the job
14. Remaining runtime of the job

[136] Werma Signaltechnik (2014), Accessed 10 Jan. 2015

This sub-system includes modules for automatic report generation and a means to create customizable reports for productivity and runtime (Figure 23). The system can also send notifications of production status change via email or SMS. It can also be configured to be remotely accessed and operated. It uses Microsoft SQL server database and is expandable as well as accessible for other applications.

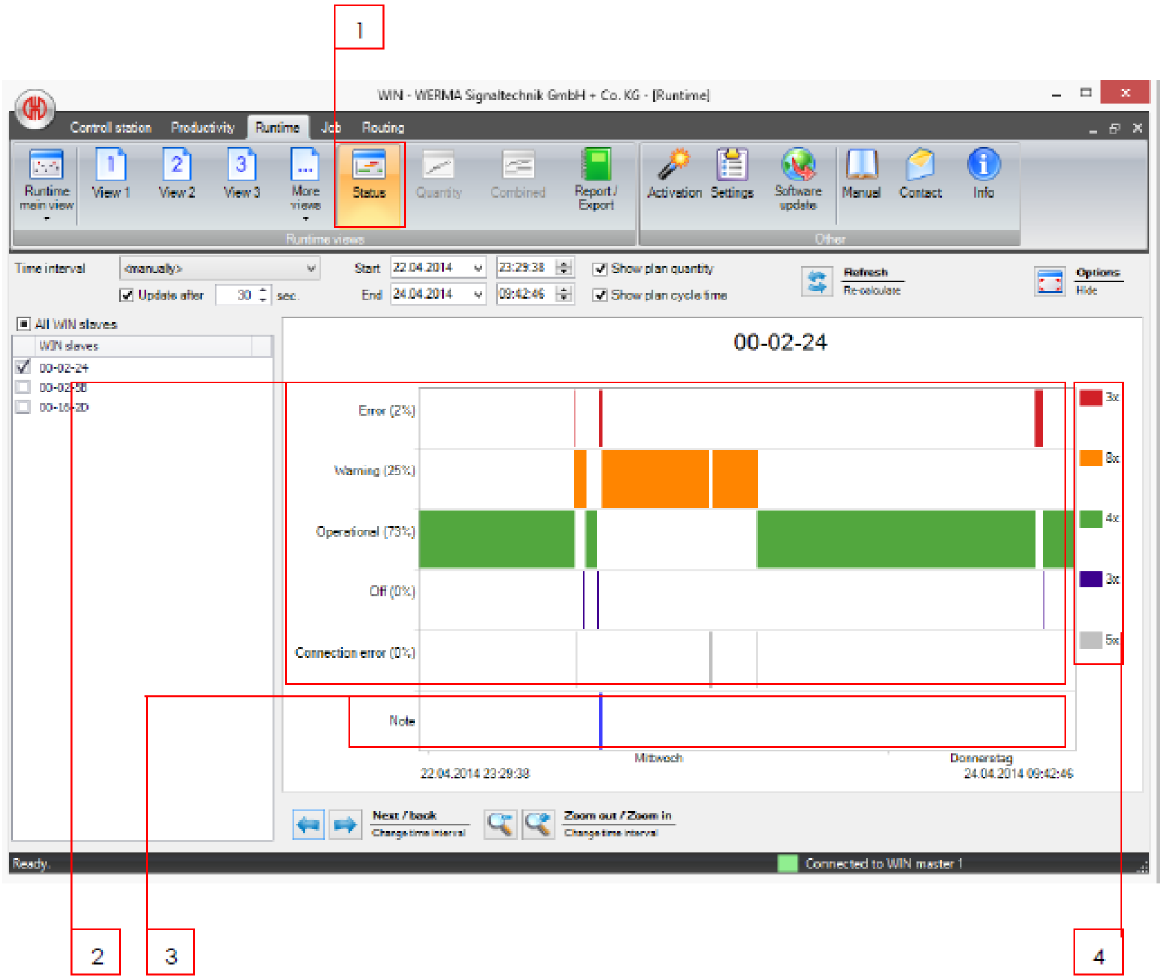

Figure 23: Reporting Screen: Runtime[137]

1. Status display
2. Depiction of the statuses in the selected time interval
3. Note field
4. Number of occurrences in the selected time interval

[137] Werma Signaltechnik (2014), Accessed 10 Jan. 2015

The third sub-system the WIN (Wireless Information Network) system which uses Wifi components to create an information network. Each andon tower includes a Wifi slave that connects to a central Wifi master which is then directly connected to a computer via USB. The Wifi slaves can connect directly to the Wifi Master, or they can connect to another Wifi slave. This creates an easily expandable Wifi network that can contain as many as 50 devices. The manufacturer offers the WIN system as stand-alone system and independent of the andon system in order to connect previously unconnected machines. To create this functionality, machines are connected to the wireless slave module via a specially designed actuator sensor interface (AS-i) module. There are certain limitations to this application, such as the voltage must be 24V.

In the LeanLab, the WIN slaves will also be applied to the 3D printer and the CNC milling machine so they can be activated automatically when an order is started. In order to achieve this this, a signal will be sent to the 3D printer and CNC whenever a product variant is scanned at the first work station that requires their services. This means the system will need to be linked to the RFID system. The Wifi equipment is part of the andon system, but the software integration will need to be integrated into the RFID system.

The system configuration for one work station can be seen in Figure 24. As mentioned previously, the color of the andon light represents the production status at the work station. These definitions are important to the configuration of the system and interpretation of the data. As such, the andon definitions for the LeanLab system are listed below:

- Red: Production Stoppage/ Serious danger / Hazardous condition
  Flashing: Supervisor is required and is in route to work station.
  Solid: Supervisor at work station addressing the problem.
- Orange: Caution / Imminent critical condition / Production stoppage pending
  Flashing: Supervisor is required and is in rout to work station.
  Solid: Production not stopped and supervisor not required or at work station.
- Green: Production in Operation/ Normal condition
  Solid: Production in normal operation and on schedule.
  Flashing: No defined meaning.
- Blue: Notification of the completion of 1 product.
  Solid: No defined meaning.
  Flashing: One product produced.

Figure 24: Complete System[138]

[138] Werma Signaltechnik, n.d., Accessed 10 Jan. 2015

The budgetary quote for the system was submitted for four work stations instead of five, so the quotation was scaled to fit our application. The interface to the RFID system was considered separately. The quotations have not been negotiated nor have any special considerations been made for cooperation with TU Graz. See Table 10 for a summary of the quotation for the Smart Andon system. For a detailed quotation and for supplier contact information, see Table 14 of Appendix B.

