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Industry 4.0 Implementation in the Injection Molding Industry

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ABSTRACT

Industry 4.0 and additive manufacturing processes are enabling the growth of the injection molding industry. Smart companies are the next step in technological advancements, sometimes called Industry 5.0. German manufacturers have been repeatedly found in literature to be the most prepared for this next step. However, companies in the United States are not yet advanced enough to move to smart factories. This thesis will discuss the many factors that affect a company's preparedness for Industry 4.0 and Industry 5.0. It will also discuss some of the barriers to implementing Industry 4.0 technologies as well as the advantages gained from implementing these technologies. Then, several Industry 4.0 technologies used in the plastics industry will be discussed. It is expected that Industry 4.0 adoption will continue at an exponential rate until reaching a certain threshold, which will vary for different industries. In order to further understand current practices and implemented technologies, a survey was conducted and sent to numerous injection molding manufacturers. The survey was sent to over 350 individuals and had a response rate of roughly 5%.

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Chapter 1

Industry 4.0

History

One of the social considerations engineers face is the determination of how to improve manufacturing processes. Increasing the efficiency and manufacturability of processes is a major goal for companies around the world. One of the major factors driving this advancement is the ability to control machinery more intelligently [1]. How can companies control machines more intelligently? The answer likely lies in Industry 4.0 technology.

Industry 4.0 was introduced by the German Federal Government. This term refers to the current trend of establishing intelligent products and production processes and is often referred to as the fourth Industrial Revolution. This emerging technology is also known as the smart factory, intelligent factory, Internet of Things (IoT), and cyber physical system (CPS) [2]. Smart factories are also the start of Industry 5.0, which looks to connect entire factories to the internet for real time monitoring. These technological advancements provide competitive advantages for companies that implement them. For the purpose of this thesis, Industry 4.0 is defined as the current manufacturing processes that utilize the digital media, such as the Internet of Things (IoT), in order to add value to the process.

Germany stands to gain many benefits from the potential of Industry 4.0. Industry is a huge part of Germany's economy, and the country is a world leader in machine building, automation technology, and plant engineering. Given the major importance of small and medium-sized enterprises, also called the Mittelstand, for the German economy, Industry 4.0 technology stands to greatly enhance the productivity of these enterprises. Around 95% of all companies in Germany are considered part of the Mittelstand, and there are roughly 690,000 small and medium-sized enterprises (SMEs) in production alone without including the large enterprises [3]. Coupling the fact that Germany is leading the world in plant engineering and has a major dependence on its Mittelstand, it seems obvious that the country would have high levels of Industry 4.0 implementation. However, full implementation has not yet occurred on a country-wide scale.

The United States currently lags European companies in the implementation of Industry 4.0 technology by approximately five years [1].

Due to the large expenses incurred in implementing Industry 4.0, large companies are more likely to introduce the new technology than small companies. Currently, 5.6% of machinery and plant engineering companies have achieved advanced implementation of Industry 4.0, while just under 18% are exploring Industry 4.0 concepts in order to implement the first steps in putting them into practice. A fifth of machinery and plant engineering companies, along with one fourth of companies in the manufacturing industry, claim that Industry 4.0 is unknown or unimportant to them. Embedded systems are a key component for adoption of these new technologies, as cyber physical systems (CPS) are basically mini-computers, which can be used to measure physical states, such as temperature or pressure, through sensors [3]. These CPS systems, as well as the sensors, are not cheap, making implementation an expensive upfront cost without a guaranteed return.

As Industry 4.0 is implemented more in the workplace, workers will need to think in more interdisciplinary ways. Industry 4.0 involves interfacing IT and machinery with machine operators. These operators will need to have IT knowledge in order to properly run the equipment. In addition, the boundaries between companies in the production supply chain will become increasingly blurred [3]. As suppliers and manufacturers utilize data generated from Industry 4.0 technologies, it will allow for companies to be more knowledgeable about the current status of orders.

Several framework conditions will determine the readiness and ability of small to medium sized companies to adopt Industry 4.0 technologies. Some of the key conditions are the financial environment, the availability of skilled workers, extensive and high-performance broadband access, state support and legal framework conditions. In order for new technology to be accepted, it must be introduced in a socially and humanly acceptable manner. Simply put, the interests, skills, and experiences of employees will need to be understood before introducing Industry 4.0. Germany currently has the high technical knowledge required for each of these phases. This knowledge comes from their education in the MINT subjects (mathematics, informatics, natural sciences and technology). German education in mathematics and natural sciences was deemed to be high quality relative to international standards by World Economic Forum experts [3].

Arburg demonstrated the latest state-of-the-art technology at the Fakuma 2015 trade show by producing office scissors. Visitors had the opportunity to transform a mass-produced item into an individualized, one-off product through the use of Industry 4.0 implementation. The host computer would assign a web page to each part in the cloud, and then use a code to retrieve the part-specific web page any time and from any place in the world using a mobile device – even after several years. This feature would be key for traceability purposes in safety-related parts, like airbags or medical implants. This level of individual part tracking is also the foundation for just-in-time production. The control system was developed in-house by Arburg. The operating panel was comprised of a high-performance industrial PC with a multi-touch screen. The touch screen could also be intuitively operated via gestures. The 3D CAD data for the manufactured parts were prepared offline on a separate PC according to quality and material-dependent criteria. The required production data were then generated using special software by slicing. With this implemented technology, Arburg had the full extent of its production at its fingertips, which would be very useful for manufacturers in production meetings with customers (or suppliers) [4].

Chapter 2

Barriers to Industry 4.0

Size of Company

Small to medium size companies struggle to implement Industry 4.0 technology. They lack adequate resources to assess the technological maturity of the relevant solutions for their business uses. There is currently no methodical approach to implementation from a management standard. With this flaw, four out of ten SMEs do not have a comprehensive Industry 4.0 strategy as opposed to two out of ten among large companies [3].

As mentioned previously, large enterprises are more likely to implement Industry 4.0 technology than small or medium sized companies. There is a significant correlation between a company's size and its Industry 4.0 implementation. This is most likely due to the fact that large companies can have much higher efficiency gains from the use of Industry 4.0 technologies than SMEs. Large companies are significantly more advanced in integrating their production plants with higher-level IT systems than medium-sized entities and medium-sized companies are generally much more advanced in integrating higher-level IT systems than small enterprises [4]. SMEs struggle with Industry 4.0 implementation due to limited resources and inexperience managing new technologies [5, 6].

