A Concept Relationship Map for Industry 4.0

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Abstract

History has seen three industrial revolutions: mechanization of production, assembly lines for production, and automation of production. However, society is facing a fourth revolution, the digitization of production or Industry 4.0. The new revolution spawned from companies necessitating a new form of production to meet increased customer demands. This research will develop a concept relationship map (CRM) for Industry 4.0 that offers a visual depiction of the connection between the main pillars of Industry 4.0. The implementation of Industry 4.0 will be further envisioned through the simulation of a modern manufacturing floor in RoboDK® software. This visual representation explains the abstract Industry 4.0 in a more concrete way.

Keywords
Industry 4.0, Concept Map, Manufacturing, Simulation

1. Background
The history of modern manufacturing dates back to 1850's when the automobile industry began producing cars - a rigorous process, at the time, as each car was produced in its entirety before the production of a new car began (Siemens, n.d.). The invention of Henry Ford's assembly line, however, revolutionized the industry. With this innovation, the assembly of a single car dropped from 12 hours to just 90 minutes, and thus, Mass Production was born (Ford Motor Company, n.d.). While Mass Production increased productivity, many aspects of it were still considered tedious. Through technological advancements and the ever-present human yearning for improvement came the revolution of Industry 3.0, which focused on automation. Rather than humans working on the assembly line, rows of machines with different functions could be seen building the world's future. However, humans were still needed to program these machines (Chan, n.d.). It is here that Industry 4.0 has innovated.

Like its predecessor, Industry 4.0 focuses on increasing productivity and automation; however, the main source of this automation differs. Through Industry 4.0 practices, data supplies the source of automation rather than human input, and the integration of every machine into *smart* systems yields highly beneficial manufacturing data (Chan, n.d.) (Driver, 2017). A key component of Industry 4.0 is using technology where appropriate to make tasks more efficient (Driver, 2017). Therefore, Industry 4.0 takes on a broader meaning as a status achievable by any company of any size and any industry. Experts describe Industry 4.0 similarly to a state of existence (i.e. it is possible to reach Industry 4.0 status). Because of this, one can find advice explaining how smaller companies "can achieve transformative impact by focusing on pragmatic solutions that do not require large investments" (World Economic Forum and McKinsey & Company, 2019). As such, it is important to note while small companies may make smaller adjustments, these adjustments do not inherently yield small rewards, a common misconception. The ability to integrate into Industry 4.0 does not discriminate between companies, and especially not by size. Industrial engineering usually employs a creative allocation of resources rather than a replacement of them.

However, Industry 4.0 does require the replacement of parts or machines to some extent. Smaller companies, unfortunately, struggle with this ultimatum, stalling action during a vital time in the transition. A review by the World Economic Forum details the immense effect early actions produce in the long run, finding that companies who adopted Artificial Intelligence within the first five to seven years of implementing Industry 4.0 saw a 122% increase in revenue versus 10% from those who adopted this predictive technology later in the process (World Economic Forum and McKinsey & Company, 2019). Although Industry 4.0 can have a large improvement in cash flow, it proves difficult to introduce into a company that has taken no steps toward integration. As Industry 4.0 is a relatively new concept, its implementation has yet to be perfected. There are several tribulations that may occur throughout the transition process, of which the acquirement and training of talent, genuine interconnection between systems, and capital investment are key concerns (Zaouini, 2017).

However, if this concept is studied more, it is believed that there is potential for Industry 4.0 to become as ubiquitous as the assembly line. Even in its early stages, there are several benefits to incorporating Industry 4.0. These existing advantages include enhanced productivity, transparency of real-time data, decrease in downtime due to increase in monitoring capabilities, higher quality products, greater connectivity, and customization opportunities (Zaouini, 2017). Therefore, Industry 4.0 has the potential to effectively shape the world of systems across all industries. For instance, process efficiency is a vital part of industrial engineering and can be improved through further research of Industry 4.0, which is still in its infancy. In part, Industry 4.0 focuses on the digitization of data for users to easily determine said solutions. There is an existing gap between companies who have the industrial knowledge and those who have the tools to model them.

By involving industry, academia, and government, experts and practitioners can interact to develop technical solutions and models for Industry 4.0 (Kusiak, 2017). There are skeptics from the misconception that automation and digital modeling create job disruption and limit the number of human jobs. However, reports suggest less than five percent of occupations are fully automatable, that is the human operator can be removed, while sixty-two percent of occupations can automate almost one-third of their tasks, proving the applicability of Industry 4.0 in almost two-thirds of the world's industries (World Economic Forum and McKinsey & Company, 2019). Therefore, automation embeds itself in over half of global occupations, while less than a fraction of these are fully automated. Although most articles on Industry 4.0 center around manufacturing occupations, this workforce philosophy can be applied to many different sectors including healthcare and food services.