Description	Budget Quote (EUR)	Notes
WERMA Win System for 5 work stations	6643,15	Does not include AS-i interface
Interface for RFID system	2640,75	WERMA AS-i, ADAM-6050-CE DI/O Module

Table 10- Budgetary Quote for Smart Andon

6.4.3 System #3: Smart C-Parts Management

In the LeanLab, there are no established part suppliers or an external supply chain management system. As this is a large topic in manufacturing, it was decided to address this need. One of the first orders of importance is to select a supplier with that has a knowledge of and commitment to Industry 4.0. The company selected is based in Austria and has experience with a C-parts management system called I-bin (Figure 25). This is a system that utilizes a custom designed bin for holding parts that is fitted with a camera system. The system estimates in real-time the number of parts in the bin by comparing a real-time picture of the inside of the bin to reference pictures of known quantities. The camera system includes a battery and an active RF antenna to wirelessly transmit the data to a shared database. This database can be accessed equally be the supplier and factory. When the quantities fall below a pre-determined amount, an order is automatically triggered and scheduled for fulfillment. The supplier then fills the order and delivers to the factory.

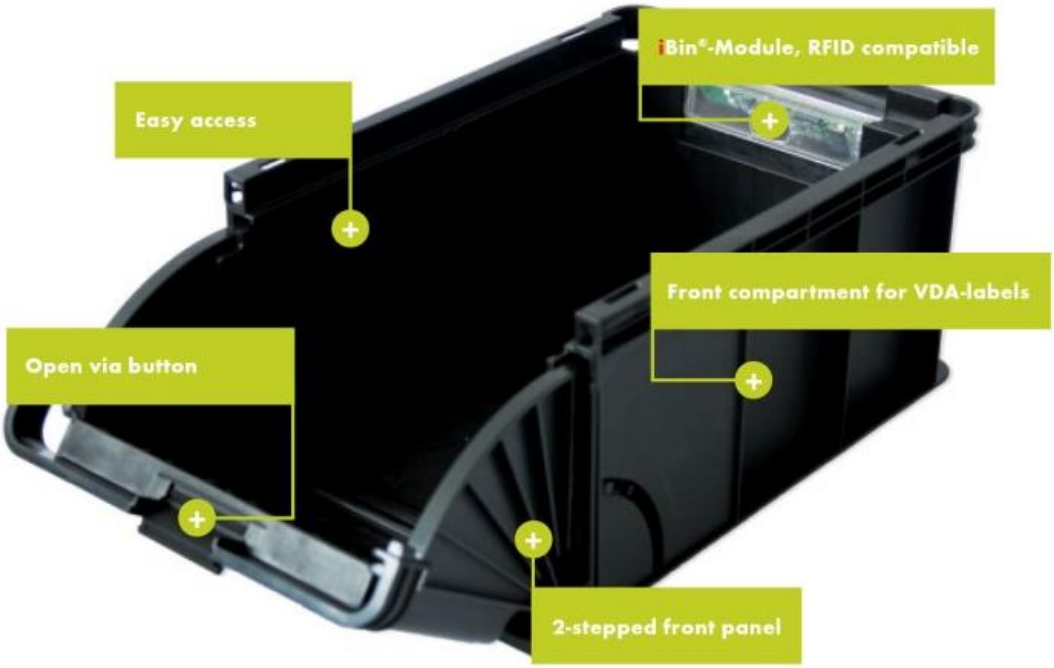

Figure 25: iBin System[139]

The delivery of parts can be done in two ways:

- Deliver to the warehouse where the company receives the parts and places them in their warehouse and is responsible for filling the bins on the production floor.
- Deliver directly at the point-of-use on the production floor. This eliminates the in-house warehouse space needed for these parts, double handling of the parts, and reduces labor hours for the company.

The external parts supply chain system and related personnel was not originally considered in the scope of the LeanLab. It was decided that new technologies should not affect the current process and definitely should not add work to the process. Therefore, the point-of-use delivery plan was chosen for the iBin system. This will allow the entire supply chain to be simulated in the LeanLab while addressing the topic of single source suppliers. This system is illustrated in Figure 26.

[139] Wuerth Industrie, n.d., Accessed 02 Feb. 2015

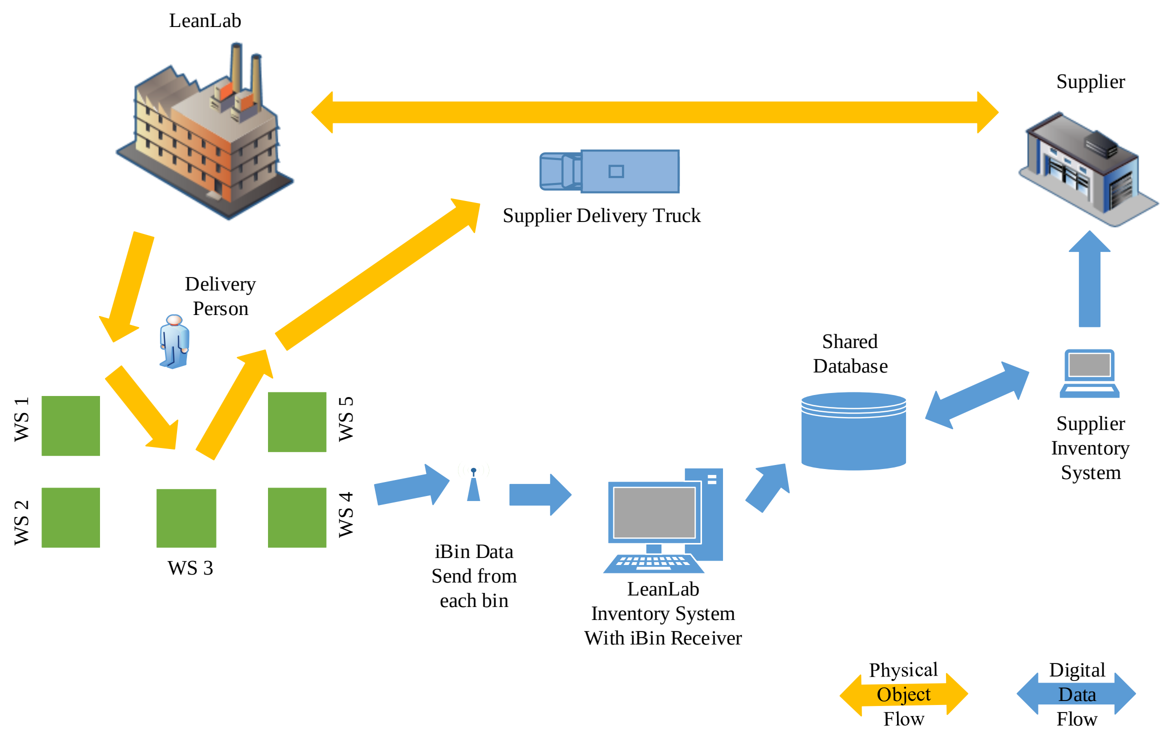

Figure 26: iBin Point of Use Delivery Plan

By selecting the point-of-use delivery plan, the iBin system becomes more of a service than a technology. In fact, the supplier does not sell the iBin system, they utilize it to become a single source supplier. There is no capital investment required for the iBin system, however the C-parts will be more expensive. This additional cost is due to the cost of the iBin system equipment and the labor for the person to deliver the parts. It is up to the company to decide if the point-of-use delivery plan warrants the additional cost of the parts. For reference purposes, the overall cost of the iBin system is 12.710,00 EUR. For the detailed quotation and contact information, see Table 15 of Appendix C.