Cost of Implementation

Industry 4.0 has the potential to provide companies with strong global competitive advantages. In 2020, 50% of Canadian plastics companies experienced growth despite the pandemic. Several reasons were cited for the limited growth, including competitive Asian pricing and rising resin prices. However, many plastics companies did not implement Industry 4.0 technology in 2020. In fact, several companies suggest that their lack of implementation limited their growth [2]. Why didn’t these companies invest in new technologies? The perceived value of implementation was low.

SMEs work under significant resource constraints, especially financially. Financial limitations cause management to be careful with their investments and capital spending decisions. With this in mind, it is clear that only SMEs with significant resources would be confident in implementing Industry 4.0 projects [7]. Industry 4.0 costs accrue from a variety of sources, including, “dismantling existing physical infrastructure, new digital hardware, software applications and modules, security measures, licensing, external experts and consultation, in-house training of employees, new system integration and debugging, as well as maintenance,” [8]. There is a high correlation between perceived value of investing in Industry 4.0 technologies and their implementation [7].

Lack of Skilled Workers

Industry 4.0 relies on the practical knowledge of production workers and their reflective and adaptive capacities can be paired with machine precision and speed to increase effectiveness. As these technologies advance and are implemented on higher levels, full automatization can be achieved. This development will cause a shift in employment in several manufacturing facilities. First, Frey and Osborne (2013) suggest a frightening future: a large percentage of human labor could be performed by machines. According to their calculations, nearly 47% of

United States workers are in jobs that will likely be automated over the next 10 to 20 years. Bonin et al. (2015) have examined these studies for Germany and computed a figure of 42% of German jobs will be automated in the next 10 to 20 years. As these jobs are erased, more technical jobs and skills will be required in order to support Industry 4.0 [3].

Keeping up with the new demands of Industry 4.0 will require heavy investment in skills development. In fact, in a survey conducted in the UK, 88% of manufacturers said that the skills gap is the biggest barrier to implementing smart manufacturing technologies. This gap has an important impact in the UK, as an estimated £63 billion loss per year for UK companies. Even educated engineering job candidates have been found to possess the required academic knowledge but lack the necessary workplace skills [9]. In Germany, SMEs have been aware of the need for improved employee skills and have gotten their employees trained in IT skills at a higher rate than the European average [3].

Clearly, this advancement of technology relies on emerging graduates from MINT subjects. However, graduates in MINT subjects have not caught up to the demand for several years. With this shortage of graduates, there has been a shortage of skilled workers in occupations that are necessary for the implementation of Industry 4.0, including electrical engineering, informatics and software development. It takes over 110 days to fill a vacancy in these positions in Germany [3]. With the United States lagging in education and skilling compared to Germany, it is likely similar positions will remain open even longer in the United States [9].

Standards and Data Control

There is a lack of general standards for data control between interconnected companies using Industry 4.0 technologies, such as between an automotive part manufacturer and Ford, for example, which makes it difficult for SMEs to join value creation networks, as they all have different standards and norms. These different standards make it more difficult for the SMEs to maneuver with other companies, limiting their opportunities. With few set standards, there is often concern that the high investments associated with different technology will have to be written off if managers purchase interface technology that does not end up being used. For this reason, a large segment of producers in the Mittelstand only adopt Industry 4.0 technologies if there is high CPS interoperability and project security from standardized interfaces and protocols [3].

Standardization is not only a problem for SMEs but also regulators and legislators. Technology is rapidly changing in the realm of Industry 4.0, and this rapid development can have a broad impact on customers and their interests. For this reason, it is crucial for regulators and legislators to develop ways to safeguard customers. Regulators must have the capability to adapt quickly to the changing technology landscape to be able to understand what they are regulating [10].

Lack of Knowledge

Industry 4.0 requires new skills from employees, especially concerning IT. Employees' existing qualifications and experience must be considered in the introduction of Industry 4.0 in order to reflect on production processes and to facilitate continuous improvements. Industry 4.0

necessitates a reallocation of tasks as well as new responsibilities that need to be paired with appropriate training measures. Training must also be completed on the consensus-oriented concepts of data protection and mobile work, which must be developed with the participation of workplace codetermination bodies [3].

One of the most cited reasons by managers for low growth in the plastics industry was the lack of Industry 4.0 implementation. Specifically, there appears to be a great knowledge gap for Industry 4.0 in the plastics industry compared to other sectors. A study for Industry 4.0 implementation discovered that several SMEs have not become aware of the advantages and potential that Industry 4.0 offers. In the paper [2], it is argued that there is a great lack of knowledge about Industry 4.0 in the plastics industry, having conducted a literature review of Industry 4.0 publications compared with Industry 4.0 focused on the plastics industry.

In their research exploring two databases, they found 26,382 publications for Industry 4.0, with only 138 publications specifically related to the plastics industry. Similarly, the most productive author for Industry 4.0 had 268 publications on the topic, while the most productive author focusing on the plastics industry had 5 publications. Considering one author has written nearly two times the number of publications that were written with regard to the entire plastics industry, it is obvious that there are huge gaps in knowledge. Germany and the United Kingdom were more focused on plastics research than the United States. Clearly, more research needs to be completed in the United States, and the findings could potentially influence the future of Industry 4.0 adoption rates here [2].

Chapter 3

Advantages of Industry 4.0

There are several advantages to using Industry 4.0 technology. One of the most important of which is the advanced planning and control using relevant, real-time data that it provides. These data allow for real feedback from different machines and processes after they have been adjusted. This information is critical for injection molding, as cycle time changes can make a huge difference in run times. Being able to constantly monitor processes allows for safer work conditions, as fewer employees are needed on the plant floor [11, 12].

Industry 4.0 technologies allow for higher quality, flexible products. These flexible products can be personalized with ease. This development leads to mass customization of products to fit different customers' needs. These personalized products can enable a new level of customer satisfaction. Companies can react more quickly to changes in demand, inventory, or errors using these technologies. For instance, a rejected part may be found by a customer from a certain production run. Using a digital tracking database, a company can quickly track the other parts from that run, in order to check them and ensure that other bad parts were not being shipped to customers. Implementation allows for an increased competitive advantage for companies.