2. Research Goals and Methods

There is still a great deal of grey area regarding what exactly Industry 4.0 entails and what industries it applies to. While it was previously mentioned that Industry 4.0 applies to businesses of all sectors and sizes, many still believe the misconception that Industry 4.0 belongs to the manufacturing sector alone. Through this research, it is hoped that a better understanding of Industry 4.0 and its fundamental concepts can be formed to help businesses understand its many applications and begin their transition. This is to be achieved using a concept relationship map to visualize the different concepts that fall under Industry 4.0 and how they interrelate to one another. The validity of the relationships demonstrated in the CRM is denoted in tabular form which incorporates a dotting method to represent the relationship strength. The research also presents a simulation of a model Industry 4.0 manufacturing floor using RoboDK® software (robodk.com). While it is important that the research extends beyond the realm of manufacturing so as to be applicable in other sectors, the simulation was deemed an important tool to aid in the visualization and realization of one of many practical Industry 4.0 applications.

3. Industry 4.0 Pillars

As previously stated, expansive literature can be found regarding Industry 4.0 as it applies to the manufacturing sector, but there are many more applicable fields. For example, the healthcare industry greatly benefits from it as well. Extensive research has been completed on the topic with conclusions amounting to Industry 4.0 having the capability to save lives (Elhadary, 2018). Given Industry 4.0's interdisciplinary applications, a wide variety of topics fall within its scope. Of these topics, there are nine pillars on which the foundation of Industry 4.0 rests upon: the internet of things, big data analytics, the cloud, autonomous robots, simulation, augmented reality, horizontal and vertical system integration, additive manufacturing, and cybersecurity (Gerbert et al., 2015). Each pillar holds a primary connection to Industry 4.0, while some pillars connect with one another as well. This is shown in Table 1 and Figure 1. While the CRM is intended to be self-explanatory in terms of the interconnectivity of Industry 4.0 concepts, this section outlines a general overview of each of the nine pillars and how they relate to one another.

3.1 The Internet of Things (IoT)

Perhaps the most considerable contribution to the rise of Industry 4.0, Internet of Things (IoT) aims to facilitate the interconnectivity of a variety of 'things' via data to achieve increased communication and information; these 'things' can be sensors, machines, pieces of equipment, smartphones, other devices, or even humans (Yang et al., 2019). An important aspect of IoT is the way it connects these 'things.' As the name suggests, information and communication within the IoT is done via the internet, making it easier than ever to stay connected given the advent of smartphones and 'smart' devices (Yang et al., 2019). This data can be analyzed and used to make insightful decisions, increasing productivity, reliability, and efficiency. These 'smart' items are typically physical items that exhibit increased functions via their IoT connections, such as monitoring, control, optimization, and autonomy (Wortmann & Flüchter, 2015) (Porter & Heppelmann, 2014). Autonomous robots, for example, can utilize these IoT technologies to monitor their status and alert human programmers when needed (Porter & Heppelmann, 2014).

If applicable, these robots may also be able to control and optimize their own functions, furthering their autonomy (Porter & Heppelmann, 2014). An important facet of IoT is sensors. Depending on the device's intended functions, sensors exist to measure a variety of attributes such as temperature, humidity, motion, etc. (Perera et al., 2014). These sensed attributes are data which can be converted into useful insights. However, due to the increase in device interconnectivity and the number of IoT-enabled devices (several billions more than the human population), this data (deemed Big Data) can far exceed traditional in-house computing capabilities. To combat this, companies have moved toward Cloud Computing, which decreases their in-house infrastructure cost while allowing for scalability and flexibility (Perera et al., 2014). Beyond a more industrial setting, cloud services, like those offered by Amazon and Google, utilize IoT technologies to provide home security options, stream music, store important files, and connect smart devices. These actions can be accessed via smart assistants, such as Amazon's Alexa, which are now being sold at consumer level prices.

In conjunction with home-based applications, IoT has found uses in the healthcare industry ranging from wearable monitoring devices, equipment tracking, and staff deployment, where they have aided in reducing costs and improving treatment outcomes (Karjagi & Jindal, n.d.). Known as Internet of Medical Things (IoMT), the applications for IoT in the healthcare industry have become so widespread that it necessitated a specialized designation. Here, the term IoMT is used to describe the connectivity of medical devices and requires advanced cybersecurity measures (Hatouillat et al., 2018). However, the creation and implementation of IoT connected devices requires a great amount of detail. To aid in this process, Amazon Web Services (AWS) offers an IoT Device Simulator for those who wish to create IoT applications without investing in or maintaining infrastructure (aws.amazon.com). Similar IoT simulators are also on the market. Like AWS IoT Device Simulator, these simulators allow businesses to test their IoT tech, helping them understand their products' capabilities and limitations (www.iotglobalnetwork.com).