In the original set-up of the LeanLab, several parts were classified a C-parts. The list of C-parts includes standard low value parts such as nuts, bolts, screws, and washers. Other parts were added to the C-parts to fit the process and set-up of the kanban system. In order to prevent any changes to the established process, the list of C-parts was not changed. This list includes 25 parts and can be found in Table 16 of Appendix C. The maximum and minimum amounts for each part based on the number of days of production: 2 days maximum and 0.5 day minimum. The calculation of the maximum and minimum amounts for each C-part can be found in Table 17 of Appendix C.

Using the description of the C-parts, the maximum amount of inventory, and minimum amount of inventory, the supplier can calculate the cost to supply. This cost was calculated as follows:

Total Part Cost = Supplier Cost for Part + Delivery Cost + Cost of iBin System + Supplier Profit.

This means the parts will cost more than the standard list price. In order to justify this additional cost, a comparison needs to be made between two supply models:

- Standard Model
- Point of Use Delivery.

The calculations for each system are included in Appendix C and are summarized as follows:

Standard system cost of parts per day:	1012,92€
Cost for iBin Point of Use Delivery:	1164,86€
Additional cost of iBin System:	151,94€

In order to simplify the calculation, the overall cost to inventory a part is estimated to be an industry standard nominal value of 25%.[140] This yields:

Cost to inventory all 25 C-parts per day:	253,23€

Since the additional cost of the iBin system is less that the cost to inventory all 25 C-parts, the iBin system shows a sizable yearly savings over the standard system as calculated below:

Savings (per day):	101,29€
Number production days per year:	270€
Savings iBin System (per year):	27.348,84€

The detailed calculations can be found in Table 16 of Appendix C.

In an effort to estimate the risk of using the iBin system, we assumed a worst case downtime of 3 days as experienced by Ford experienced in 1998. Making another assumption that this occurs one time per year, the total losses for 3 days of downtime are summarized below (see Table 18 of Appendix C for detailed calculations):

Cost of manpower:	
(29,57 €/ hour[141])	3.548,40€
Loss of Profits:	5.754,00€
Total losses:	9.302,40€

[140] Cavinato (1984)

[141] Statistik.at, n.d., Accessed 10 Jan. 2015

Based on this, it would require a downtime of 8,82 days to compensate for the savings of the iBin system. Based on the savings and the risk assessment, the iBin System proves to be a worthwhile endeavor.

6.4.4 System #4: BLE Beacons

Beacon have been primarily used in retail stores and for location services, but there is a large potential for applications in manufacturing. They could be applied to the products, operators, equipment, or many other objects. One limiting factor with this technology is that each sensor is approximately 30€, and this high cost limits its practical applications. For reference, the RFID chip chosen for the LeanLab application has a cost of under 1€. Placing the beacon on the products is not a cost effective application. It could be used on the operators, to track their movements within the production site and could be analyzed in the same manner as the Macy's use case. As this task is very complex at the moment, it will not be applied, but it could be expanded to include this application later.

There are two main applications for beacons in the LeanLab. The first application is to apply it to a piece of equipment and use it to access the electronic work instruction and specifications related to the use of that tool. A single beacon (Figure 27) will be physically attached to each of the drill machines used in the current state of the LeanLab. When the operator picks up the drill, the beacon's accelerometer detects the movement and sends a signal to the work instruction system to display the specific information for the current working step. A video will automatically play to show the proper use of the tool and illustrate any techniques that are difficult to explain in words or pictures. The display of videos, specifications, and work instructions will display in sequential order as determined by the process and will reset after each product is scanned out of the work station. It can also be linked to the version control system so that customized information can be displayed for each version.

Figure 27: Estimote Beacon[142]

A second application is related to the actual use of the tool. Using data from the accelerometer, movement and position of the tool can be calculated. This data can be used to determine the optimal usage of the tool. Different operators and tools can be compared as well as different techniques for use. The process can be analyzed to determine if there are any slippages or misalignment during tool usage.

The sensors will cost 30€ for each (120€ total for four). While this is not expensive, the real costs are related to the system set-up. The programming to link the sensors to the display system will need to be done by the creator of the RFID system. It was estimated that the initial setup of this system can be done in two workdays at a cost of €3200 bringing the total cost to €3320.

[142] Estimote, n.d., Accessed 10 Jan. 2015

7 Conclusions and Future Perspectives

The path to Industry 4.0 is uncharted and filled with potential pitfalls, however the benefits are great and there are many companies, research institutes, and universities working to pave the way. The outlook for widespread implementation of Industry 4.0 is more in terms of decades than years. Due to this, many small and medium sized companies are hesitant to engage in the concept of Industry 4.0 because it seems too daunting of a task for them to undertake by themselves. This thesis serves to shed light on the unknown parts of Industry 4.0 and presents a real solution to make the first steps towards Industry 4.0.

In this thesis, the concepts laid out in the Platform Industry 4.0 strategy are utilized to create what could be considered as an Industry 4.0 blueprint for small or medium sized business that have yet to start down the path. This blueprint is based on the selection of four uniquely technologies that provide technological benefit to the company and fit into one of the priority research categories of Platform Industry 4.0.

The selected technologies range from the well-established and commonly used RFID to the recently created iBin system which the hardware was released in December 2014. The systems were configured so they do not overlap in functionality, but rather they build upon each other. For example, the RFID system includes a component to manage the work instruction display at the work station. This can then be augmented by the beacon use to provide an interactive and real-time experience for the operator that was not possible with either system alone.

The first technology is RFID and it serves as the technology backbone for the LeanLab. An immense amount of data can be automatically generated by utilizing RFID tags on each product, each part bin, and operator. The system can track the production progress of each individual product produced as well as the operators that assembled them. The production schedule can be digitally operated and optimized as the heijunka system will be integrated into the software. Likewise, the inventory management operates seamlessly as it combines the kanban system with digital data collection. Quality and error tracking are handled in an effective and quick manner so as to minimize their effects on the production process.

In addition to the data collection, the RFID backbone will include a system to manage and display the work instructions. Each variant has specific work instructions and they can be displayed at the work station in real-time as needed when the product is assembled. The system will also be customizable by the operator. For example, an experienced operator may require more of a check list while a new operator would need very detailed instructions. This system is expandable to include various inputs from other systems as well.

The second system is a Smart Andon which wirelessly connects the andon light towers to a database software package. The system improves the notification of errors to the supervisors and will result in less related downtime. When an error occurs at the work station, an email or SMS will be sent immediately to the supervisor. This starts the downtime clock which is stopped when the supervisor corrects the error and restarts the work station. The downtime is recorded in the database and is combined with the production data to produce a multitude of pre-formatted reports covering the topics of cycle time, downtime, and production efficiency.