Additionally, there are significant potential cost and waste reductions from using Industry 4.0 technologies. The potential cost benefits are shown in Table 1 below. Industry 4.0 technology increases productivity in the workplace, as it reduces waiting time and enables proactive strategies due to the real-time monitoring. This can reduce scrap costs, costs associated with wasted motion and waiting, and quality costs. Operational efficiencies were expected to increase by an average of 3.3% year over year from 2015 to 2020, which was expected to reduce costs by 2.6% annually. These cost reductions lead to higher margins, and the growth caused by Industry 4.0 is expected to generate a 6% increase in employment by 2025 [11].

Table 1: Evaluation of Potential Benefits from Industry 4.0 [3]

Inventory Costs	-30% to -40%
Manufacturing Costs	-10% to -20%
Logistical Costs	-10% to -20%
Complexity Costs	-60% to -70%
Quality Costs	-10% to -20%
Maintenance Costs	-20% to -30%

There are several environmental advantages gained from using Industry 4.0 technology. As mentioned previously, there is a reduction in waste as well as overproduction. Interconnectivity allows for the reduction of waste in the product development phase, as stakeholders can access and examine prototypes in order to assess the developed product. This limits the use of natural resources until necessary and can reduce transportation and travel for individuals [11].

Industry 4.0 serves to benefit manufacturing companies around the globe. Creating smart products integrated with smart production, smart logistics and smart networks with the Internet of Things allows for new, innovative and highly efficient business models. This combination sets the baseline of the smart factory, which is expected to be part of future smart infrastructures. Smart factories will rely heavily on vertical integration through the Cloud. Using this integration, several feats can be accomplished, such as using virtual and augmented prototyping to allow all stakeholders to explore a product's features and benefits or up-to-date information on part production from a supplier as it is being made [11].

Chapter 4

Industry 4.0 Technology

Robotics

Robotics have been in use since 1959, when the first commercially available robot was developed by Planet Corporation. Robotics have been used in a variety of ways, such as car assembly, spray-painting, arc-welding, military and law enforcement applications, and space exploration, to name a few. The first internet connected industrial robot was used in 1994. This advancement in technology allowed the robot to be operated from anywhere using the internet. One of the most influential reasons robotics are used in today's manufacturing environments is that they cut costs, reduce variation, and improve efficiency [13].

As internet usage gained popularity, cloud robot and computing automation systems have become more popular. "Cloud Robot and Automation systems can be broadly defined as follows: Any robot or automation system that relies on either data or code from a network to support its operation, i.e., where not all sensing, computation, and memory is integrated into a single standalone system," [14]. As a very competitive industry, injection molding manufacturers utilize robotics for several tasks, such as assembly, packaging, and differentiation between product and waste material. Connecting robots to the Cloud allows for quality control throughout these different operations. This Cloud connection also allows for big data generation, which can be used for machine learning [14].

Sensors

Sensors are used in several different ways, such as to improve performance, allow for higher integration, and for multi-parameter sensing. In this context, sensors have been identified by the term Sensor 4.0. There have been four designations of sensors. They are identified as purely mechanical indicators, electrical sensors, the state-of-the-art electronic sensors, and smart sensors [15]. As seen in Figure 1, industrial evolution has been heavily reliant on the development of sensors and instrumentation.

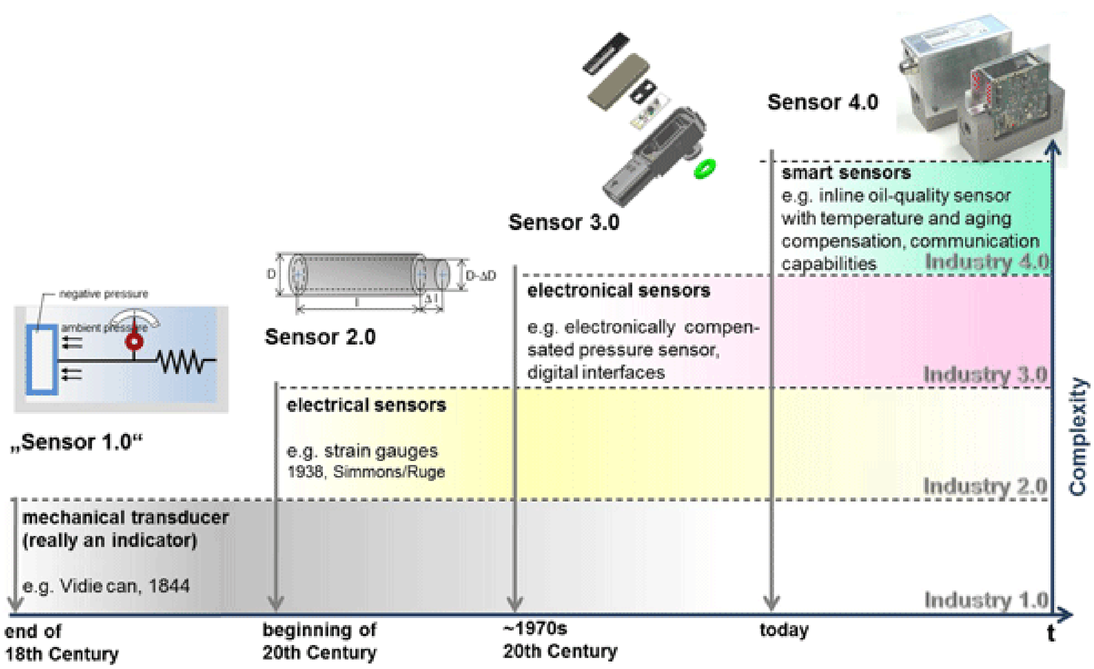

Figure 1: Industry 4.0 Sensor Development [15]

One of the biggest technical challenges facing use of robotics is gripping a new part. What is the optimal way to grip a part in order to be efficient, use minimal resources, and not cause damage to the part? This is one way in which sensors connected to the Cloud are valuable. Combining sensor data with CAD models from an online database, grasp techniques can be determined. Sensor data can be 2D image features, 3D features, and 3D point clouds [14]. This practice can often be found in the injection molding industry.