3.2 Big Data Analytics

With the increase in 'thing' interconnectivity given the IoT, data has become bigger in a multitude of ways, earning the term Big Data (Yang et al., 2019). Big data can be summarized as "data that exceeds the processing capacity of conventional database systems" (Dumbill, 2013). While most businesses are equipped with analytical tools and data storage capabilities, the amount of data being produced via Industry 4.0 and IoT revolutions far outweighs traditional solutions. Therefore, big data analytics are new tools suitable for the analysis of large data sets which could not be analyzed otherwise. Big Data has several important characteristics: volume, variety, velocity, and value (Witkowski, 2017). Volume represents the amount of data. As previously mentioned, large amounts of data are exceedingly difficult to work with (Witkowski, 2017). This is especially true if the data has a large Variety, such as the data source and data type (Witkowski, 2017). Under IoT tech, new data is constantly being created; therefore, an important factor of Big Data is its velocity, which is the speed of which the data is acquired and its subsequent analysis (Witkowski, 2017). Concepts such as cloud-computing become important players here given the velocity and importance of the data. As such, Value refers to differentiating important information from the seemingly endless amount of information being processed (Witkowski, 2017). While all information provides insights, not all of the insights are valuable.

Analyzing this data allows for more concrete decision-making and optimization practices, which enhances productivity and reliability (Yang et al., 2019). IoT-connected 'things' can use this data to monitor and self-optimize, as well, further lessening the need for human intervention (Porter & Heppelmann, 2014). Alongside this, it is now cheaper than before to own and operate a high-powered computer; however, data continues to outmatch company capabilities, causing a loss of valuable insights without significant investment. To mitigate this issue, cloud services have become a viable and monetarily efficient alternative for storage, processing, infrastructure and other needs. This is a game changer for companies, especially SMEs, who may not be able to afford the processing power necessary to handle Big Data otherwise. Google, for example, has created Google Cloud which offers data management and smart analytics solutions (cloud.google.com).

3.3 The Cloud

The Cloud allows for off-site storage, computing, and services to be easily accessed via the internet (Yang et al., 2019). While in-house storage and computing systems may offer a higher level of security, there are several benefits when transitioning to the cloud. Those with insufficient computing capabilities, such as a small business with limited resources, can make use of cloud computing to achieve an operational level far beyond their traditional in-house capabilities, due to the smaller capital and the negation of space requirements "on site" (Yang et al., 2019). Whether it be an artist in need of extra storage for commissions or a design team looking to decrease build queue time, nearly any business can make use of the cloud. Many cloud service providers offer monthly, yearly, or pay-as-needed subscriptions for cloud services at relatively low rates, making it an economically efficient alternative. Given its scope, the cloud is integral to a multitude of Industry 4.0 concepts. Innovations in the simulation field are currently being made, with companies offering cloud-based simulation services for collaborative, readily shareable work (The Anylogic Company, n.d.). The cloud has also seen a significant influx of its use over the past few decades. This is in part due to the increase in internet-connected devices which stem from the IoT paradigm. While the Cloud and IoT have evolved separately, IoT devices, and therefore the Big Data that comes with them, further drive the need for the Cloud.

With billions of devices now connected to the internet, the amount of data, and thus processing and storage power needed, has increased dramatically (Perera et al., 2014). The Cloud aims to meet these demands with its innovative services. This interweaving has led to the coining of the term Cloud of Things (CoT): a model based upon the consolidation of IoT and the Cloud (Patel & Parmar, 2017). There are several real-life applications of CoT. Google, for instance, has begun to offer cloud-based IoT and big data analytics services (Google, n.d.). Cloud-based manufacturing programs aim to bring the benefits of IoT and the cloud to additive manufacturing services (Rudolph & Emmelmann, 2017). Healthcare systems can also benefit from transitioning to the cloud. To increase efficiency, patient information can be stored in the cloud, providing a consistent and singular storage place for those working with the patient (UIC, 2019). This, however, opens up issues in security, as patient information is confidential and requires extensive protection (UIC, 2019). Leaks and mismanagement of confidential patient information could pose a risk for the patient or the organization and open the system up to legal ramifications.