The third system is a system to manage C-parts by utilizing iBin devices. The iBin is a specially design parts bin that replaces all the bins for C-parts at all work stations. The iBin integrates camera into each bin and uses it to determine the number of parts contained in that bin. This information is transmitted wirelessly to a shared database which is accessible by the LeanLab and the supplier of the C-parts. The C-parts supplier uses this information to directly manage the C-parts. They are responsible for the entire supply chain including the delivery of the parts directly into the bins at the work stations. In essence, this system represents the horizontal integration of a supplier based on a shared technology (iBin).

The final system is based on implantation of a Smart Beacon. This device includes a microprocessor, an accelerometer sensor, multiple other sensors, and battery. It communicates via Bluetooth to a handheld device. The application in the LeanLab is to assist the operator perform their duties. A smart beacon is physically attached to each drill machine that is used in production. It is configured to send a signal out when the motion of the device exceeds a pre-set value. This signal is received by the work instruction management system which then displays a video for the proper use of the tool. As such, it is deeply integrated into the work instruction management system. The introduction of BLE 4.2 will allow the beacons to communicate via Wifi which will greatly expand the capabilities of this technology for future applications.

These four systems combine to provide a robust technology backbone for the LeanLab. They are flexible, expandable, and scalable which makes them suitable to serve as a basis for a test-bed. New technologies can be attached to the RFID backbone using a standard and economical input/ output device. The data can be integrated into an all-encompassing shared database for a “big data” analysis.

The total budget for the entire project was defined to be €40.000. Total for all stages of the RFID system, Smart Andon with AS-i, iBin, and Smart Beacon is equal to €74.258,90 which is well above the budget (Table 11). These quotes were not negotiated and all companies except the Smart Beacon were interested in forging a cooperation with the IBL institute to have their technologies included in the LeanLab test-bed. This means the overall cost could be greatly reduced by pursuing a cooperation with these companies. In order to obtain approval and start the project, it is recommended that the overall cost be calculated using RFID Stage 1, Smart Andon with AS-i, iBin, and Smart Beacons which totals 36.409,90 EUR (Table 11). Upon approval of the budget, negotiations can be made with the suppliers to allow for the remaining RFID stages.

Technology	Use Cases Addressed	Quotation (EUR)
RFID	Stage 1a	23.806,00
	Stage 2	23.059,00
	Stage 3 & 1b	14.790,00
Smart Andon	System without AS-i	6.643,15
	AS-i	2.640,75
iBin	Full system	0,00
Smart Beacon	Full system	3.320,00
Total Cost for All Technologies		74.258,90
Total Cost for RFID Stage 1a, Smart Andon with AS-i, iBin, and Smart Beacon		36.409,90

Table 11- Summary of all Technology Quotations

With regards to the future development of this project, the first item to address is the negotiations with the equipment suppliers. With a few concessions by the IBL, the equipment could be donated and the software programming could be provided at a greatly reduced price. Once these details are finalized, the next action is to purchase and install the systems starting with the RFID and Smart Andon Systems. The iBin system will operate somewhat independent and will only need to link to the part inventory database. The Smart Beacon should be the last system installed because it requires the framework of the RFID system in order to function.

The process for selecting the technologies for the LeanLab yielded a clear separation of technologies with the exception of one technology which fell only 5 points short of being in the top four. This technology is human assist mechanisms, and it would make an excellent topic for a future project for the LeanLab. The specific application could be related to an improved tool holder for the drill machines. It could also be implemented as a hybrid-fixture that can both hold the scooter during assembly and also allow it to be moved and rotated in to pre-defined positions to assist with assembly. One possible mechanism is called "ZeroG" as it can fully support the weight of the tool and can be configured to provide multiple positions to create perfect tool alignment. This could improve the speed of the process and reduce the operator strain, thus making the job more suitable to operators which were previously unqualified. A link to the supplier of this equipment can be found below:

http://www.equipoisinc.com/application/other/

In the research of this thesis, a second potential for further study was found. It is related to Dale's Cone of Experience. It is a well-known theory for learning experience, however the origin of the exact percentages attributed to each category is somewhat disputed.[143] A research experiment at the IBL institute could be conducted to justify the percentages bases on two courses at the IBL that cover the same information in two different ways: Industrial Engineering and LeanLab. Two weeks after presenting the Lean Manufacturing information in each course, volunteers from the course could fill out an anonymous quiz based on information that was originally presented using passive and active learning.

[143] Thalheimer (2006), Accessed 02 Feb. 2015

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11 Abbreviations

AMP	Advanced Manufacturing Partnership
ASQ	American Society of Quality
BLE	Bluetooth Low Energy
CAD	Computer Aided Engineering
CAGR	Compound Annual Growth Rate
CMMS	Computerized Maintenance Management System
CNC	Computerized Numerical Control
CPS	Cyber Physical System
ERP	Enterprise Resource Management
Etc.	Et cetera
EUR	Euro (currency)
FG	Finished Goods
FIFO	First-In-First-Out
GDP	Gross Domestic Product
GPS	Global Position System
I4.0	Industry 4.0
ICT	Information and Communication Technology
IoT	Internet of Things
IoS	Internet of Services
MES	Manufacturing Execution System
NFC	Near Field Communication
PCAST	President's Council of Advisors on Science and Technology
PLM	Product Lifecycle Management
PPP	Public Private Partnership
Qty.	Quantity
RFID	Radio Frequency Identification
SMS	Short Message Service
USB	Universal Serial Bus
USD	United States Dollar (currency)
WIP	Work-In-Process
WMS	Warehouse Management System
Wifi	Wireless Fidelity

Appendix A RFID Design

Use Case 2- Smart Kanban

Goal:

- WIP Tracking (A and B-Parts)
- Inventory On-Hand.

Process:

1. Attach RFID Sticker to each Bin with information regarding kanban.
2. At Work Station, when Bin is empty, scan it and place it in discharge tray. This will trigger Refill Order.
3. At Warehouse, prepare refill Bins according to Work Station orders.
4. Deliver Bins to Stations. Scan the Bin with the hand held unit then scan the location at the WS. This will attribute the parts to the location.
5. Pick-up empty Bins.
6. At Warehouse, scan the Bin before delivered to Work Station (between steps 3 and 4). This will reduce Warehouse inventory by 1 Bin amount and increase WIP by 1 Bin amount.
7. WIP is calculated by adding #Bins at Work Station and the parts already assembled at work station.

Use Case 3: Finished Goods Tracking

Goal:

- Real time tracking of finished goods (FG) and orders for transparency.

Process:

1. Scan the FG at input into FG Station. Example: Variant A goes into a separate storage spot as Variant B and Variant C. The signal from the RFID sticker on the fork should be able to be read through the box, so no unpacking is required. You can confirm the contents of the box for quality purposes. Utilize first- in first-out (FIFO) by loading in the front & remove from rear.
2. Data sent to DB for evaluation. When order is complete (or eta is within 1 process cycle), then notification is sent to proper recipient.
3. Order receipt vs delivery statistics can be maintained via historical DB.

Case 4: Real Time Tracking of Quality Rejects

Goal:

- Real-time tracking of Quality Rejects
- Fast process to handle defect parts.