Automated Guided Vehicles

Automated Guided Vehicles (AGVs) have become more popular in several different areas of industry. AGVs are often used in internal transport systems [16]. AGVs are utilized in order to enhance efficiency and productivity in manufacturing and distribution environments. These vehicles follow a planned route in order to complete objectives without the use of an operator. Achieving an efficient AGV system can effectively reduce operational costs [17].

AGV systems have rapidly evolved over time. Traditional AGV systems' vehicles followed fixed guide-paths. However, newer systems allow AGVs to be free ranging. The preferred tracks are software based, and these tracks can be altered with ease to account for new work areas or flows. Another development from traditional AGV systems is the way AGVs are controlled. New technology allows for the AGVs to make decisions that were once completed by central controllers. This adaptive technology has given rise to self-learning systems. This change has allowed AGVs to go from small and simple systems with only a few AGVs to large and complex systems with many vehicles and the potential for vehicle interference [16].

AGV systems are run using single-load AGVs. However, a new concept, multi-load AGV, was developed. The multi-load AGV is more advanced, as it can pick up multiple parts from each station and can also pick up objects from more than one station. Using one multi-load AGV does take more time to complete its objectives than several single-load AGVs, but the total operating time is drastically reduced. Multi-load AGVs would therefore be best suited for injection molding companies since there would most likely be several different loads.

Color Blenders and Material Loading

Colorants and additives are important for numerous injection molded parts in order to give the parts better aesthetic or physical properties. Manually blending and feeding plastic into an injection machine hopper is an inefficient process with associated problems. These issues can include color variation due to poor mixing, color streaks, increased process rejections, wasted time due to machine stoppages, and high labor costs associated with material mixing. The major variables to consider when blending plastic materials is the accuracy of the blending ratios and the blend homogeneity [18].

There are four main blending processes. The first process is manual blending. This type of blending is not commonly used. The advantage of using this system is avoidance of investment or installation costs. However, these cost savings are often offset by high labor costs [18].

The second process is proportional vacuum loader blending. In this method, air is sucked through a loading system at high speed to create a low pressure which pulls material through the system. In order to blend material, two pipes are used in a single hopper. This system loads a single material at a time. The amount loaded is based on a timer, and then the vacuum switches to the other material. The advantages of this system are simplicity and low cost, while the loading and blending are completed in one unit. However, there is low blending accuracy and inhomogeneous blending with proportional vacuum loader blending due to the loading mechanism. These issues can be improved using an auger to better mix the material [18].

The third process uses volumetric blenders. There are several different forms of volumetric blenders in the plastics industry. A common method of using volumetric blenders is consists of introducing an additive to the desired material using a feeding screw. The material drops into a mixing chamber to the feed throat of the machine. The material and additive are blended together in a mixing chamber. The mix heavily depends on the rotation speed of the screw and screw size. The screw's speed is dependent on the mixing ratio, the groove size of the screw, and the size of the additive pellets. The advantages of volumetric blenders are that they are simple and inexpensive and more accurate than proportional loaders. The disadvantages are that there may be inconsistent blending, they require skilled operators and observation, and in process adjustments are often needed [18].

The fourth process is gravimetric blending. This blending process is the most accurate among those listed. In this method, the weight is used to mix the additive and material. Since the system is determined based on weight, the accuracy of the blender is determined by the load cell, which weighs the material, and the blender's operating software. There can be several hoppers on volumetric blenders, and each blender is controlled by a gate. Each gate will open and drop material until it has reached the desired amount. Then, the material is dropped from the load cell into the mixing chamber. The material is then mixed and fed into the machine. The advantages of gravimetric blending are its consistency, higher accuracy, trouble-free operation, and homogeneous blending [18].

As injection molding companies get larger with associated high-volume production, manually filling machine hoppers becomes quite time consuming and expensive. One of the main approaches used to combat this problem is by using hopper loaders. Hopper loaders operate on a vacuum principle. The material is sucked from the source of raw material, whether it is a bag or a master tank containing the material. Based on the amount of material being used in each shot as well as the time required for a machine cycle, operators will set a time on the hopper loader. At the specified time, the loader powers on and stays running for the pre-set amount of time, filling the loader with material [19].

Hopper loaders have evolved to include level sensors, self-buzzers, and coils which are operated by pneumatic cylinders. The level sensor signals when to empty the loader, and the coil causes the cylinder to open the valve for vacuum suction. Material is sucked into the loader and then the suction stops when the level sensor indicates that the loader is full. This kind of hopper loader has several advantages. First and foremost, there is no need for human intervention compared to the configurations previously mentioned, which required operators to manually set the vacuum time. Hopper loaders prevent operator fatigue. There is also no productivity loss based on lost time, which aids in reduced process rejection [19].

Assembly Equipment

The development of Industry 4.0 technology has led to improvement of assembly line efficiency and flexibility. Cyber-physical systems (CPS) and additive techniques are two of the emerging technologies that allow assembly lines to be more flexible. Physical components with computational functionalities make up CPS systems. These systems are often managed or monitored using computer algorithms. CPS systems enable additive manufacturing (AM) processes [20]. AM allows for mass customization of parts and permits parts to be made efficiently [21]. As Industry 4.0 technologies continue to be implemented, mass customization will become particularly important for mass personalization business strategies. Managing production of these customized goods will become a new challenge for companies to meet. With several distinct factors to consider, CPS will be vital to this work structure. It is even possible that CPS can plan and operate mass customization production processes in a decentralized and autonomous manner. At peak performance, a CPS can collect information and specifications from a customer and develop production plans for every part or product using recorded processes and 3D design tools [20].

Assembly line systems will have the potential capability to accommodate late customization as production flexibility increases. This will have a significant effect on production and afford companies who successfully utilize this technology a competitive advantage. Allowing for late customization of already mass customized products gives customers the ability to monitor production through the Cloud and propose modifications to their starting product. In this production method, the client would need real-time information about the production development of their goods. This structure is possible only in an Industry 4.0 environment, as it relies heavily on fully operational IoT, CPS, and cloud linkages [20].