3.4 Autonomous Robots

As the name suggests, Autonomous Robots are machines that operate with little to no human input (Melanson, 2017). This makes them suitable for unsupervised tasks such as those done by Autonomous Mobile Robots (AMRs) (Melanson, 2018). While Automated Guided Vehicles (AGVs) have been a staple in factories for nearly half a century, they are merely guided, meaning they are forced to stick to one or several pre-crafted operation routes (Fetch Robotics, 2018). In contrast, autonomous robots can be designed with deliberation in mind, allowing them to perform a variety of tasks in a variety of environments (Ingrand & Ghallab, 2017). Autonomous robots, therefore, can detect objects around them and react to these objects accordingly, making these machines suitable for environments where people may operate (Melanson, 2018) (Fetch Robotics, 2018). While autonomous robots do not specifically require IoT technology, manufacturers like Aethon have opted to offer remote and cloud monitoring services to detect future repair needs, a testament to the benefits of both cloud computing and the IoT (Aethon, 2018a). However, while the additional services may offer important insights, connecting these robots to the internet poses new security risks, which gives way to the importance of cybersecurity.

This is of even greater importance in reference to the use of autonomous robots in the healthcare sector. Aethon offers autonomous mobile robots capable of meeting nursing, pharmacy, lab, food service, environmental, and linen needs (Aethon, 2018b). Given autonomous robots' flexibility, the technology has found use in additive manufacturing operations as well, in which groups of autonomous robots work together to create 3D printed parts (Sondgrass, 2019). When these autonomous robots work together to perform a task, such as with Tesla's autonomous car, each autonomous piece of machinery must be able to communicate with one another. For example, when the Tesla autonomous car is on the road, the sensors must work in tandem and can indicate that a vehicle ahead is slowing down and therefore coming closer. Data collected by the sensors is sent to the cloud where an IoT is established. Following these readings from sensors, the car will respond by performing an action, such as applying brakes or safely switching lanes. (IoT For All, 2018). In much the same way, autonomous robots on the floor of a (manufacturing) facility can communicate with itself, or in some cases, with other machines around it. This allows a much safer and efficient workspace for people as well, due to the incredibly flexible nature of these machines. Rather than having to section off zones suitable for robot operation, robots would be able to use the same paths as people do to get between work zones throughout the day, depending on what needs to be done at the time (Matthews, 2019).

3.5 Simulation

Simulations are virtual representations of products, environments, materials, and other relevant objects often used for analytical or training purposes (Yang et al., 2019). In the context of Industry 4.0, simulations can be used in the manufacturing sector with software such as Ansys, often employed to determine the response of a model under specified conditions (ANSYS Inc., 2020). Simulations can also provide testing or optimization of potential changes in (plant) operations, as these changes can be analyzed in the virtual world prior to implementation in the real world (Gerbert et al., 2015). Companies may want to save previous simulations, employing organizations like Anylogic® that offer cloud-based simulation services with capabilities such as cloud computing, analytics dashboards, readily shareable models, and collaborative multi-user access (The Anylogic Company, n.d.). Using these simulations, it is easier and faster for a company to decide on the fine details of their floor plan. Rather than physically measuring space for the addition of a machine, designers can create a virtual room matching the exact dimensions of the room the machines will be added to and plan from there. Companies would have complete control to model the specific machines and implementation zones and, in some software, even see the time efficiency of the layout that was established. In more advanced cases, it may be possible to find a layout that improves many aspects of the overall floor plan, such as ease of access by human workers or technicians, increased safety, faster production times, or even planning space for future expansions in the production line (Gélinier et al., n.d.).

3.6 Augmented Reality

Via human interaction with technology, Augmented Reality (AR) transforms the physical world into a cohesive mesh of real-time actions and interactive digital overlays (Nee et al., 2012) (Scholz & Smith, 2016). Currently, AR has made its way into videogames, entertainment, manufacturing, advertising, and healthcare environments, with its use becoming more popular in other markets as well. The videogame and entertainment industry has made use of AR in popular videogames such as Pokémon Go and Mojang's more recent addition, Minecraft Earth (Metcalfe, 2017). Social Networking sites also have a leg in the race, with major companies such as Facebook, Instagram, and Snapchat now offering new and exciting "lenses" with animated effects to up their users' selfie game (Metcalfe, 2017). Manufacturers have reasons to implement AR into their daily functions as well. PTC, a popular software company, has recently studied the effects of manufacturing companies adopting AR, noting an increase in optimization, reduced costs, assistance with quality control, and improved on-time delivery (Hastings, 2018). The promise of benefits in the Healthcare industry have also been studied, with research going at least as far back as 2004 detailing the possibility of AR-based surgical training (Shuhaiber, 2004).