Process:

1. When Quality reject is encountered, the operator scans the yellow ‘scrap’ card for that part. This is an RFID card that corresponds to the part number.
2. The operator then places the part in the scrap bin and put is on the discharge slide underneath the work station.
3. Process should take no more than 20 seconds. If there are a lot of defects, this will reject process affect production dramatically.

Case 5: Lifecycle Tracking

Goal:

- Attribute all production data and part information to each individual scooter.

Process:

1. A database would be created for Use Cases 1, 2, 3, and 4.
2. The information would be associated to the scooter by the unique serial number of its RFID tag.
3. The database would be maintained so that in the future all information in the database could be accessed. For example, in the case where an entire batch of supplied parts is found to be faulty, you could track batches of supplied parts and which scooter includes a part from a specific batch. You could then notify the affected customers of the recall. You could also scan the RFID on any scooter to determine if there are any recalls. This could be very valuable information for tracking defects and minimizing claims in case of faulty parts or recalls.

Website Links:

RFID Reader:

http://www.kathrein-rfid.de/pdf/52010190_ERU4-ETG-E4_936B027B.pdf

RFID Antenna:

http://www.kathrein-rfid.de/pdf/52010082_MiRa%20ETSI_9363752E.pdf

RFID Mobile Reader

http://www.kathrein-rfid.de/pdf/52010229_RUH-ACD-M260-ECE_936B079.pdf

RFID Accessories:

http://www.kathrein-rfid.de/en/products/accessories.html

Description	Qty.	Cost (EUR)	Total (EUR)	
Stage 1a:				
5 RFID antennas - incl. cables	5	180	900,00	
2 Readers- 4 port	2	700	1400,00	
Software:				
Cycle time tracking	5	800	4000,00	
Heijunka management	6	800	4800,00	
Heijunka Tracking	8	800	6400,00	
Quality Tracking	5	800	4000,00	
RFID stickers for Heijunka				
20 red	20	0,3	6,00	
20 green	20	0,3	6,00	
20 blue	20	0,3	6,00	
Quality Reject Cards-				
25 cards 5 each with 5 different colors	25	0,3	7,50	
Personnel ID cards- 50	50	0,6	30,00	
21" LCD monitor	5	300	1500,00	
stick pc	5	150	750,00	
	Total for Stage 1a			**23805,50**

Table 12- Budget Cost for RFID System: Stage 1a

Description	Qty.	Cost (EUR)	Total (EUR)	
Stage 2:				
1 portable RFID reader	1	2000	2000,00	
1 RFID antenna	1	180	180,00	
1 reader- 4 port	2	950	1900,00	
RFID stickers for all bins				
RFID stickers for all WH locations				
-estimate(250)	250	0,3	75,00	
on metal	30	1,8	54,00	
Software:				
Kanban tracking & management	8	800	6400,00	
Inventory Tracking- warehouse and work in process	5	800	4000,00	
Finished Goods Tracking	6	800	4800,00	
Order tracking & management with suppliers	4	800	3200,00	
monitor	1	300	300,00	
stick pc	1	150	150,00	
	Total for Stage 2			**23059,00**
Stage 3:				
NFC Reader/ Writer	1	100	100,00	
NFC Stickers: 100	100	0,4	40,00	
NFC Stickers: 100 (on metal)	100	2,5	250,00	
Software:				
Database management	6	800	4800,00	
Programming to read NFC sticker and access website.	4	800	3200,00	
Stage 1b:				
Control of 3D Printer with Heijunka control system.	4	800	3200,00	
Control of CNC Machine with Heijunka control system.	4	800	3200,00	
	Total for Stage 3 & 1b			**14790,00**
	Total for all stages			**61654,50**
Contact information:	matthias.weitlaner@erfideo.com			