Autonomous production can be completed using Industry 4.0 technology that can handle the planning and control functions autonomously. This means that instead of having people structuring production orders and material flow, the technology will do it. This requires a hierarchical structure of computing, which can be found by examining standards such as ISA 95. ISA 95 is defined by [22] as ‘the international standard for the integration of enterprise and control system. ISA-95 consists of models and terminology that can be used to determine which information has to be exchanged between systems for sales, finance and logistics and systems for production, maintenance and quality.' CPS systems communicate throughout the hierarchy from the business logistics system all the way down to intelligent devices and physical processes in order to control the manufacturing process [20].

Production and Efficiency Reporting

"Automated identification involves the automated extraction of the identity of an object," [23]. Automatic decision making and control functions have been more effective due to the advancements of identification technologies. With accurate and up-to-date information, companies have more control over the workflow in their companies. This technology has rapidly developed, with large price drops as well as reductions in the amount of required equipment and infrastructure. One common Industry 4.0 Auto ID technology is radio frequency identification (RFID). This technology uses radio frequency identification to link and trace items with attached RFID tags [24].

Objects linked through a network can interact and cooperate with each other [22, 25, 26]. These objects can range from products and phones to machinery and other units. Their interconnectivity through the network allows for capture of a complete synopsis of the product workflow. This overview gives operators and/or decision makers the opportunity to more quickly react to changes on the manufacturing floor. It also contributes to improved transportation planning of finished products through a supply chain with real-time status of all finished goods in transport [24].

Vertical integration from the shop floor to an ERP system will allow for integrated information management, which could help refine manufacturing logistics. This integration will require that production planning and control tasks and the flow of material through the factory be performed with support from IT systems. This requirement would need the necessary systems to be applied and used. In order to achieve real-time production control, Auto ID will need to be used on the shop floor [27]. Integrated IT systems must be used to fully unlock the benefits of the Auto ID technology [24].

Logistics 4.0

Logistics 4.0 is the name given to the specific application of Industry 4.0 in organization. This area deals with the management of the flow of people and things between a starting point and the point of consumption. Key areas of focus are transportation, storage, handling, identification, packaging, unpacking, making, and securing loading units [28].

There are several possibilities for efficiency and productivity improvements in the realm of Logistics 4.0. Smart logistical objects use embedded systems to gather data, interface, and network. These objects utilize identification technology and sensors to identify logistical products and their load carriers' behavior. This information is then used to develop a basis for holistic tracking and tracing solutions for quality control. Smart logistical objects include smart products, smart pallets, smart boxes, smart storage containers, smart containers, and smart packaging [28].

The possibility of autonomous driving is a developing solution that will see greater implementation in the coming years. Autonomous driving will be an effective tool for handling and transporting goods without a driver or pilot. Using these vehicles will allow for improved energy efficiency. It will also allow for vehicles to have more space for goods due to the elimination of space for a vehicle operator. It can also allow for longer, uninterrupted delivery routes, since driver to pilot fatigue will be eliminated. AGVs and robotic ships are among the newer developments in autonomous driving. They both use sensors to drive autonomously and communicate. The robotic ships also have robots, cameras, radar, sonar, and GPS, which allows for autonomous navigation as well as the ability to be centrally controlled. Other examples of these technologies include smart cars, smart vans, smart buses, mobile robots, unmanned aerial vehicles (UAVs), and driverless train operation (DTO) [28].

New holistic software solutions with CPS characteristics allow for the development of new processes. Tracking and tracing allow for better understanding of the value chain. Video sequencing can be used to check and signal variations in the process or unexpected situations. Optimizing the supply chain helps companies to find potential savings and avoid effectivity losses. Big data can be used to identify different patterns and other useful information [28].

Chapter 5

Survey Methodology and Results

In order to gauge the degree of Industry 4.0 implementation in the injection molding industry, a survey was developed using Qualtrics. The survey consisted of 36 general questions. The questions were designed to determine the general experience level of the responder, basic information about their company, the current levels of industry 4.0 technology implemented, and their general thoughts on how Industry 4.0 technology has and will affect the company. The survey was sent to over 350 individuals and received a response rate of just over 5%. The survey questions can be found in Appendix A.

The questionnaire had a combination of multiple choice, short answer, and matrix table questions that offered respondents the opportunity to choose and rank among several options or the possibility to grade on a “very low” to “very high” scale. For these questions, there was an option to elaborate on the answer provided, which was considered of high importance for this survey. This contribution allows for improved interpretation of survey results as well as providing additional valuable information.

The sample size for this survey was small. In addition, not every respondent completed all questions in the survey. For future research, a larger sample size would be very beneficial.

The results of the survey indicate that it was effectively a top-level executive survey, with 18 out of the 21 respondents being the CEO and/or president of their respective companies. The three remaining respondents were managers and are assumed to be at second level positions in the company. Following a similar trend, 19 of the 21 (90.5%) survey respondents had 20+ years of industry experience. The other two respondents indicated somewhere between 6-10 years of experience and 11-20 years of experience, respectively. This adds great credibility to the results of the survey, since responses largely represent the perspectives and opinions of high-level executives and managers with decades of combined experience in the plastics industry. This somewhat mitigates concerns associated with relatively low response rate and sample size.

The most frequent result for time spent on technical activities was 50%, with 7 responses. The average sales of companies surveyed was $37.62 million, and most companies do not manufacture more than 500 distinct products. Many companies appear to be small to medium, with an average of 98 employees and 38 injection molding machines. The majority of companies only have one or two manufacturing plants. Most respondents had SIC code 3089.

Among the survey participants, the business performance in the past year was mainly below average, average, or great. The companies surveyed were mainly national and global. It was found that over 75% of companies had less than 50% implementation of Industry 4.0 technologies. All companies surveyed used employee sponsored on-the-job training for professional development. Employee-sponsored seminars were also very popular, as over 80% of respondents claimed to use this method of professional development. One major finding was that employer-sponsored professional development was much more common than employee-initiated professional development.

When exploring the implementation levels of different technologies, robotics was found to be the most widely implemented technology. With the diverse nature of applications for robotics, this finding is not surprising. The least implemented technology was AGVs. Again, this result is not surprising. There are several challenges that companies face when implementing AGVs [17]. With the low levels of Industry 4.0 research in the plastics industry, it is unlikely that AGVs would be seriously considered or discussed in detail [2]. Also, the cost and complexity of AGV systems make it a deterrent for implementation in injection molding companies.