While AR implementation has become increasingly widespread, Magic Leap, a company specializing in Virtual and Augmented reality solutions, aims to make AR an essential part of society's daily lives (Abovitz, 2019). Through the use of IoT technology and the cloud, Magic Leap hopes to create Magicverse, an AR Cloud model set to transform society, in which both a virtual and physical coexist naturally (Abovitz, 2019) (The Foundry, 2019). In the healthcare field specifically, increases in the use of augmented reality are seen for both training as well as practical use. For example, healthcare professionals have been able to use augmented reality in order to more easily identify patient's veins for blood work, rather than the traditional method of finding them. Additionally, surgeons have found a use for augmented reality through three-dimensional models of various surgeries, which allow them to manipulate the tools "touch free" so as to maintain the sanitary nature of the operating room (Bautista et al., 2018). In addition, it allows patients to see what is wrong faster, with a better understanding. Yan Fossat, vice president of Klick Labs at Klick Health explained that by "giving someone the ability to instantly see a disease or condition on their own skin, or enabling them to see what someone with – say – macular degeneration sees is more impactful than other forms of visual and textual representation," (Sosna, 2019). As with all technology, augmented reality will continue to evolve and grow, with recent hardware and software changes improving usage by consumers tremendously (Sosna, 2019).

3.7 Horizontal and Vertical System Integration

System integration is a key factor of Industry 4.0 implementation (Pérez-Lara et al., 2018). Integration either follows a vertical or horizontal system; each of which pertains to different aspects of the business. Vertical integration is synonymous with Internal Integration and refers to the flow of information and diagnostics between different layers of the company including the staff and faculty, management information, research & development, or operations performance. Siemens manufacturing, headquartered in Germany, has been utilizing vertical system integration as a design process to create the "digital twin of physical devices such as products, production equipment and logistics equipment" (Petrisor & Cozmiuc, 2018). Thus, vertical integration connects the devices and resources within the business, allowing the company to make timely strategic decisions in response to dynamic market variables (Manufacturing Business Technology, 2019).

Conversely, horizontal integration focuses on connectivity throughout the production process (Pérez-Lara et al., 2018). This usually means measuring machine statuses, delegating plant tasks, or even monitoring the supply chain as a whole (Manufacturing Business Technology, 2019). An extensive review of Industry 4.0 topics as they relate to the global industry found horizontal integration contains the topics of supply chain flexibility, supply chain visibility and distributed manufacturing (Brettel et al., 2014). Supply chain flexibility and visibility can be attributed to being dynamic and having the ability to “adapt” according to changes such as schedules; however, it focuses mainly on the “ability to track commodity flows, [as well as] delivery reliability and customer satisfaction” (Brettel et al., 2014). Distributed manufacturing speaks to horizontal integration’s ability to maintain an efficient business flow using multiple facilities and systems (Brettel et al., 2014). Although these definitions pertain specifically to manufacturing industries, the general concepts can be applied to many others. For example, vertical integration contains technology and management levels as well as staff organizational structures. Companies of all sizes and all industries organize themselves to improve their flow of information, inherently applying vertical systems to every and all industries. Moreover, the same can be said about horizontal systems as they deal with most if not all aspects of connectivity within a business or factory (Petrisor & Cozmiuc, 2018).

3.8 Additive Manufacturing

Over the past decade, additive manufacturing has experienced a surge in interest. While technically an umbrella term, additive manufacturing is often interchangeable with 3D printing, which is a manufacturing process that operates by constructing a three-dimensional object layer by layer (Attaran, 2017) (Debushmann, 2016). There are a multitude of materials and processes that can be used for additive manufacturing. Currently, powdered metal additive manufacturing is becoming a more researched topic, with plastic filament being the most commonly used material to date (GE Additive, n.d.). Additive manufacturing allows for a level of complexity in parts that could often not be done otherwise or without significant expense (GE Additive, n.d.). Customization is also an added benefit of additive manufacturing. The model files on which 3D printers operate can be produced and switched out significantly quicker than that of traditional manufacturing methods, which would often require the creation of additional components such as molds and cores before the manufacturing process could start.

Though the process can still seem time consuming, a key aspect of additive manufacturing is Rapid Prototyping (RP), which significantly reduces launch time (lead time) (GE Additive, n.d.). However, even with the decrease in lead time, a significant amount of work is still involved throughout the ordering process (UIC, 2019). Researchers have proposed a model of their cloud-based manufacturing platform which provides “...automated, web-based quotation costing, order acceptance, and part screening,” in order to decrease time to market (UIC, 2019). Their model utilizes Internet of Things and Services (IoTS), a variant of IoT, and cloud technologies to innovate the additive manufacturing space (Patel & Parmar, 2017). Before printing starts, Computer-Aided Design (CAD) is employed. Using CAD software, a user can design the product to their needs and specifications. Given the layer-by-layer printing process of additive manufacturing, typical product design limitations are relatively minimal. User can then import the model into a simulation program that will help with design optimization, material selection, and other features to increase reliability and reduce trial-and-error process (Gélinier et al., n.d.).