Table 13- Budget Cost for RFID System: Stage 2, 3, 1b, and Total for All Stages

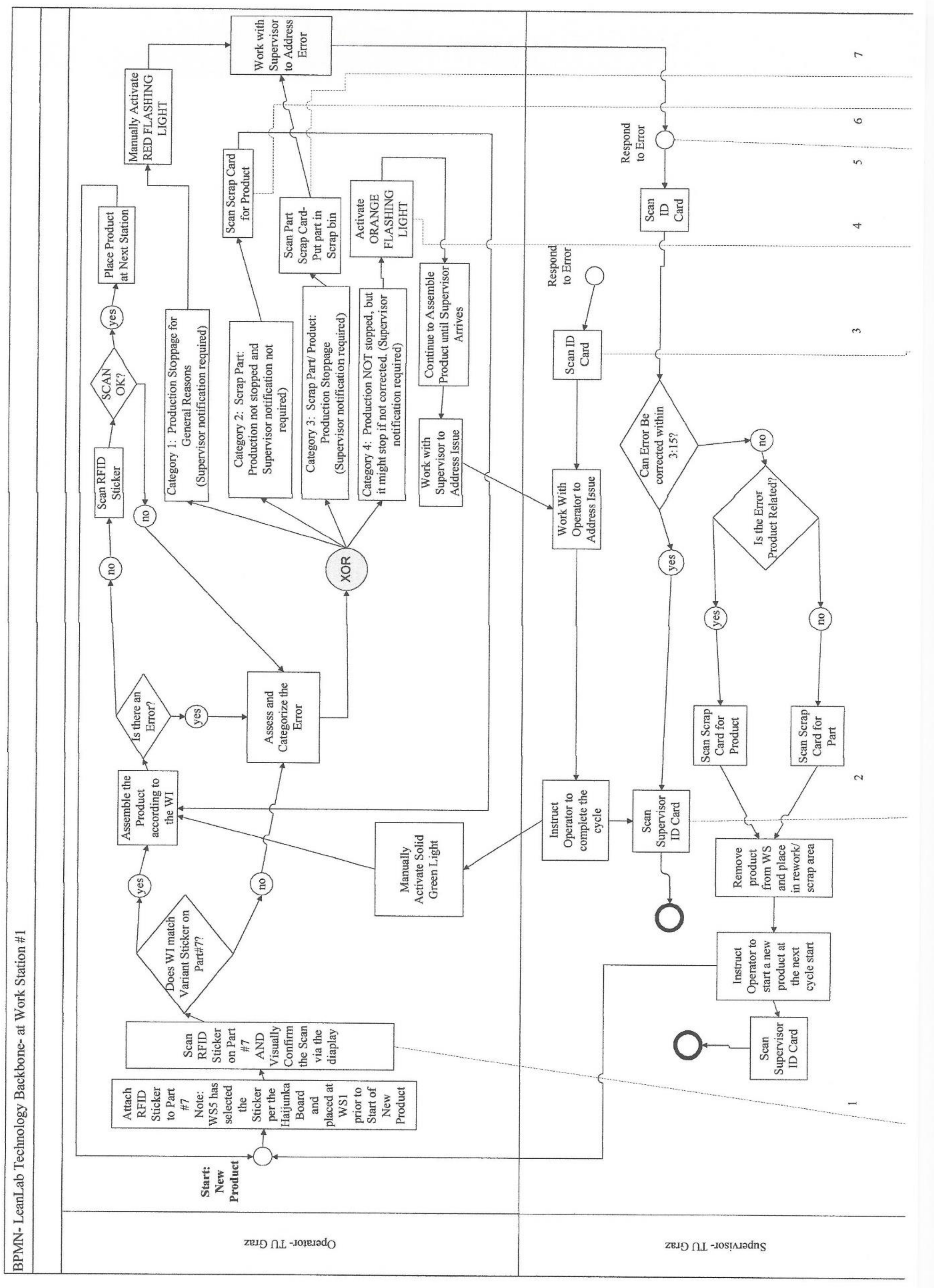

Figure 28: BPMN- LeanLab Technology Backbone- Part 1: Operator & Supervisor

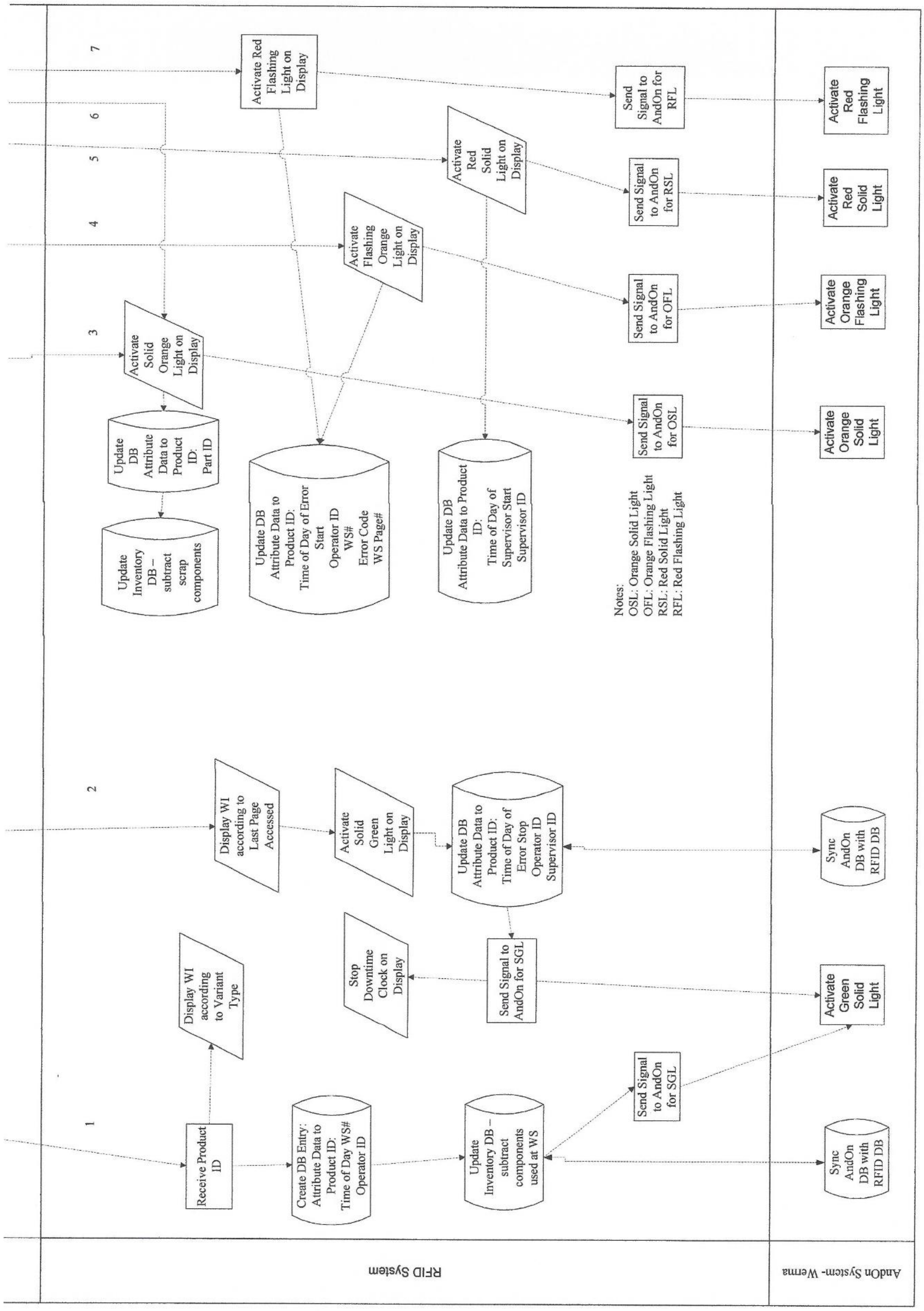

Figure 29: BPMN- LeanLab Technology Backbone- Part 2: RFID & Andon

Appendix B Smart Andon

Website Links

Werma WIN System Manual:

http://www.werma.com/d_d136021igdn/a8a4945059fd5d83531492300c86e7b5/werma_manual_2-86064013.pdf

Werma System Description:

http://www.werma.com/gfx/file/report/2014_15_Catalogue_en_Cover_Web.pdf

AS-i device to connect to RFID system

http://www.werma.com/en/s_c1005i685/AS-Interface_Module_BK/64681055.html

ADAM-6050 Device to connect Andon system to RFID System:

http://downloadt.advantech.com/ProductFile/PIS/ADAM-6050/Product%20-%20Datasheet/ADAM-6050_DS20140613100406.pdf

Andon System Cost- 4 WS				Additional Cost for 1 additional WS	
Description	Qty.	Cost Each (EUR)	Cost Total (EUR)	Qty.	Cost Total (EUR)
WIN System KS 71	1	1943,5	1943,5	0	0
Win Slave perf. KS 71	2	396,75	793,5	0	0
LED EVS Element- RD	4	96,55	386,2	1	96,55
LED EVS Element- GN	4	158,7	634,8	1	158,7
LED EVS Element- YE	4	96,55	386,2	1	96,55
LED EVS Element- BU	4	158,7	634,8	1	158,7
Mounting Base	4	17,2	68,8	1	17,2
Cage Clamp RM BK	4	20,07	80,28	1	20,07
Andon Box BWM BK	4	194,93	779,72	1	194,93
Cable 5m with M12 Stecker	4	38,53	154,12	1	38,53
Total Cost for 4 WS			5861,92		
Total Cost for 1 Additional WS					781,23
Total Cost for 5 WS			6643,15		

Interface of Andon System to RFID System			
Description	Qty.	Cost Each (EUR)	Cost Total (EUR)
AS-i module	5	114,55	572,75
ADAM-6050-CE - software	1	163	163
ADAM-6050-CE - modules	5	158	790
ADAM-6050-CE - power supply	5	94	470
ADAM-6050-CE - OPC Server	5	104	520
ADAM-6050-CE - hardware	5	25	125
Total Cost			2640,75