The majority of respondents did not indicate that they felt their companies were set up well to implement Industry 4.0 technologies. The main deterrents were company size, budget, and the technical skills of current employees. These barriers are expected for SMEs, and the majority of respondents were from SMEs [5, 6]. Respondents indicated that most companies had ‘somewhat’ implemented Industry 4.0 technologies and that these technologies had been in use for an average of approximately 10 years.

Industry 4.0 technology received mixed reviews in terms of shop floor acceptance. Some respondents cited no issues or resistance from floor workers, while others reported slow adoption and distrust of new technology. Numerous respondents expect Industry 4.0 technology to increase productivity and competitive advantage to a great extent. However, Industry 4.0 implementation has mixed results for its anticipated effect on increasing sales. The most common response was Industry 4.0 was expected to increase sales ‘to some extent’, and increasing sales ‘to a moderate extent’ was the second most common response.

The survey attempted to answer several questions regarding Industry 4.0 implementation in the plastics industry. One of the main questions investigated was “Do more professional development trainings/ offerings result in a higher level of Industry 4.0 implementation?” It was expected that more trainings would result in higher implementation, as it suggests a commitment to advancing the business. Also, as mentioned previously, more Industry 4.0 implementation will require workers to think in more interdisciplinary ways [3]. This would require more training from companies in order to have employees with the required skills to utilize Industry 4.0 technologies.

In order to investigate this question, a linear regression was conducted relating the total number of employer-sponsored employee trainings with the level of Industry 4.0 implementation. The results were found to be significant, with the significance less than 0.05. According to the regression analysis, the number of trainings accounts for roughly 22% of Industry 4.0 implementation. The results aligned with expectations, but a larger sample size could return a different result.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.507[a]	.257	.218	1.378

a. Predictors: (Constant), total_1

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	12.476	1	12.476	6.567	.019[b]
	Residual	36.096	19	1.900		
	Total	48.571	20			

a. Dependent Variable: Q15Fixed

b. Predictors: (Constant), total_1

The next question posed was “Do companies with higher sales have a higher degree of Industry 4.0 implementation?” Again, a regression analysis was completed using the company sales figures and the degree of Industry 4.0 implementation. The expected results of this analysis were that higher sales figures would be associated with higher Industry 4.0 implementation, as the companies with higher sales would have higher income and could spend more money on new technology. Similarly, large enterprises generally have higher sales than SMEs and are expected to be more likely to implement Industry 4.0 technologies [3].

Based on the regression analysis, the results did not match expectations. There was not a significant correlation between sales and Industry 4.0 implementation. There are several possible explanations for why higher sales levels would not lead to Industry 4.0 implementation. For instance, high sales numbers do not necessarily indicate anything about profit margins. High sales with a low profit margin would make it very difficult to implement Industry 4.0 technologies, due to budget limitations.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.025[a]	.001	-.058	1.372

a. Predictors: (Constant), Q6

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.019	1	.019	.010	.920[b]
	Residual	31.981	17	1.881		
	Total	32.000	18			

a. Dependent Variable: Q15Fixed

b. Predictors: (Constant), Q6

Chapter 6

Further Research

This study is not all-encompassing and there are many topics and concepts that should be examined further. Industry 4.0 technologies are constantly evolving and transforming the way that manufacturing facilities operate. This study had a small sample size, and larger samples should be used in future research.

There are several avenues along which further research could be considered. Comparison between Industry 4.0 implementation in the plastics industry and another manufacturing sector could be explored. Surveys could be used to compare plastics implementation in the United States against that in the United Kingdom, Germany or other countries.

Research could be performed on the perceptions of workers on the plant floor to determine likely attitudes to the implementation of Industry 4.0 technologies. The research could focus on whether the individual would be open to learning new skills to become a viable employee for the Industry 4.0 landscape or if they would change career paths.

The cost to fully implement Industry 4.0 technologies could be examined. There are several costs associated with using this kind of technology, and further exploring what equipment, employees, and skillsets are required for sustainable Industry 4.0 systems could benefit managers who are trying to decide if they want to implement a system or technology in their plant.

There are many more realms within which Industry 4.0 can be explored. The plastics industry is rapidly evolving, and Industry 4.0 technologies are evolving with it. Industry 4.0 is the next step for plastics companies intending to remain competitive with large players in the industry. Further examining the technology and people involved in industry can yield practical knowledge and understanding of how the industry can improve and what the future of the industry will look like.

Appendix A

Survey

Industry 4.0 Plastics Survey Master

Start of Block: Background Information

Introduction My name is James Goodsel, and I am a senior triple majoring in Plastics Engineering Technology, Interdisciplinary Business with Engineering Studies, and Finance at Penn State Erie, The Behrend College. I am conducting this survey for a research project through the Schreyer Honors College at Penn State. In my research, I plan to explore the adoption rates of Industry 4.0 in the plastics manufacturing industry, focusing on injection molding. I would appreciate any and all responses you could give me, and I would be more than willing to send the results of my research upon its completion as requested. No question is mandatory to answer, continue or submit.

Consent for research Those who wish to continue to the survey provide implied consent. Those who do not consent will not complete the survey.

○ I agree (1)

○ I disagree (2)

Q1 What is your job title?

____

Q2 How many years of experience do you have?

○ 1-2 years (4)

○ 3-5 years (5)

○ 6-10 years (6)

○ 11-20 years (7)

○ 20+ years (8)

Q3 How many years are you above entry-level?

____

Q4

Indicate, on the scale below, the amount of time you spend on technical activities versus non-technical activities.

- ○ 0% - No Technical Activities (1)
- ○ 10% (2)
- ○ 20% (3)
- ○ 30% (4)
- ○ 40% (5)
- ○ 50% (6)
- ○ 60% (12)
- ○ 70% (7)
- ○ 80% (8)
- ○ 90% (9)
- ○ 100% - All Technical Activities (10)

Q5 What is your company SiC code?

____

Q6 What is your total sales revenue?

____

Page

Break

Q7 How many distinct products do you manufacture?