3.9 Cybersecurity

Cybersecurity protects the integrity of information systems such as the Internet of Things (IoT). A journal article from the Institute of Electrical and Electronics Engineers (IEEE) defined the IoT as having 4 layers that need protection: Sensing, Networking, Middleware, and Application layers (Lu & Xu, 2019). IoT specifically requires cybersecurity to protect against attacks attempting to gain information or disrupt the system. These attacks can be classified in eight different ways: Attack on the device, location, or access level, an attack for the purpose of information damage, host promise, strategy, protocol, or a specific layer. More specifically, attacks to purposefully damage information illustrates the importance of cybersecurity. If the attack is successful, it can “[interrupt] the availability of the system” causing the victim’s smart objects to shut down if the victim cannot fight it by utilizing resources (Lu & Xu, 2019). The article explains how cybersecurity blocks or deters the attack from modifying any of the digital information and protects the privacy of the system. The internet of things is very broad and highly adaptable to any specific sector, but not nearly as much as cybersecurity.

To explain, cybersecurity can maintain confidential healthcare documents in a hospital database or protect the owners of a smart home by ensuring sole control of their network-connected devices and privacy of their digital information. As these Industry 4.0 related fields have been developing, so has cybersecurity. When connecting a device to the internet, one of the main concerns has always been that of security, and devices within this field are no different. When a cyber-attack happens, the attacker will be searching specifically for the weakest link in the overall security. In these cases, it is best to have layers of defense, so that if one layer fails, there are still measures in place for protection. "If you have these multiple layers, then you still have a reasonable chance of protecting your system, maybe attackers can compromise one or two layers, but the more steps they have to go through, the harder it is for them to compromise the system. Eventually they will give up if you make it hard enough," (Anandan, 2018). Another level of defense that one may establish to safeguard data is called data encryption. Using software available, one can encrypt data using what is called an encryption algorithm or a cipher to hide the contents of pieces of data, should it be intercepted by an attacker. By using these algorithms, the only way to break through them without the proper decryption key would be with massive amounts of computing power and a lot of time, which wouldn't be feasible by a majority of attackers.

The most commonly used type of encryption method in big business is called asymmetric, which means that there are two linked keys, one that is public for encryption, the other being kept private and used for decryption. This helps mitigate what is called "man in the middle" attacks, as any data they would be able to grab using this cyber-attack method would be encrypted and as stated above, not feasibly broken by most attackers (Forcepoint, 2018). This is similar to the encoded messages sent by the parties involved in World War II. In order to ensure messages weren't intercepted, they used these same ciphers on their text and data transmissions that were typically done either by hand or using physical cranks in the case of the German machine, called Enigma. Even with the best efforts by the Allied powers, even the top code crackers had trouble with this seemingly impossible cipher used. The only reason the code was eventually cracked was due to carelessness by Germany which led to the code being cracked. (Mitel, n.d.). In current times, software can encrypt data in a way that far exceeds Enigma's encryptions, with much faster and secure methods of doing so. In fact, most data will even go through multiple layers of this encryption, resulting in data only usable by those with the right set of decryption keys.

4. Concept Relationship Map

Concept Relationship Maps (CRM) visually organize and represent the connections between multiple diverse concepts. The main concepts are linked with a line and "linking word" to explain how the two are connected (Elhadary, 2018). These main topics usually connect in a hierarchical fashion, meaning the more significant and broad topics are above those that are less so (Elhadary, 2018). In addition to this linear style, a CRM also relates interdisciplinary concepts through cross-links in different "domains" or subsets of the research – in this case Industry 4.0. Visualizing concept relationships poses a great benefit, as it explains to businesses the intricacy of their project or research topic. Being able to recognize even the most simplistic connections can create a better overall understanding. Additionally, the intuitive and ever-changing nature of CRMs standout as one of the greatest advantages to a Concept Relationship Map. It is never truly complete, it can always be improved and updated, with some of the most efficient CRMs requiring three or more revisions (Elhadary, 2018). Methods were designed to create a map for the understanding of Industry 4.0 on a broad scale. The CRM developed in this study is based on literature studies that discussed the different building blocks of Industry 4.0 and their interactions.

To make CRM easier to read, cybersecurity connections are colored in blue to easily discern the origin of each connection. Table 1 represents the connections of the nine pillars. While each pillar is essential to Industry 4.0, the connections between them may differ in strength. Therefore, a dotting system was utilized to indicate this strength. The key is provided below. Using the connections outlined in the table, the CRM aims to visually represent these connections. In order to maintain simplicity and readability, only those connections of three dots were included in the map. This CRM, as well as the table, can be built upon or rearranged in the future to give a more in-depth visualization of Industry 4.0. This is especially important as the rapid pace of innovation in technology may pose different connections.