Contact information: birgit.schmidberger@werma.com

Table 14- Budget Cost for Andon System and Interface to RFID System

Appendix C Smart Supply Chain Management

iBin System:

https://www.wuerth-industrie.com/web/en/wuerthindustrie/cteile_management/kanban/ibin_intelligenterbehaelter/ibin.php

Local Distributor for iBin System:

http://www.reca.co.at/de/dienstleistungen/reca-rfid/flexibel-in-den-varianten.html#c9603

Description	Quantity	Cost each (EUR)	Total Cost (EUR)
KLT storage Bin	80	7,00	560,00
iBin Module with camera	80	75,00	6.000,00
Master access point	1	4.800,00	4.800,00
Installation cost (per day)	3	450,00	1.350,00
		Total Cost	12.710,00
Contact information:		Guenther.Altenburger@reca.co.at	

Table 15- Quotation for iBin System

List of C-Parts								
WS #	Part #	Part Description	1 Day Qty.	Standard Cost*	Standard cost (1 Day Qty.)	iBin System Cost	iBin System cost (1 Day Qty.)	Total Part Cost (1 Day Qty.)
1	A	Caged Ball Bearing	276	0,85	234,60	0,13	35,19	269,79
1	B	Spring - ϕ8x50L	138	0,50	69,00	0,08	10,35	79,35
1	C	M5x60L Bolt	138	0,15	20,70	0,02	3,11	23,81
1	D	M5 Flat Washer	276	0,01	2,76	0,00	0,41	3,17
1	F	M4x10 Flat Head Cap screw	138	0,05	6,90	0,01	1,04	7,94
1	G	Slide Clip- Plastic	138	0,10	13,80	0,02	2,07	15,87
1	H	Screw- ϕ6x6L- Phillips	138	0,05	6,90	0,01	1,04	7,94
2	A	M4x74L Brake Bolt	138	0,20	27,60	0,03	4,14	31,74
2	B	M4 Lock Nut	138	0,10	13,80	0,02	2,07	15,87
2	C	M5x25 Cap screw	414	0,08	33,12	0,01	4,97	38,09
2	D	M5 Lock Washer	414	0,01	4,14	0,00	0,62	4,76
2	E	ϕ6x45L Shoulder Bolt	138	0,15	20,70	0,02	3,11	23,81
2	F	M5x15L Cap screw	138	0,10	13,80	0,02	2,07	15,87
3	A	M5x40L Skewer Bolt	138	0,15	20,70	0,02	3,11	23,81
3	B	M2.5x5L Setscrew	138	0,05	6,90	0,01	1,04	7,94
3	C	M5 Skewer Nut	138	0,05	6,90	0,01	1,04	7,94
3	D	Skewer Washer- Plastic	138	0,05	6,90	0,01	1,04	7,94
3	E	M5 x30L Cap screw	276	0,10	27,60	0,02	4,14	31,74
3	F	ϕ5x22L Dowell Pin	138	0,10	13,80	0,02	2,07	15,87
3	G	Steering Tube	138	2,50	345,00	0,38	51,75	396,75
4	A	M5x15L Cap screw	138	0,10	13,80	0,02	2,07	15,87
4	B	ϕ6x75L Shoulder Bolt	138	0,15	20,70	0,02	3,11	23,81
4	C	ϕ6mm-10L Spacer	276	0,10	27,60	0,02	4,14	31,74
4	D	M5x20L Cap screw	276	0,10	27,60	0,02	4,14	31,74
4	E	M5 Lock Nut	276	0,10	27,60	0,02	4,14	31,74
				1 Day Cost (Standard)	1.012,92		1 Day Cost (iBin & Deliver)	1.164,86

Assumptions

15% additional cost for iBin system

Refill C-parts bins 1 per day at Work station

cost to inventory 25%

Standard price was rounded to 0.05

extra cost for iBin System	151,94	per day
cost to inventory	253,23	per day
Savings with iBin system	101,29	per day
#production days	270,00	per year
Savings with iBin system	27.348,84	per year

Table 16- List of C-Parts and Cost Savings Calculation for iBin System

Takt Time Calculation	
Yearly Consumption	37.000
production days / year	270
hours/ day	7,5
# shifts	1
hours/ year	2025
minutes/ year	121.500
Takt Time	3,28378
Calculation of #products produced per day	
hours/ day	7,5
#minutes/ day	450
#products/ day (based on Takt)	137
Calculation of Max & Min inventory	
Max # parts (# production days)	2
Max # parts (qty.)	274
Min # parts (# production days)	0,5
Max # parts (qty.)	69

Table 17- Calculation of Max & Min Inventory Level for C-Parts

Cost of labor for 1 day of downtime		
Size of assembly crew	5	**people**
Work hours per day	7.5	**hours**
Hourly burden rate***	29,57	**€/hour**
Total labor cost per day	1.182,80	**EUR**
Downtime (days)	1	
Cost for 1 day downtime	1.182,80	
Loss of profit resulting from lost sales due to 1 day of downtime		
Number of scooters produced in 1 day	137	
Sales price of scooter	70,00	**EUR**
Revenue of 1 day of production of production	9.590,00	**EUR**
Profit per scooter	20%	
Loss of profit from loss of 1 day of sales	1.918,00	**EUR**
Total loss due to 1 day of downtime		
Total losses for 1 day of downtime	3.100,80	**EUR**
Risk Assessment calculation		
Total yearly savings of iBin System	27.348,8 4	**EUR**
Number of downtime days required to negate the yearly savings of the iBin system	8,82	**days**

*** see reference #125

Table 18- Downtime Cost and Risk Assessment Calculation

Appendix D BLE Beacons

Website Links

Beacon manufacturer:

http://estimote.com/

Use Cases:

Macy's: https://www.umbel.com/blog/brands-agencies/macys-ibeacons/

Japan Airlines, American Airlines, Virgin Atlantic:

https://www.umbel.com/blog/mobile/15-companies-using-beacon-technology/

Nivea: http://www.ibeaconsblog.com/nivea-ibeacons-beach/

https://www.sticknfind.com/sticknfind.aspx

Contacts:

Konrad: info@estimote.com

Piotr Krawiec: piotr.krawiec@estimote.com

Appendix E Reference Information

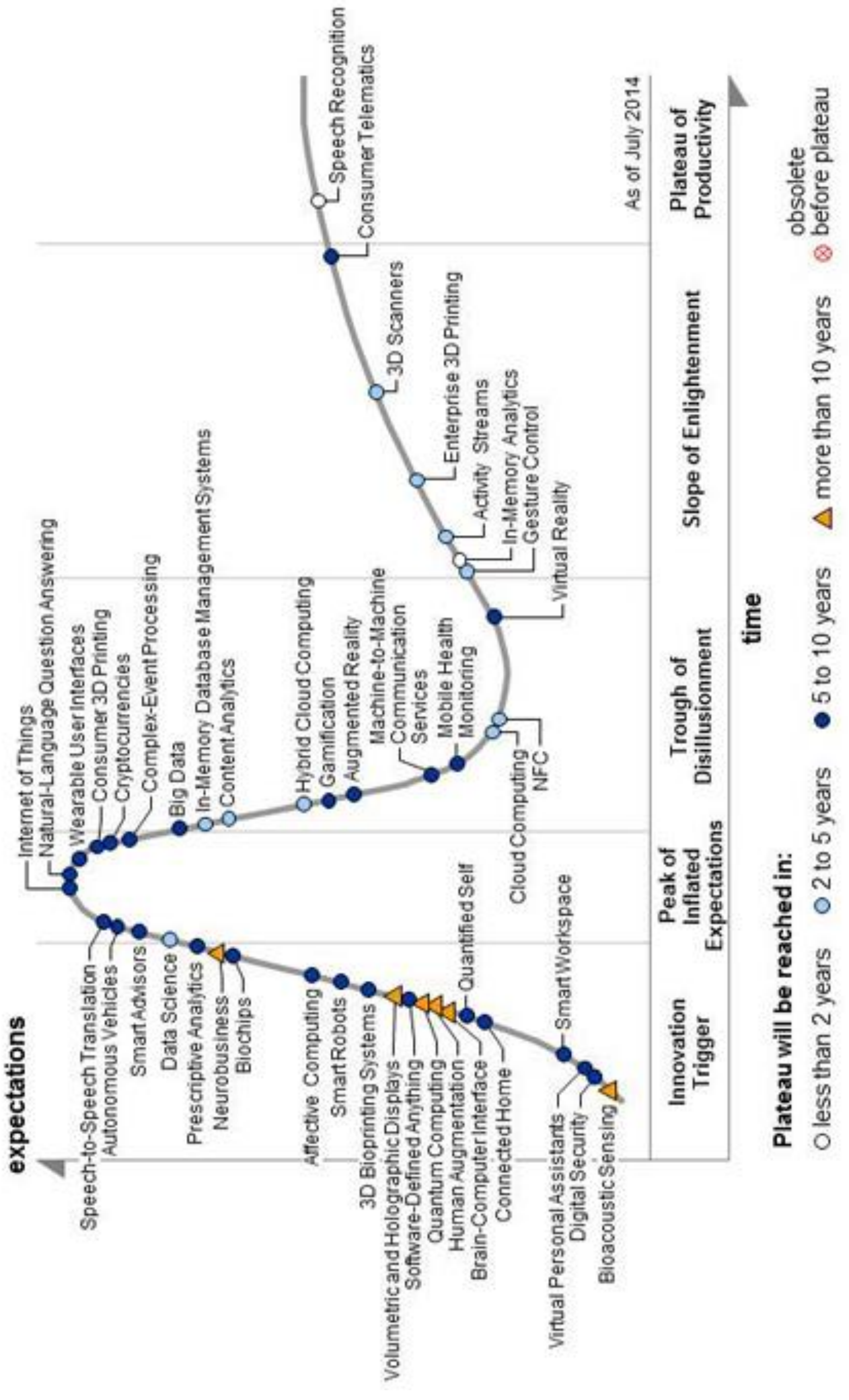

Figure 30: Gartner Hype Curve for Emerging Technologies- 2014-2015

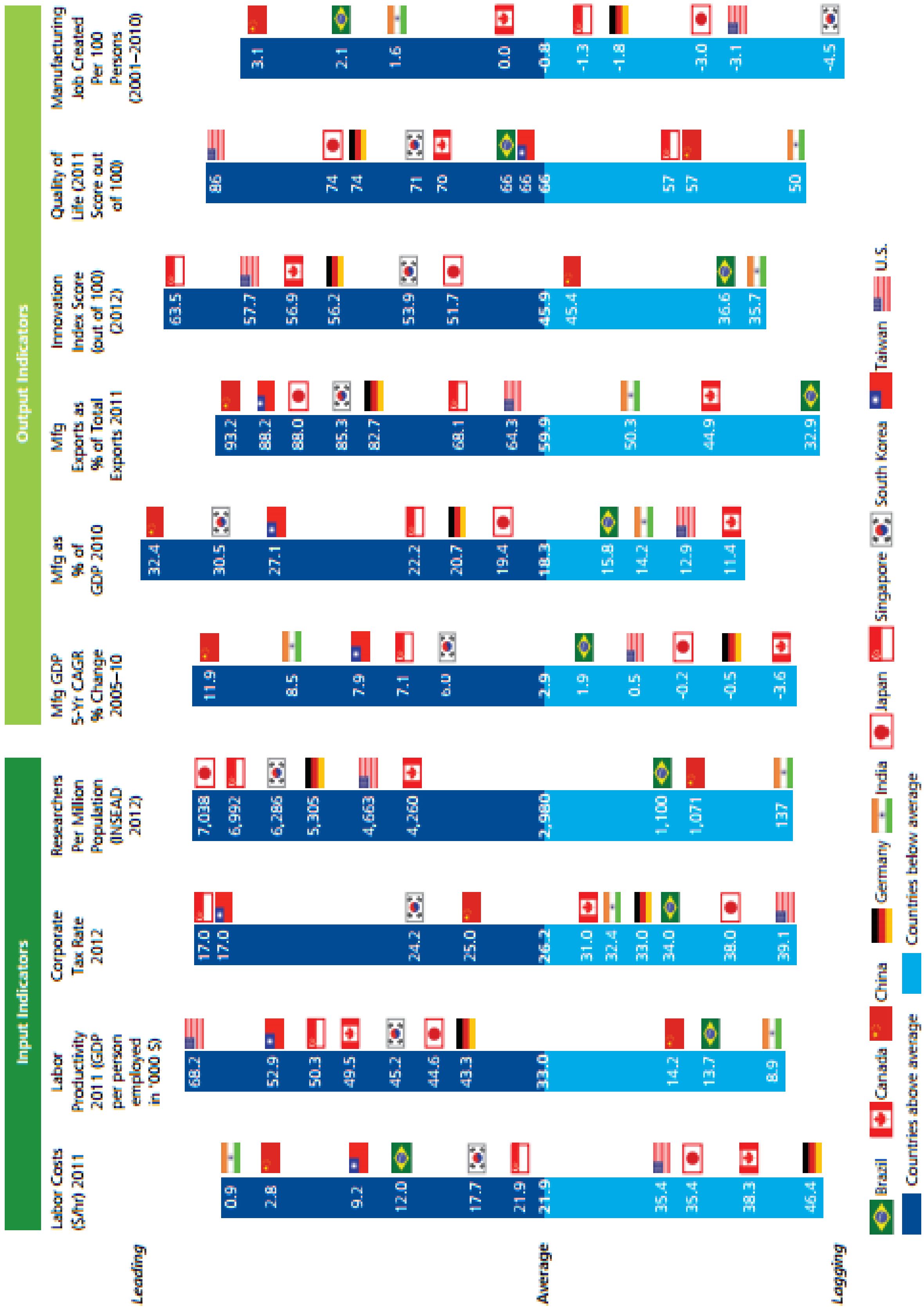

Figure 31: Competiveness driven differently among most competitive nations