____

Q8 How many employees do you have in your location? Overall firm?

____

Q9 How many injection molding machines do you have?

____

Q10 How many plants does your business have?

____

Q11 What is the industry category of your products?

____

Q12 Please indicate the overall performance of your business last year

- 1 - Troublesome (1)
- 2 - Poor (2)
- 3 - Below Average (3)
- 4 - Average (4)
- 5 - Above Average (5)
- 6 - Great (6)
- 7 - Outstanding (7)

Q13 Relative to major competitors, the overall performance of the business last year was:

- 1 - Troublesome (1)
- 2 - Poor (2)
- 3 - Below Average (3)
- 4 - Average (4)
- 5 - Above Average (5)
- 6 - Great (6)
- 7 - Outstanding (7)

Q14 Do you consider your market regional, national, multi-national or global?

- Regional (1)
- National (2)
- Multi-National (3)
- Global (4)

Q15 Describe the degree of Industry 4.0 implementation in your company:

- Not at all (1)
- 1%-10% (2)
- 11%-25% (3)
- 26%-50% (4)
- 51% - 75% (5)
- 75% - 99% (6)
- Full Automation (7)

Q16 Please select all the ways in which professional development is accomplished in your organization.

	Seminar (1)	On-the-Job Training (2)	Formal Degree Program (3)	Continuing Education Program (4)	Other (please specify) (5)
Employer-Sponsored (1)	▢	▢	▢	▢	▢
Employee (Self-Initiated) (2)	▢	▢	▢	▢	▢

Q17 If you selected "Other" in the previous question, please specify here:

____

Q18 Define Industry 4.0 in your own terms or as you understand it.

____

____

____

____

____

Q19 In what industries do your major customers participate? List up to three (3).

____

____

____

____

____

Q20 What 4.0 technologies are implemented (check all that apply)

- ▢ Sensors (1)
- ▢ Embedded Sensors (2)
- ▢ Local Temperature Measures (3)
- ▢ Robotics (4)
- ▢ Color Blenders (5)
- ▢ Assembly Equipment (6)
- ▢ Poka-Yoke Equipment (7)
- ▢ Quality inspection equipment (8)
- ▢ Automated Guided Vehicles (AGVs) (9)
- ▢ Inventory Management Equipment (10)
- ▢ Production and Efficiency Reporting (11)
- ▢ Other (Please specify): (12) ____

Q21 What machines/tools do you use the technology with? Please list:

____

____

____

____

____

Q22 Do you perform training on Industry 4.0 technology?

○ Yes (1)

○ No (2)

Q23 If so, how often?

____

Q24 If so, who is trained? Check all that apply.

○ Floor workers (1)

○ Processors (2)

○ Engineers (3)

○ IT (4)

○ Other (please specify): (5) ____

Q25 If Industry 4.0 has not been broadly implemented in your operations, how well do you feel that your company is set up for implementation of new Industry 4.0 technologies?

____

____

____

____

____

Q26 What are some of the limiting factors in adopting new technologies? Check all that apply:

- ▢ Company size (1)
- ▢ Budget (2)
- ▢ Technical Skills of Employees (3)
- ▢ Existing Machine Capabilities (4)
- ▢ Availability of Training (5)
- ▢ Facility Location (Access to internet) (6)
- ▢ Other (please specify): (7) ____

Q27 To what extent have you implemented Industry 4.0 technology?

- 1 - Not at all (1)
- 2 - Somewhat (2)
- 3 - To a moderate extent (3)
- 4 - To great extent (4)

Q28 What is your approximate ROI to date from implementing Industry 4.0 technologies? If unknown, please type N/A.

____

Q29 How long ago did you implement Industry 4.0 technologies? If unknown, please type N/A.

____

Q30

If you put N/A for the two previous questions, please answer the following questions. If not, you may skip to the next section.

What is the acceptance level on the floor for implemented 4.0 technology?

____

____

____

____

____

Q31 What initiatives to encourage adoption of Industry 4.0 technology? Please list up to three (3).

____

____

____

____

____

Q32 To what extent do you feel that implementation of Industry 4.0 technology will increase productivity?

- 1 - Not at all (1)
- 2 - Somewhat (2)
- 3 - To a moderate extent (3)
- 4 - To a great extent (4)

Q33 To what extent do you feel that implementation of Industry 4.0 technology will increase sales?

- 1 - Not at all (1)
- 2 - Somewhat (2)
- 3 - To a moderate extent (3)
- 4 - To a great extent (4)

Q34 To what extent do you feel that implementation of Industry 4.0 technology will give your company a competitive edge?

- 1 - Not at all (1)
- 2 - Somewhat (2)
- 3 - To a moderate extent (3)
- 4 - To a great extent (6)

End of Block: Background Information

Appendix B

Code Book

Question Number	Question
Q2	How many years of experience do you have?
Q3	What level is your job?
Q6	What is your total sales revenue?
Q7	How many distinct products do you manufacture?
Q11	What is the industry category of your products?
Q11	What is the industry category of your products?
Q12	Please indicate the overall performance of your business last year
Q13	Relative to major competitors, the overall performance of the business last year was:
Q14	Do you consider your market regional, national, multi-national or global?
Q15	Describe the degree of Industry 4.0 implementation in your company:
Q16	Please select all the ways in which professional development is accomplished in your organization.
Q16	Please select all the ways in which professional development is accomplished in your organization.
Q16	Please select all the ways in which professional development is accomplished in your organization.
Q16	Please select all the ways in which professional development is accomplished in your organization.
Q16	Please select all the ways in which professional development is accomplished in your organization.
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Q16	Please select all the ways in which professional development is accomplished in your organization.
Q16	Please select all the ways in which professional development is accomplished in your organization.
Q16	Please select all the ways in which professional development is accomplished in your organization.
Q16	Please select all the ways in which professional development is accomplished in your organization.
Q19 Primary	In what industries do your major customers participate? List up to three (3).
Q19 Secondary	In what industries do your major customers participate? List up to three (3).
Q19 Tertiary	In what industries do your major customers participate? List up to three (3).
Q20	What 4.0 technologies are implemented (check all that apply)
Q20	What 4.0 technologies are implemented (check all that apply)
Q20	What 4.0 technologies are implemented (check all that apply)
Q20	What 4.0 technologies are implemented (check all that apply)
Q20	What 4.0 technologies are implemented (check all that apply)
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Q20	What 4.0 technologies are implemented (check all that apply)
Q20	What 4.0 technologies are implemented (check all that apply)
Q20	What 4.0 technologies are implemented (check all that apply)
Q20	What 4.0 technologies are implemented (check all that apply)
Q20	What 4.0 technologies are implemented (check all that apply)
Q27	To what extent have you implemented Industry 4.0 technology?
Q32	To what extent do you feel that implementation of Industry 4.0 technology will increase productivity?
Q33	To what extent do you feel that implementation of Industry 4.0 technology will increase sales?
Q34	To what extent do you feel that implementation of Industry 4.0 technology will give your company a competitive edge?