Table 1. Relationship Matrix for Industry 4.0 Pillars

	Autonomous Robots	Simulation	Systems Integration	IoT	Cybersecurity	The Cloud	Additive Manufacturing	Augmented Reality	Big Data Analytics
Autonomous Robots									
Simulation	•• (Knudson & Tumer, 2011) (Townsend, 2017)								
Systems Integration	•• (Melanson, 2018)	•• (Townsend, 2017)							
IoT	•• (IoT For All, 2018) (Aethon, 2018a)	• (Brundu et al., 2017)	•• (Yang et al., 2019)						
Cybersecurity	••• (Aethon, 2018a) (Anandan, 2018) (Zlotowski et al., 2017)	•• (Radanliey et al., 2018)	••• (Sauter, 2007)	••• (Lu & Xu, 2019)					
The Cloud	•• (Aethon, 2018a)	•• (Asenjo et al., 2019) (Chen & Chiu, 2017)	•• (Moghaddam & Nof, 2018)	••• (Google, n.d.)	••• (UIC, 2019) (Google, n.d.)				
Additive Manufacturing	•• (Songdgrass, 2019)	•• (Parteli & Pöschel, 2016)	•• (Qin et al., 2017)	• (Rudolph & Emmelmann, 2017)	••• (Vaidya et al., 2018)	•• (Rudolph & Emmelmann, 2017)			
Augmented Reality	• (Kuts et al., 2018)	••• (Gelenbe et al., 2005)	• (Liu & Xu, 2017)	•• (Blanco-Novoa et al., 2020)	••• (Pinzone, 2017)	•• (Bautista et al., 2018)	• (Lhachemi et al., 2019)		
Big Data Analytics	• (Sherif et al., 2017)	• (Shao et al., 2014)	••• (Wang & Wang, 2016)	••• (Yang et al., 2019) (Ahmed et al., 2017)	••• (Ilhan & Karaköse, 2019)	••• (Dumbill, 2013)	• (Francis & Linkan, 2019)	• (Eledath et al., 2016)	

• Connects on Occasion   •• Connects Indirectly   ••• Connects Directly

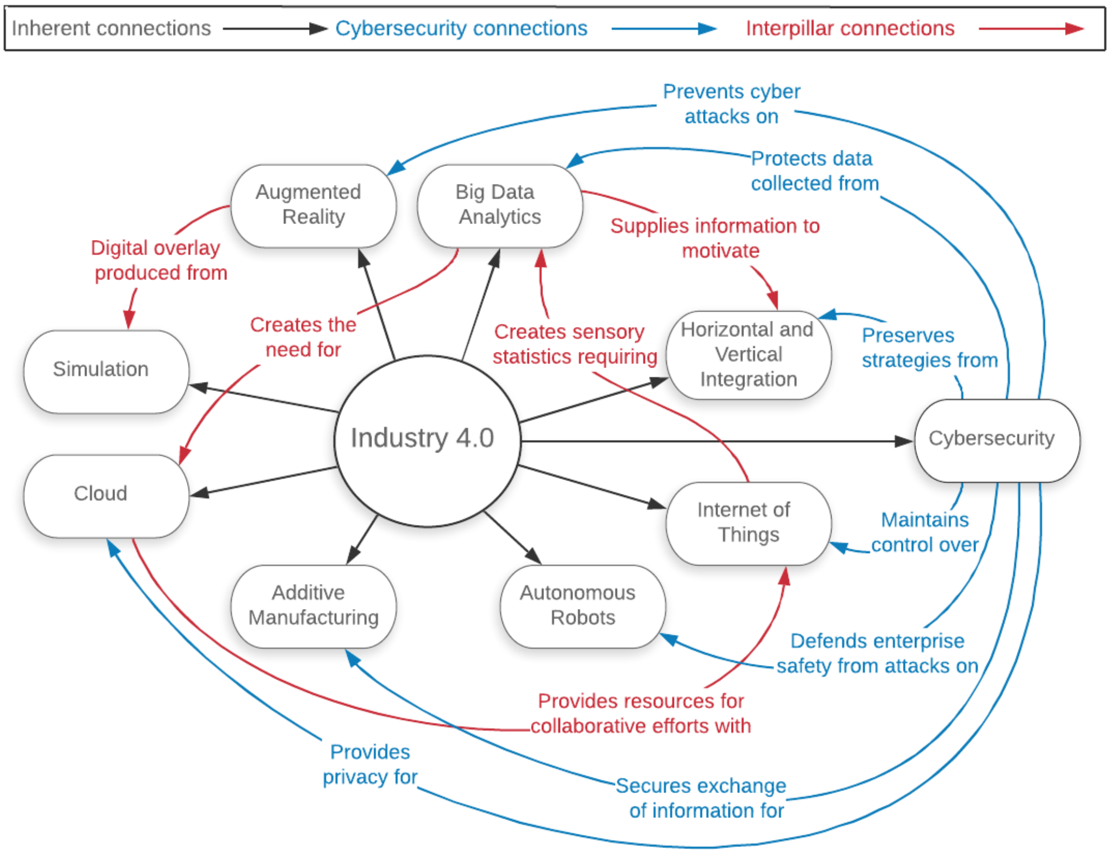

Figure 1. Concept Relationship Map Representing Three-Dot Pillar Connections

5. Simulation Implementation

This Section presents a simple implementation of Industry 4.0 using RoboDK® software, which is a powerful simulator for industrial robots as well as robot programming. It allows a user to layout and setup machines from the vast online library provided, or even import 3D models, machines, etc. RoboDK® is viable for a multitude of situations, and has even seen use by NASA for automated inspections in 2017 and 2019. RoboDK® is simple enough for a user to learn the software quickly, but powerful enough to produce real world applications. Using RoboDK®, an example simulation was set up, wherein there are three additive manufacturing machines, as well as three scanners. As seen in Figure 2, the center scanner detects a defect and promptly stops the machine that created the part, and flags the error for a technician to inspect further.

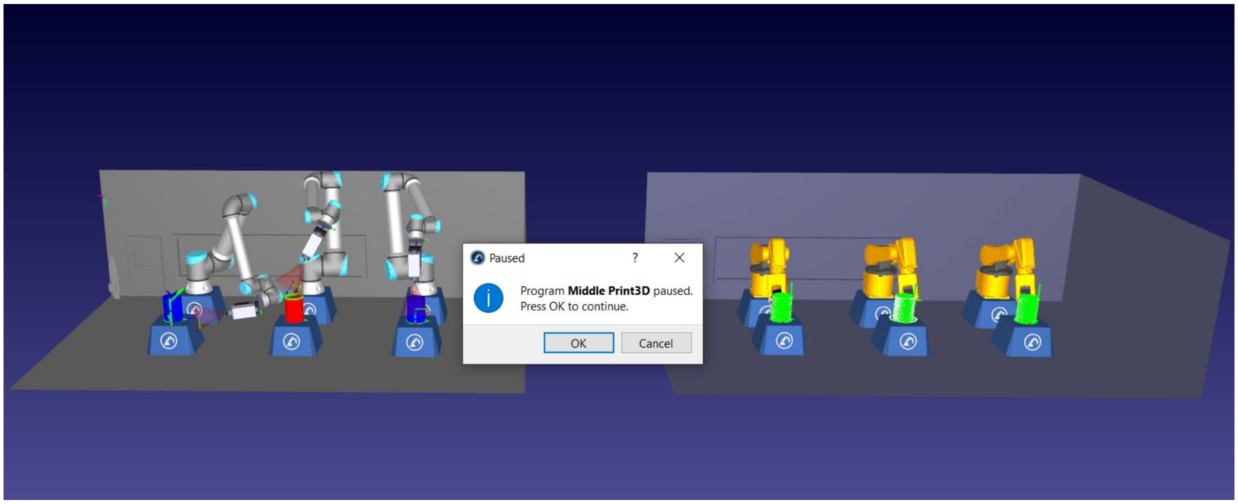

Figure 2. Error message following scan failure

6. Conclusion

Industry 4.0 is an emerging and ever-changing concept built upon customization, connectivity, and data-driven optimization. Through the implementation of Industry 4.0, companies are set to see increases in productivity, reliability, flexibility, and profits. While expansive amounts of literature exist for manufacturing implementation, Industry 4.0 can be used in wide variety of sectors by businesses of all sizes. To reach this implementation companies must first understand what Industry 4.0 is and the pillars upon which it rests. The paper set out to summarize each of the nine fundamental pillars of Industry 4.0, their importance in the real world, and their connections. Visual representations of these connections were made to increase the ease of conceptualization and comprehension. A simulation model for Industry 4.0 implementation of a manufacturing floor was developed. With technology and innovation increasing at such high rates, the CRM connections shown in this report are subject to change within the coming years.

Future work will focus on building a more detailed simulation model for Industry 4.0 and Digital Twins as well as collecting and analyzing data from the simulation. Further, the team will develop a maturity model for Industry 4.0 implementation that can assist organizations in their transition to digitalized and smart manufacturing.

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