Appendix Figure 1: Code Book Questions

Question Number	Code
Q2	25 = 25+ years, 15 = 11-20 years, 8 = 6-10 years)
Q3	1=Top Level, 2=Second Level
Q6	Answers In Millions of Dollars
Q7	1=0-200 parts, 2=201-500 parts, 3=501-1000 parts, 4=1000+ parts)
Q11	Primary (Automotive = 1, Military = 2, Industrial = 3, Medical = 4, Consumer=5, Life Safety =6, Multi=7)
Q11	Secondary (Automotive = 1, Military = 2, Industrial = 3, Medical = 4, Consumer=5, Life Safety =6, Multi=7)
Q12	1=Troublesome, 2=Poor, 3=Below Average, 4=Average, 5=Above average, 6=Great, 7=Outstanding
Q13	1=Troublesome, 2=Poor, 3=Below Average, 4=Average, 5=Above average, 6=Great, 7=Outstanding
Q14	Regional = 1, National = 2, Multi-National = 3, Globlal = 4
Q15	1=Not at all, 2=1-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=75-99%, 7=Full Automation
Q16	1=Yes, 0=No
Q16	1=Yes, 0=No
Q16	1=Yes, 0=No
Q16	1=Yes, 0=No
Q16	1=Yes, 0=No
Q16	1=Yes, 0=No
Q16	1=Yes, 0=No
Q16	1=Yes, 0=No
Q16	1=Yes, 0=No
Q16	1=Yes, 0=No
Q19 Primary	Automotive = 1, Military = 2, Industrial = 3, Medical = 4, Consumer=5, Life Safety =6, Sports=7, Pharmaceuticals = 8, Automation = 9, Other = 10, 0=No answer
Q19 Secondary	Automotive = 1, Military = 2, Industrial = 3, Medical = 4, Consumer=5, Life Safety =6, Sports=7, Pharmaceuticals = 8, Automation = 9, Other = 10, 0=No answer
Q19 Tertiary	Automotive = 1, Military = 2, Industrial = 3, Medical = 4, Consumer=5, Life Safety =6, Sports=7, Pharmaceuticals = 8, Automation = 9, Other = 10, 0=No answer
Q20	1=Yes, 0=No
Q20	1=Yes, 0=No
Q20	1=Yes, 0=No
Q20	1=Yes, 0=No
Q20	1=Yes, 0=No
Q20	1=Yes, 0=No
Q20	1=Yes, 0=No
Q20	1=Yes, 0=No
Q20	1=Yes, 0=No
Q20	1=Yes, 0=No
Q20	1=Yes, 0=No
Q20	1=Yes, 0=No
Q27	1=Not at all, 2=Somewhat, 3 = To a moderate extent, 4= To a great extent
Q32	1=Not at all, 2=Somewhat, 3 = To a moderate extent, 4= To a great extent
Q33	1=Not at all, 2=Somewhat, 3 = To a moderate extent, 4= To a great extent
Q34	1=Not at all, 2=Somewhat, 3 = To a moderate extent, 4= To a great extent

Appendix Figure 2: Code Book Codes

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ACADEMIC VITA OF JAMES GOODSEL

EDUCATION

The Pennsylvania State University | Erie, Pennsylvania

Bachelor of Science in Plastic Engineering

Bachelor of Science in Interdisciplinary Business and Engineering

Bachelor of Science in Finance

Schreyer Honors College

Beta Gamma Sigma Honor Society

Chi Alpha Sigma Honor Society

WORK EXPERIENCE

Research Intern, **Beaumont Technologies** | Erie, PA May 2020- August 2020

- Modeled and analyzed parts in Creo and Moldflow and compared them with actual results
- Developed and optimized processes for a new research mold for three part geometries
- Ran MFI to generate data on multiple polypropylene materials

Plastics Engineering (Intern), **Comar** | Buena, NJ May 2019- August 2019

- Assisted process engineers in sampling a new single cavity tool
- Shadowed process engineers throughout daily operations
- Analyzed shrinkage data and tolerances on a non-conforming product line
- Updated and created control plans for injection and blow molding facilities

Plastics Engineering (Intern), **Truck-Lite** | Falconer, NY June 2018- August 2018

- Reviewed dimensions on part analysis report to ensure specifications were met
- Created, reviewed, and managed supplier PPAPs

Plastics Engineering (Intern), **Viking Plastics** | Corry, PA September 2016- August 2017

- Researched and analyzed LiDar for autonomous cars and its potential for the plastics industry
- Reviewed and updated PowerPoint presentations to match redesigned molds/CAD drawings

RELEVANT ACADEMIC EXPERIENCE

- Designed output screen for material characterization process
- Analyzed likely market for the material characterization system
- Developed financials for expected sales of the project over its lifetime
- Designed an injection mold for material characterization purposes
- Analyzed mold geometries in Moldflow to determine approximate pressure requirements and temperature drop across the flow channel

COMMUNITY INVOLVEMENT & VOLUNTEERISM

Captain, Men’s Volleyball Team	August 2020 – Present
Member, Men’s Volleyball Team	August 2017 – Present
Member, NOBE club	Penn State Erie	September 2020 – Present
Member, Student Athletics Advisory Council	May 2020 – Present
President, Student Athletics Advisory Council	May 2021 – Present

SKILLS

Software: SolidWorks, Creo Parametric, Word, Excel, Outlook, PowerPoint, MoldFlow, WorkBench